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Chapter 1
Introduction

1.1 Preface

1.1.1 Power Grid Emergency

In recent years, various natural disasters have been occurring frequently and showing an increasing trend. Disasters such as typhoons, heavy rainfall, geological earthquakes, snow and ice storms, and others have caused significant losses to the power grid, severely impacting the safe and stable operation of the grid and the normal production and operation of companies.

(1) Typhoon disasters occur frequently. Since 1949, typhoons in Zhejiang and Fujian provinces have accounted for over 78% of all typhoons affecting State Grid Corporation's provinces and cities. These two provinces are hit by typhoons approximately four times each year. During the occurrence of typhoon meteorological disasters, a large number of power transmission equipment often shuts down, and even chain failures can lead to widespread power outages. For example, in 2004, Typhoon "Aere" made landfall in Zhejiang, damaging 3,342 km of transmission lines, causing 10 trips of 550 kV lines, power outage in 9 220 kV substations, 68 trips of 110 kV system lines, and 5 trips of main transformers. In 2016, Typhoon "Meranti" and Typhoon "Nepartak" caused 11 trips of 500 kV lines, 51 trips of 220 kV lines, and 109 trips of 110 kV lines in the Fujian power grid. Typhoon "Meranti" was particularly historic, causing damage to 7 500 kV towers and 15 220 kV towers. In 2019, the super typhoon "Lekima" made landfall in Zhejiang, resulting in 4,823 disrupted lines and power outages for 7.72 million households, causing massive losses.

(2) Heavy rainfall severely affects power supply. From the 17th to the 21st of July 2021, Henan Province was hit by an unprecedented heavy rainfall. In many areas, the rainfall within 4 days exceeded the local annual average rainfall. The situation regarding rainfall, water levels, flood control, and disasters was

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extremely severe. The power infrastructure suffered significant damage. The cumulative impact of the disaster resulted in the shutdown of 42 35 kV and above substations in Henan's power grid. Among them, the entire Songshan 500 kV substation was completely shut down, leading to a rare and major N-7 risk in the main grid structure, severely compromising the reliability and power supply capacity of the power grid. A total of 1,854 10 kV and above power lines were disrupted, and 17 cities including Zhengzhou, Xinxiang, Anyang, Jiaozuo, Hebi, Kaifeng, Luoyang, and Zhumadian experienced power outages for 580,000 distribution transformers and 3.7433 million households. In the summer of 2020, the Jiangnan, middle and lower reaches of the Yangtze River, and Jianghuai regions experienced the longest rainy season in the past 20 years, as well as the highest rainfall recorded for the same period since 1961, resulting in severe flooding and geological disasters. 20 units in Anhui, Hubei, Hunan, Henan, Jiangxi, Sichuan, Chongqing, and Gansu suffered damage. The cumulative impact caused 26 substations of 35 kV and above to shut down, 4,833 power lines of 10 kV and above to be disrupted, and power outages for 149,000 distribution transformers and 9.2558 million users.

(3) Earthquake disasters have severe consequences. On April 20, 2013, the strong 7.0-magnitude earthquake in Lushan, Ya'an, Sichuan Province, resulted in power outages for a total of 186,600 households in Ya'an, Chengdu, Neijiang, and Garze, with a loss of 446,700 kilowatts in load. Specifically, in the Ya'an region, 126,000 households experienced power outages, with a loss of 310,000 kilowatts (37.35% of the pre-earthquake load). Power outages were observed in the entire counties of Lushan, Baoxing, and Tianquan. In terms of damage to power grid equipment and facilities, a total of 34 substations of 35 kV and above were shut down, including 2 substations at 220 kV (Huanggang in Ya'an and Tianquan), 10 substations at 110 kV, and 22 substations at 35 kV. Two 500 kV substations experienced damage to a total of 3 main transformers and were shut down. In total, 626 units (including sets) of substation equipment were damaged, 265 power transmission and distribution lines of 10 kV and above were disrupted, including 1 line at 500 kV, 15 lines at 220 kV, 16 lines at 110 kV, and 61 lines at 35 kV. Additionally, 102 towers collapsed, 1,212 towers were damaged, and 83 lines were severed. In terms of the impact on power plants, the Sichuan power grid canceled the connection of 5 220 kV interconnecting power plants and 1 110 kV power plant. A total of 16 direct-controlled power generation units tripped (including 3 thermal power units and 13 hydropower units), of which 5 units had a capacity of over 100 MW. The total loss of output from the direct-controlled power generation units amounted to 1,917 MW. Seventeen power stations with a capacity of 68.83 MW managed by Ya'an Power Group were shut down. Two company personnel died (one was a construction worker from Hubei Transmission and Distribution Company in Sichuan, and the other was a worker from Ya'an Baoxing County Power Supply Company), and 13 personnel were injured, including 2 serious injuries.

(4) Severe losses due to freezing rain and snow disaster. From 2008 to early 2018, China experienced more than 20 instances of rain, snow, and ice weather events in various regions, which had a significant impact on power grid safety. In total, 25,045 power transmission lines of 10 kV and above were disrupted, resulting in power outages for 44.0312 million users. The following are the most significant impacts:In early 2008, a rare large-scale and prolonged low-temperature rain, snow, and ice weather event occurred in southern China, causing disruptions to 119 lines at 500 kV, 348 lines at 220 kV, 888 lines at 110 kV, 35,385 lines at 10–35 kV, 8,381 towers for 110–500 kV lines, 300,000 towers for 10–35 kV lines, and 700,000 poles for lines below 10 kV. Additionally, 2,018 substations at 10–500 kV were damaged. The disaster affected power customers in 13 provinces, 95 regions, and 568 counties within the operating areas of State Grid and Southern Grid. From winter 2009 to spring 2010, there were seven instances of widespread strong winds, rain, snow, and ice weather events, leading to line galloping in 13 regions including Northeast China, North China, East China, and Central China. From winter 2015 to spring 2016, parts of Liaoning and North China experienced rain, snow, and ice weather events, resulting in 173 lines being disrupted and 98,400 households experiencing power outages. From winter 2017 to spring 2018, ice disasters affected 18 regions including East China, Central China, Northeast China, Southwest China, and Northwest China. Among them, Hunan, Hubei, Anhui, and Jiangxi were the most severely affected, causing 6,729 line disruptions and power outages for 10.6836 million households.

1.1.2 Emergency Requirements for the Power Grid

(1) **The government has placed high demands on emergency response in the power grid sector**

Since the 19th National Congress of the Communist Party of China, the Party Central Committee has put forward the requirement to strengthen, optimize, and coordinate the national emergency response capacity, and build a unified, authoritative, and efficient national emergency response system with unified command and clear responsibilities. The goal is to enhance capabilities in ensuring production safety, maintaining public safety, disaster prevention, reduction, and relief, in order to ensure the safety of people's lives and property as well as social stability. In the context of national emergency response capacity building, monitoring and early warning of risks and hazards, as well as disaster loss assessment, have become of paramount importance.

All regions and relevant departments are focusing on curbing major production safety accidents and promoting the upgrading of intelligent monitoring systems for major risks in high-risk industries. They are implementing high-level planning and step-by-step efforts to improve the coverage and quality of major risk intelligent monitoring systems. They are also establishing advanced Internet of Things monitoring systems with a scientific layout of various sensing devices to effectively control the risks of major production safety accidents. Accelerated work is being carried out in the monitoring and early warning of safety production risks, including accessing key safety production online monitoring data from high-risk industry enterprises, conducting remote online inspections and enforcement, and supervising the effective implementation of safety production responsibilities by enterprises.

A comprehensive approach is being employed, using various means such as on-site inspections, sensor monitoring, video surveillance, and remote sensing monitoring, to carry out dynamic monitoring of natural disaster hazards. Efforts are being made to improve the timeliness and quality of natural disaster monitoring and early warning. Moreover, regions and relevant departments are continuously strengthening research on emergency command and decision-making support. National departments are gradually realizing the scientific resource allocation and deployment for disaster response based on the national emergency management big data application platform. They are improving the emergency command and dispatch system, conducting comprehensive analysis and dynamic display of disaster situation, evacuation and resettlement of affected populations, and establishing an emergency rescue command network connecting emergency management departments at all levels, emergency rescue teams, and disaster sites. This enables unified command, multi-party coordination, and collaborative response, effectively ensuring scientific and efficient emergency command decisions.

The joint release of a document by the State Council's Work Safety Committee, the National Disaster Reduction Committee Office, and the Ministry of Emergency Management (Document No. [2019] 8) clearly requires the strengthening of emergency basic information management, integration of resources, promotion of information sharing and utilization, reinforcement of supervision over disaster risks and hazards, enhancement of safety production and comprehensive disaster prevention, reduction and relief capabilities, and the formation of a distinctive Chinese emergency management system characterized by unified command, versatility, responsiveness, coordination between different levels, and integration of peacetime and wartime efforts. The goal is to effectively guarantee the safety of people's lives and property and social stability.

Strengthening the monitoring and early warning of risks and hazards is crucial. All regions and relevant departments should focus on curbing major production safety accidents and implement high-level planning to promote the improvement of intelligent monitoring systems for major risks in high-risk industries such as coal mining, non-coal mining, hazardous chemicals, fireworks, transportation, metal smelting, and fishery production. The aim is to increase the coverage density and construction quality of these monitoring systems. It is necessary to establish and improve advanced Internet of Things monitoring systems with a scientifically designed layout of various sensing devices to effectively control the risks of major production safety accidents.Efforts should be accelerated in conducting monitoring and early warning of safety production risks. This includes accessing key safety production online monitoring and surveillance data from high-risk industry enterprises, enabling remote online inspections and enforcement, and supervising the effective implementation of safety production responsibilities by enterprises. A comprehensive approach should be adopted, utilizing various methods such as on-site inspections, sensor monitoring, video surveillance, and remote sensing monitoring to carry out dynamic monitoring of natural disaster hazards. The goal is to enhance the timeliness and quality of natural disaster monitoring and early warning.

Enhancing the level of intelligent emergency prediction and early warning is essential. The Ministry of Emergency Management guides all regions and relevant departments to utilize advanced technologies such as big data to analyze changes in information regarding major risks and significant hazards. This includes identifying potential sources of danger, strengthening prediction and judgment, and improving data-supported intelligent emergency prediction and early warning capabilities. Furthermore, leveraging the foundation of emergency basic information, in-depth research on catastrophic and compound disasters should be conducted. This involves refining trend analysis of disaster incidents and developing emergency prediction models. By assessing the occurrence and development patterns of disasters, proactive measures and recommendations can be provided for emergency management. The goal is to prevent and minimize casualties and property losses caused by disasters to the greatest extent possible.

Enhancing the support for emergency command decision-making is crucial. All regions and relevant departments should rely on the National Emergency Management Big Data Application Platform to achieve scientific resource allocation and deployment for disaster response. It is important to improve the emergency command and dispatch system, conduct comprehensive analysis and dynamic display of disaster situations, evacuation of affected populations, and resettlement information. Establishing an emergency rescue command network that connects emergency management departments at all levels, emergency response teams, and disaster sites is essential.This network enables unified command, multi-party coordination, and collaborative response, effectively ensuring the scientific and efficient decision-making of emergency command.

(2) **The company's disaster and emergency command technology urgently needs improvement**

Since 2008, State Grid Corporation of China has embarked on the construction of its emergency command information system. The system has played a proactive role in the company's emergency response to unforeseen events in recent years. However, it lacks sufficient capabilities in on-site information collection, information exchange, information integration, situational analysis, and other aspects of emergency command and decision-making. Specifically, the following issues have been observed.

Inefficient collection of post-disaster damage information: The conventional method of collecting damage information heavily relies on manual on-site surveys and subsequent reporting. This approach leads to challenges such as difficulties in obtaining data, slow data acquisition, significant limitations, and a limited number of data sources. These issues hinder scientific decision-making during emergency response and impede the timely and comprehensive collection of data on damaged equipment at the disaster site. The efficiency of data collection needs improvement.

Insufficient flexibility in emergency information exchange: After natural disasters such as typhoons, heavy rainfall, geological earthquakes, snow and ice storms, communication between on-site rescue personnel and on-site rescue command centers or emergency command centers mainly relies on telephone or text messaging, lacking flexibility. This limits the ability to upload and transmit on-site images, audiovisual disaster information, and hampers effective communication.

Limited level of intelligence in emergency support decision-making: Due to the lack of real-time data collection and analysis of various professional emergency data, emergency command mainly relies on the experience of command personnel and relevant provisions of emergency plans. The support provided by data analysis results for emergency decision-making needs improvement.

Lack of intelligent perception of power grid disaster situations and emergency command platforms: The current emergency command information system primarily focuses on daily emergency management tasks and fails to provide intelligent perception of power grid disaster situations. This deficiency undermines emergency command support and does not meet the requirements of the company's ubiquitous power Internet of Things construction.

1.1.3 Emergency Objectives for the Power Grid

To cope with emergency incidents in the power grid, it is necessary to fully utilize Internet of Things (IoT) technology and overcome key technologies such as diverse data collection, information integration, real-time interaction, and situational prediction. The development of an intelligent sensing and emergency command system for power grid disasters and innovation of the power grid disaster command system are required. This will enable rapid and automated collection of on-site information during power grid emergencies and real-time integration with power emergency command centers at all levels. By integrating information analysis and power grid damage prediction, the efficiency and accuracy of emergency decision-making can be improved, thereby enhancing emergency response efficiency. It supports comprehensive operations such as joint emergency command and optimized coordination analysis, thereby enhancing emergency command capabilities and the level of power grid security:

(1) Improve the efficiency of power emergency response by enabling rapid disaster perception, accurate analysis and trend prediction of disasters, and efficient collaborative interaction, thus reducing power outage duration and minimizing economic losses for the company.
(2) Establish an intelligent sensing and emergency command platform for power grid disasters, and achieve commercialization through industrial conversion, resulting in economic benefits.

(3) Shorten the restoration time through the operation and use of the power grid disaster sensing and emergency command system, enhance the social responsibility of power grid enterprises, and generate social benefits.

1.2 Current Development Status

1.2.1 Current State of Grid Sensing

The United States has been at the forefront of research on grid sensing technology. The U.S. Department of Energy and several research institutions started investigating situational awareness technology in power systems several years ago and have achieved significant results. With the advancement of the Federal Smart Grid Deployment Plan, power companies in New York State have begun implementing situational awareness technology in their power systems to enhance operational management, improve visibility and reliability of the grid, and enhance equipment utilization efficiency.

The Smart Grid Standards Research Group of the Electric Power Research Institute (EPRI) believes that a smart grid should possess six main functionalities, including wide-area situational awareness, demand response, energy storage, power transmission, advanced metering, and distribution grid management. Among these functionalities, situational awareness plays a crucial role in power systems. It helps understand the state of power system components, identify hidden problems in a timely manner, coordinate the control of numerous power system components, and provide effective management systems and optimal solutions for problem resolution.

EPRI has listed several typical applications of situational awareness in power systems, including accident analysis. Accident analysis is an application of Energy Management Systems (EMS) used to analyze the security of the power system, such as its ability to withstand the shutdown of critical infrastructure within the power system. Situational awareness systems can compute, identify, and define priorities, and they can predict the likelihood and magnitude of problems such as equipment overcurrents, excessive bus voltages, and system instability when unexpected accidents occur in the future, such as equipment failures or outages.

Indeed, the application research of situational awareness technology in the domestic power grid started relatively late. Due to the significant social and economic impacts caused by multiple power outages both domestically and internationally, the security of the power grid has become more prominent. As a result, situational awareness technology has gradually become a focal point in power grid research in recent years.

In 2004, the State Grid Electric Power Research Institute (SGEPRI) initiated the research on the fundamental theory and key technologies of the wide-area security defense system in power systems. This was the first major project funded by the National Natural Science Foundation of China in the field of power systems. The project aimed to gain a deep understanding of the dynamic behavior and characteristics of large-scale power systems, explore corresponding analysis methods, develop theories and methods for protection and control based on wide-area dynamic phasor measurement, and establish theories for online dynamic early warning of power system security and stability. From this research, it can be seen that the capability requirements for situational awareness were initially established.

In recent years, research on situational awareness technology in the domestic power grid has mainly focused on grid dispatching. The information and data in the power grid are vast and complex. The challenge lies in presenting operational information in a vivid manner, providing real-time data categorized for dispatchers, and mining data that has significant impacts on grid operations. This enables early warning and control of system weak links and potential security issues, which is an important issue faced by grid dispatchers.

The Key Laboratory of Smart Grid in Sichuan Province has proposed a five-indicator system covering various aspects of the power grid. These indicator systems can quantitatively describe the characteristics of different parts of the power grid, enabling effective analysis, evaluation, and prediction of the macroscopic security situation of the power grid.

In 2013, SGEPRI led the research project "Research on Power Grid Operation Trajectory Characterization Method Based on Situational Awareness," which aimed to accurately and effectively predict the security situation of the power grid by understanding and comprehending various factors influencing the changes in grid operation. The project also aimed to construct an indicator system to characterize the operation trajectory of the power grid through the extraction and summarization of massive operational information. The research contents of the project included comprehensive state awareness technology for grid operation considering external environmental influences, real-time operation trajectory indicator systems, and power grid operation trajectory characterization methods based on risk degree. The goal was to lay the foundation for achieving automatic intelligent dispatch control through online calculation and control of operational trajectory indicators and to assess future operational situations based on the indicator system of risk degree.

1.2.2 Current Status of Power Grid Emergency Command

(1) **Power Grid Emergency Organization System**

In January 2005, the former National Electricity Regulatory Commission established the Emergency Leadership Group for Large-scale Power Grid Blackout Incidents. Its purpose was to unify and coordinate the emergency response efforts for large-scale power grid blackout incidents nationwide. At the same time, State Grid Corporation of China, China Southern Power Grid, and major power generation companies established their respective emergency management organizational systems as required to ensure the orderly organization and implementation of emergency management tasks. This initiative strengthened the construction of emergency repair and rescue teams and enhanced the ability to respond quickly to unexpected events.

(2) **Power Grid Emergency Response Plan System**

China's Power Grid Emergency Response Plan System has been continuously improved since the implementation of the "National Emergency Response Plan for Dealing with Large-scale Power Grid Blackout Incidents" in 2005. Power companies have developed emergency response plans for different levels and types of accidents, focusing on rescue, handling, and power grid restoration based on their specific circumstances.

Currently, China Southern Power Grid, State Grid Corporation of China's North China, Northeast China, East China, Central China, and Northwest China subsidiaries, as well as the power grid (electricity) companies of 31 provinces (autonomous regions, municipalities directly under the central government), have formulated emergency response plans to deal with major and extraordinary incidents in the power grid, accompanied by specialized contingency plans. In addition, over 310 power supply (electricity) companies and their grassroots units across the country have also developed corresponding emergency plans. Major power generation enterprises have also established overall emergency response plans and specialized plans for specific situations, such as "Black Start Plan," "Factory Power Supply Plan," "Hydropower Dam Accident Emergency Plan," and "Flood Control Emergency Plan." These emergency plans have played a vital role in practice.

For example, on July 1, 2006, a situation occurred in Henan Province where four 500 kV and five 220 kV transmission lines tripped, causing multiple power generating units to shut down and resulting in power oscillation incidents in the Central China Power Grid, posing a threat to the safety and stable supply of the power grid. In this case, the emergency response plan played a critical role. State Grid Corporation of China promptly initiated the emergency response mechanism, effectively preventing the accident from escalating and successfully avoiding a large-scale power grid blackout incident.

(3) **Power Grid Emergency Information Platform**

Each power company has established its own information reporting system and has intensified the construction of emergency management information platforms. State Grid Corporation of China and China Southern Power Grid rely on their existing dispatch communication systems to integrate network communication resources and establish robust information communication platforms. Currently, regulatory authorities are also promoting the construction of power grid emergency command information platforms. This involves leveraging existing specialized information systems and command systems in the power grid, expanding their functionalities, integrating, transmitting, and sharing emergency information resources, uploading and issuing command instructions, and achieving interoperability with government emergency platforms.

(4) **Emergency Training and Plan Drills**

Many power companies actively carry out emergency training, plan drills, and joint accident exercises to enhance their emergency response capabilities in dealing with power grid-wide blackouts and other power emergencies. These activities aim to improve the comprehensive handling capabilities of major power emergencies and the overall coordination of social emergency response during large-scale power outages. For example, on June 8, 2006, the State Grid Dispatch Center successfully organized the 2006 Peak Summer Joint Anti-Accident Exercise, involving five regional power grids of the State Grid Corporation. A total of 382 units participated in the exercise, with over 8,000 participants. The collaborative coordination abilities of personnel at all levels in handling accidents were comprehensively exercised. In October 2006, China Southern Power Grid Company successfully held a joint emergency drill for a large-scale power outage in Guangdong Province, with the participation of 34 units, achieving the desired results.

1.3 Organization of the Book

Chapter 2 of this book introduces the fundamental knowledge of grid perception and emergency command. The subsequent chapters are organized based on the approach of key technology research, system prototype development, and application validation, as illustrated in Fig. 1.1. Firstly, it covers the intelligent collection of diverse information on grid damage. Secondly, it discusses the fusion analysis and prediction of grid damage information. Thirdly, it explores real-time information exchange technology between the emergency site and the command center. Fourthly, it delves into grid emergency decision-making technology. Lastly, it presents the development of a prototype for power emergency site security control and its application validation in power grid companies.

Chapter 3: Multi-source Information Collection Technology for Power Grid Disaster Damage Assessment.

The main content includes the rapid acquisition and automated collection techniques of diverse information on typical power equipment damages based on the Internet of Things (IoT). A method and technical scheme for collecting diverse information on power equipment damages based on the power IoT are proposed. A technical scheme for reconnaissance and identification of power line disasters using unmanned aerial vehicles (UAVs) is presented to achieve automatic statistical analysis of power equipment losses. Intelligent collection, sharing, and integration techniques for regionally relevant social public emergency information related to damages are introduced to support the integration and fusion of damage information and achieve integration

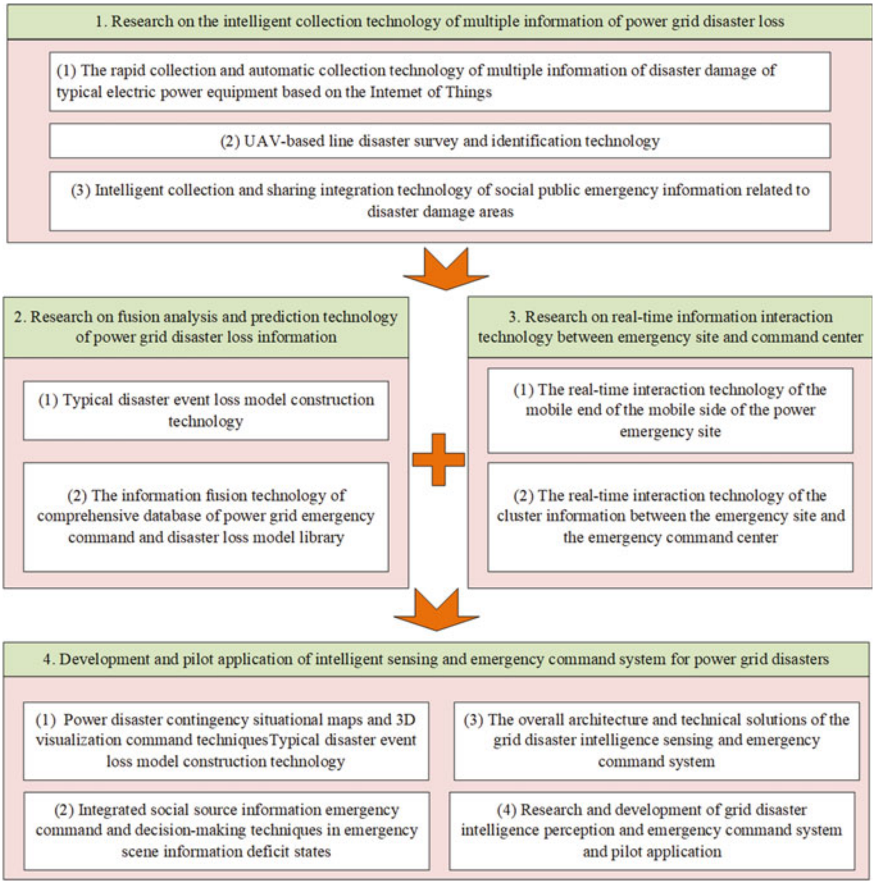

Fig. 1.1 Overall research content of the project

with government emergency management big data platforms, thereby enhancing the multi-dimensional data collection capability of the power grid disaster.

Chapter 4: Integration and Comprehensive Prediction Technology of Power Grid Damage Information.

The main content includes the construction technology of typical disaster event loss models, introduction of typical power grid disaster event loss models, proposing information integration and fusion methods and technical schemes for power grid damage information collection - damage model library - emergency command comprehensive database, supporting intelligent perception of power grid disasters. Information fusion technology between the emergency command comprehensive database and the damage model library, as well as fuzzy dynamic power grid loss prediction technology, are discussed. Mastering analytical techniques such as dynamic power grid loss prediction based on multiple data sources enhances the scientificity of emergency command.

Chapter 5: Real-time Interactive Technology for Power Grid Emergency Field Operations.

The main content includes real-time interactive technology for mobile-friendly neighbor-to-neighbor communication in power emergency field operations. It investigates real-time information exchange technology between the scene of unexpected events and the emergency command center cluster. It proposes neighbor-to-neighbor communication technology and long-distance cluster information real-time interaction technology between the field and the command center. Efficient methods for submitting various types of information are developed to enhance information exchange capabilities among different departments and locations involved in emergency response.

Chapter 6: Power Grid Emergency Decision-Making Technology.

The main content includes the situational mapping and three-dimensional visualization command technology for power grid disasters and unexpected events. It investigates comprehensive social source information emergency command decision-making technology in situations where information is lacking at the emergency scene.

Chapter 7: Power Grid Disaster Intelligent Perception and Emergency Command System.

The main content includes the overall architecture and technical scheme of the power grid disaster intelligent perception and emergency command system. It proposes situational analysis models for power grid disaster and unexpected events, as well as information interaction models between the command center and the field. The chapter introduces the power grid disaster intelligent perception and emergency command system and its pilot application in power grid enterprises. It aims to achieve intelligent perception of power grid disasters and assist decision-making and visualization command in situations where information is missing at the emergency scene. This system effectively improves emergency command efficiency in disaster assessment, operation command, and resource allocation.

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Chapter 2
Network Awareness and Emergency Command Fundamentals

2.1 Basic Concepts

2.1.1 Emergency

(1) Emergency concept

Public safety refers to the secure state of individuals, property, and social systems, without any form of destruction. Events that suddenly disrupt this state are referred to as emergencies or, more specifically, "sudden public incidents" or "emergencies." According to the "General Emergency Plan for Sudden Public Incidents" issued by the government, a sudden public incident is an urgent event that occurs unexpectedly and results in or may result in significant casualties, property damage, ecological harm, severe social risks, and threats to public safety. These incidents can vary in scale, location, nature of hazards, and level of preparedness, leading to different impacts and consequences. The occurrence of these events is characterized by randomness and uncertainty. Improper response to such events can escalate them into larger-scale accidents, causing harm, loss, and destruction to life and property. Within the framework of the "Triangle of Public Safety," sudden public incidents typically manifest as the catastrophic effects of various disaster factors. Examples include hazardous chemical leaks and large-scale outbreaks of infectious diseases (material impact), earthquakes (energy impact), and societal panic (information impact).

Internationally, sudden public incidents are generally categorized into two types: those caused by natural forces and those caused by human factors. For example, in the United States, sudden public incidents are classified as natural disasters, technological accidents, and terrorist disasters. In China, according to the "General Emergency Plan," sudden public incidents are primarily classified into four categories based on their occurrence process, nature, and mechanism: natural disasters, accidents and disasters, public health incidents, and social security incidents.

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1) A natural disaster. Natural disasters primarily refer to sudden incidents caused by natural factors. According to the "General Emergency Plan," natural disasters in China mainly include water and drought disasters, meteorological disasters, earthquake disasters, geological disasters, marine disasters, biological disasters, and forest and grassland fires.
2) Accident disaster. Accidents and disasters primarily refer to emergency events caused by human factors, including unplanned incidents or accidents resulting from human activities or development. According to the "General Emergency Plan," accidents and disasters in China mainly include various types of safety accidents in industries such as factories, mines, and commerce, transportation accidents, accidents involving public facilities and equipment, as well as environmental pollution and ecological damage incidents.
3) A public health event. According to the "General Emergency Plan," public health incidents primarily include epidemic outbreaks of infectious diseases, mass outbreaks of unknown causes, food safety and occupational hazards, animal epidemics, as well as other events that seriously impact public health and life safety. These incidents predominantly manifest as various diseases that pose a threat to human or animal life and health, with causes that can be both natural and human-induced.
4) Social security incident. Social security incidents primarily refer to sudden events generated by individuals' subjective intentions that pose a threat to social security. Social security incidents mainly include terrorist attacks, economic security incidents, and incidents related to foreign affairs.

(2) Power emergency concept

Power emergency incidents refer to sudden and urgent events that may result in casualties, damage to power equipment, widespread power outages, environmental damage, and pose a threat to the security and stability of power companies and society. Emergency response measures need to be taken to address these incidents. Depending on the nature of the events, power emergency incidents can be classified into the following four categories:

1) Natural disasters category: This includes meteorological disasters (such as rain, snow, ice, severe weather, typhoons, floods, and heavy fog), earthquake disasters, geological disasters (such as landslides, mudslides, and ground collapses), forest fires, and other natural disasters that have adverse impacts on the lives of power employees, corporate property, and social stability.
2) Accidents and disasters category: This includes personal accidents, power grid accidents, equipment accidents, network and information security incidents, fire accidents, traffic accidents, and environmental pollution incidents within the field of power production. These accidents may have adverse impacts on the lives of power employees, corporate property, and social stability.

3) Public health category: This includes epidemic outbreaks of infectious diseases, mass outbreaks of unknown causes, food poisoning, and other public health incidents. These incidents may have adverse impacts on the lives of power employees, corporate property, and social stability.
4) Social security category: This primarily refers to mass incidents and sudden news media events that may have adverse impacts on power employees, power companies, and social stability. Social security events mainly include terrorist attacks, economic security incidents, and international emergencies. Social security events are primarily caused by human factors and often involve deliberate actions.

2.1.2 Intelligent Perception

(1) Intelligent perception concept

There is currently no unified concept for intelligent perception. Generally, it is believed to be the combination of sensing and artificial intelligence. It not only includes the ability to acquire external information through sensors but also involves processes such as memory, learning, reasoning, and judgment to achieve the ability to perceive the environment, object categories, and attributes. From the understanding of the words, intelligent perception should consist of three parts-sensing, knowledge, and intelligence.

"Perception," also known as sensing, refers to the ability of sensors to detect specified physical quantities and convert them into usable signals according to certain rules. The "specified physical quantities" generally refer to the measured physical quantities, while the "rules" refer to the operating principles of the sensors. The "usable signals" typically refer to electrical signals or parameters and signals that can be easily converted into electrical signals, including digital signals. For example, in the case of an all-fiber current sensor, the specified physical quantity is current, the rule is the magneto-optic effect, and the usable signal is an optical signal that can be converted into an electrical signal through photoelectric conversion. From the definition of a sensor, it is apparent that the output signal merely reflects the measured information, and its reliability and susceptibility to interference are not clear. To improve the reliability, accuracy, and other performance aspects of the measured results obtained by sensors, the combination of sensor technology and computer technology has given rise to intelligent sensor technology, transforming sensors into intelligent sensor systems. Intelligent sensor systems have a network connection in their structure and incorporate processes such as memory, learning, reasoning, and judgment into their workflow.

"Knowledge," or knowing, refers to a human-like behavioral pattern achieved through certain technological means. Specifically, it refers to the performance achieved by intelligent sensor systems, where not only traditional sensor performance aspects like reliability are improved, but also conclusions can be directly drawn through logical reasoning based on the measured signals. Clearly, the "perception" in intelligent sensing fundamentally encompasses intelligent sensing involving logical reasoning, classification, and decision-making. It is not merely a concept similar to the "perception" defined in the context of sensors but carries a deeper connotation.

(2) Smart grid concept

The concept of a smart grid was proposed by the Electric Power Research Institute (EPRI) in the United States in 2001, and it was later defined as a future form of the power grid in 2003. Although there is no unified definition of a smart grid, its underlying principles of construction are generally similar. The goal of a smart grid is to connect various energy resources (such as coal, hydro, solar, wind, etc.) with the development, transmission, storage, conversion (generation), transmission, distribution, supply, sale, service, and storage of electric power, as well as the electrical equipment and other energy-consuming facilities of end-users, through a digital information network system.

The key characteristics of a smart grid include a digital information network system, intelligent energy management and control, flexibility and dispatchability, reliability and security, sustainability and environmental friendliness. Through a smart grid, energy can be transmitted and utilized more efficiently, and the operation of the power system can be more flexible and reliable, allowing users to enjoy more reliable and high-quality electricity services. The construction of a smart grid requires the integration of various advanced technologies and devices, such as smart metering, remote monitoring, automation equipment, communication networks, data analysis, and artificial intelligence. Additionally, the realization of a smart grid also requires policy support, regulatory frameworks, market mechanisms, and collaborative efforts from partners.

2.1.3 Emergency Command

(1) Emergency Management

Emergency management refers to a variety of human interventions that can prevent or reduce emergencies and their consequences. Emergency management can be implemented in response to emergencies to reduce the occurrence or the spatial and temporal intensity of their effects. It can also be implemented for disaster-bearing carriers, thus enhancing the resilience of disaster-bearing carriers. The study of emergency management focuses on the appropriate way, strength and timing of human intervention on emergencies and disaster-bearing vehicles, so as to prevent or control the occurrence and development of emergencies to the maximum extent, weaken the effects of emergencies and reduce the damage of disaster-bearing vehicles. The scientific and technological support for emergency management is reflected in being informed of the key objectives of emergency management, the scientific methods and key technologies of emergency management, and the appropriate timing and strength of the implementation of emergency measures.

Since the September 11 attacks, the international community has been paying more attention to public safety and emergency management. From the perspective of system theory, emergencies and their response have typical characteristics of complex systems, with complex spatio-temporal coupling among emergencies, disaster carriers and emergency management, which is an open system with high uncertainty. In the "triangle" framework of public safety, emergency management focuses on how to apply human intervention to prevent or reduce the occurrence of emergencies and weaken their role; to enhance the resilience of disaster-bearing carriers, interrupt the chain of secondary events and reduce losses; Avoiding the regeneration of emergencies and the destruction of disaster-bearing carriers that may result from improper emergency response, as well as excessive costs.

(2) Emergency command

Emergency command is an organizational leadership activity conducted in emergency situations. The concept was originally derived from Army organizational command, which refers to the special direction of troops in combat and other military operations by Army commanders and their agencies. Nowadays, the concept of command has been widely used in various social management fields, referring to the organizational leadership of the higher level to the various activities of the lower level. In the field of emergency management, emergency command specifically refers to the special organizational leadership activities carried out by higher-level leaders and their organs on the emergency activities of lower levels and the handling of emergencies in the emergency response activities of emergencies. Since the establishment of emergency management system in China in 2006, emergency command has played an important role in emergency response, including command and dispatch, resource coordination, information sharing and guiding decision making. Emergency command aims to improve the efficiency and coordination of emergency response, ensure that emergencies are responded to and controlled in a timely manner, minimize damage, and protect the safety of people and society.

(3) Emergency command system

The emergency command system is a set of mechanisms and measures established by the government and other public institutions in the process of prevention, response, disposal and management of emergencies, aiming to safeguard public life and property and promote the harmonious and healthy development of society. The system integrates modern technology and management tools to provide comprehensive real-time information support as its goal. The construction of the emergency command system is a complex system project involving several professional fields, such as public safety, monitoring and management, alarm linkage, computers and communications. The main functions of the system include: ① Information acquisition and processing: through various sensors, monitoring equipment, communication networks and other means, real-time acquisition, processing and transmission of information related to the emergency, including site images, sound, location and other specific details. ② Command and dispatch and decision support: Based on the collected information, provide comprehensive and accurate intelligence for commanders to help them make rapid and wise decisions and coordinate various departments and resources for emergency disposal. ③ Resource coordination and dispatching: Manage and dispatch emergency resources to ensure reasonable allocation and efficient use of resources, including personnel, equipment, materials, etc. ④ Communication and linkage: Establish an efficient communication network to realize real-time information exchange and linkage between multiple departments and levels to promote information sharing and collaborative work. ⑤ Command center and emergency commander training: establish an emergency command center as the core hub, equip professional commanders, and conduct training and drills to improve the capability and efficiency of emergency response.

2.1.4 Emergency Response Platform

(1) Emergency platform concept

The emergency platform is a public safety technology as the core, information technology as the support, a combination of software and hardware emergency security technology system, is the implementation of emergency planning tools; with daily emergency management, risk analysis, monitoring, prediction and early warning, dynamic decision-making, comprehensive coordination, emergency linkage, simulation exercises, information exchange and sharing and summary evaluation and other functions, can be dynamically generated command program, rescue program, security program, etc.

(2) Grid emergency platform

The power grid emergency platform is a technical security system built based on public security theory and using modern information technology, communication technology and power system analysis and control technology. Its main purpose is to respond to major emergencies and public security events such as serious accidents in power production, equipment damage, power supply crisis and serious natural disasters related to power production. The platform has emergency management functions such as emergency information collection and management, emergency watch, prediction and warning, dispatching and command, auxiliary decision making, electronic plan, resource management, exercise and evaluation, and information release.

The power grid emergency platform is a unified body of hardware and software required for power emergency management, and a fully integrated system that is a unified information support platform for the entire emergency process. It provides a full range of technical support for power emergency management. In the process of emergency treatment of large-scale power grid outage, the power grid emergency platform supports monitoring and control of danger sources, prediction and early warning, emergency command, accident rescue, social emergency rescue, post-processing, as well as emergency security, drill and training, and emergency information organization and release. In addition to emergency response to large-scale power outages, the grid emergency platform also supports basin flood control and dam safety emergencies, major construction project safety emergencies, social emergency linkages, emergency training and emergency drills. Once the grid emergency platform obtains the corresponding data, it can further analyze and process it to provide auxiliary services for emergency decision-making.

The construction and operation of the power grid emergency platform can improve the efficiency and capability of emergency management of the power system and realize timely response and coordinated response to emergencies. It is an important guarantee means to ensure the safe and stable operation of the power system, reduce losses and protect public safety, and also promotes the sustainable development of the power industry.

2.2 Theoretical Basis

2.2.1 Theory Related to Grid Sensing

Situational awareness technology is a technique for acquiring, understanding, displaying, and predicting the elements that can cause changes in system posture in a large-scale system environment. It provides data-based capabilities for macroscopic cognition and comprehensive analysis of the system's internal and external environments, similar to the intelligent cognitive processes of living things. The application of situational awareness technology in power systems can promote the integration of the application functions of various systems of power grid automation, significantly enhance the intelligence level of power systems, effectively improve the efficiency of power grid operation, and provide a strong guarantee for the safe and stable operation of power grids. Its important predictive and decision support capabilities are essential components necessary for realizing a truly smart grid.

Intelligent perception has a higher level of functionality compared to traditional perception. Traditional intelligent sensor systems mainly target specific physical quantities and aim to obtain more accurate measurement results and preliminary reasoning, classification and decision-making functions, which are relatively limited in terms of the information they obtain and their reasoning, classification and decision-making capabilities. And intelligent perception generates new feature information by acquiring more sensing information, and performs all-round reasoning and judgment through the synthesis of multiple feature information to form higher-level conclusions. Its theoretical basis includes feature extraction of sensing objects based on deep learning of big data and inference methods based on various features of bio-like mechanisms. For example, the camera is only a vision sensor, while the intelligent vision sensor can automatically focus, adjust the sensitivity according to the scene, obtain a clear image, and give preliminary judgment results, such as light intensity and spectral distribution. Monocular intelligent vision systems are capable of face recognition, identifying a specific target person in an image, while binocular intelligent vision systems are capable of simulating human vision, not only recognizing people, but also measuring the distance to the camera. Such a vision system first needs to acquire a clear image of the identified target, a function achieved by conventional smart sensors. Then, through image processing and feature extraction, it can compare, analyze and calculate with the sample set in order to produce accurate results. Intelligence is significantly improved compared to conventional smart sensors. Combining technologies such as human voice recognition, odor recognition, iris recognition and fingerprint recognition, almost 100% correct identity recognition can be achieved, further enhancing the perception capability. Such perception ability is enhanced even more.

The key technologies involved in smart grid sensing include sensor technology, artificial intelligence and big data technology, communication technology, etc.

2.2.2 Emergency Management Related Theory

Emergency management is a kind of whole process management before, during, during and after. The core objective of emergency management is to respond and dispose of emergencies, but the response and disposal of emergencies are inseparable from the emergency preparation under the normal state. Especially for routine emergencies, the effect of emergency response and disposal mainly depends on emergency preparedness. Therefore, emergency management includes not only the extraordinary work, but also the part of emergency work under normal conditions. In other words, emergency management should include the preparation work before the occurrence of an emergency, the response work after the occurrence of an emergency (such as evacuation, isolation, emergency disposal, etc.), and the social support, recovery and reconstruction work after the occurrence of an emergency.

The object of emergency management is a public emergency, that is, an emergency event that occurs suddenly and causes or may cause major casualties, property damage, ecological and environmental damage and serious social harm, endangering public safety; The main objective of emergency management is to “prevent and minimize damage caused by the occurrence of an event”. The whole process of emergency management should cover all aspects of emergency management before, during and after the incident, i.e., including prediction and warning, information reporting, emergency response, emergency disposal, recovery and reconstruction, and investigation and evaluation.

This shows that prediction and warning is the starting point of emergency management. At present, China has been emphasizing the issue of "prevention-oriented, the gateway to move forward", that is, to do a good job of "prediction and early warning" work. The main purpose of forecasting and warning (which is the starting point of emergency management) is to prevent existing "potential hazards" from becoming "emergencies". Although the current scope of emergency management has been extended to "prevention", the focus of management is still on public emergencies. In this sense, emergency management is still relatively passive. Therefore, in order to promote the transformation of emergency management from "passive response" to "active protection", we should carry out a more basic and fundamental level, that is, in "risk management". The most important thing to do is to make an effort on "risk management".

(1) The main elements of emergency management theory

1) Accident life cycle theory

Hazards include three major categories: human hazards, physical hazards and liability hazards. First of all, human hazards can be divided into life hazards and health hazards; physical hazards refer to fire, lightning, typhoon, flood and other accidental disasters that threaten the safety of property; liability hazards are the legal liability for damages that arise from the law and are generally also known as third party liability insurance. Among them, the hazard consists of the accident, the possibility of the accident occurring and the state of danger that harbors the possibility of the accident occurring. The development of a general accident can be summarized into four stages: the gestation stage, the growth stage, the occurrence stage and the emergency stage.

Conception stage: the initial stage of the accident, which is caused by the underlying causes of the accident, such as socio-historical causes, technical and educational causes, etc. In a certain period of time due to some rules and regulations, safety and technical measures and other management tools have been destroyed, so that the material risk factors are not controlled and poor human quality, coupled with mechanical equipment due to the design, manufacturing process of various unreliability and insecurity, so that its innate latent danger, these are embedded in the possibility of accidents, are the conditions that lead to accidents.

Growth stage: Due to the unsafe behavior of people or unsafe state of things, coupled with management errors or defects, prompting the growth of accident hazards, the danger of the system increases, then the accident will develop from the gestation stage to the growth stage, it is a prerequisite for the accident to occur, and play a mediating role in causing the formation of injuries.

Occurrence stage: The accident is bound to happen when the accident develops to the growth stage and then the excitation factors come into play. This stage will inevitably result in injury or loss to people or objects, and the opportunity factor determines the extent of injury and loss.

Emergency phase: mainly includes two phases of emergency disposal and rehabilitation. Emergency disposal is the emergency and rescue actions taken immediately after the accident, including alarm and notification of the accident, emergency evacuation of personnel, first aid and medical treatment, fire and engineering rescue measures, information collection and emergency decision-making and external assistance; rehabilitation should be in the first place after the accident should make the accident-affected area back to a relatively safe basic state, and then gradually return to normal. The emergency response objectives are to rescue as many victims as possible, protect potentially threatened people, control and eliminate the accident as much as possible, return to normal as soon as possible, and reduce losses.

The connotation of incident emergency management includes four phases: prevention, preparedness, response, and recovery. Although in practice these phases often overlap, each part of them has its own separate objective and becomes part of the content of the next phase.

2) Emergency management life cycle theory

According to the development cycle of emergencies, the life cycle theory of emergency management provides a theoretical framework for the corresponding stages. Among them, the PPRR (prevention, preparation, response and recovery) theory proposed by the Federal Emergency Management Agency (FEMA) of the United States is widely used. In addition, the National Governors Association (NGA) in the 1970s divided emergency management activities, policies, and programs into four phases based on the disaster cycle: mitigation, preparedness, response, and recovery, hence the name MPRR model. This is the life-cycle theory or four-stage theory of emergency management. The theory is the result of a summary of comprehensive emergency management, combined with lessons learned from numerous disasters. It starts with identifying and mitigating risks and aims to avoid preventable disaster consequences and mitigate the effects of unavoidable disasters. The response and recovery process prepares you for the next emergency.

In the PPRR model, the prevention and preparation phase is more important than the response and recovery phase. Only with good prevention and preparation can we better cope and recover. Without good prevention and preparedness, the effectiveness of the response and recovery phases will be limited. On the contrary, through good prevention and preparation, even if the response and recovery phases are not done well, the hazards and damages of emergencies can still be controlled, which reflects the importance of the "prevention-oriented" principle.

(2) Emergency management link

According to the U.S. National Incident Management System (NIMS), the emergency management link can be under four links, as shown in the following figure (Fig. 2.1).

Mitigation: i.e., prevention, refers to all measures to reduce the risk of emergencies to people and property in order to reduce the actual and potential losses caused by emergencies, the implementation of disaster prevention and mitigation measures throughout the event process, measures often obtained from the lessons learned from previous emergencies. The content of disaster prevention and mitigation involves reducing the likelihood of and losses from emergencies, as well as the exposure

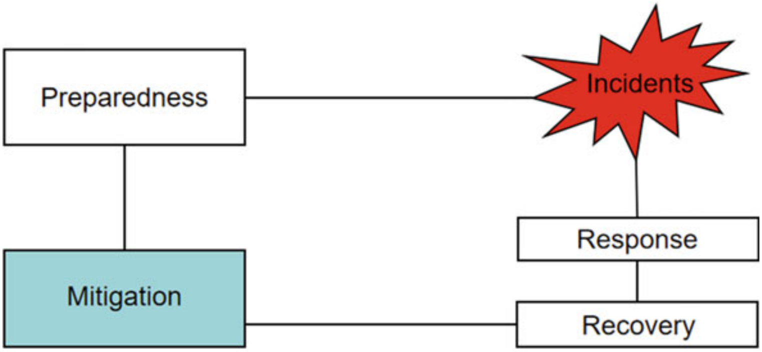

Fig. 2.1 The links of emergency management

of disaster-bearing carriers to emergencies. The task is to identify the causes of emergencies and try to reduce their likelihood of occurrence or limit their scope of impact. The key to its research problem is to try to stop emergencies before they occur, including changing natural events or human behavior, or both can reduce the likelihood and consequences of emergencies; reduce the sources of accident hazards by controlling the hazardous substances themselves or by controlling their use by humans.

Preparedness: A series of well-designed major tasks and actions necessary to build, support, and improve operational capabilities to prevent, protect people from, respond to, and recover from domestic public emergencies. Preparedness is an ongoing process that includes various efforts to identify hazards, determine vulnerabilities, and identify resource requirements at all levels of government and between government and private organizations and non-governmental organizations. The content of disaster response preparation includes risk assessment, plan development, measure preparation and comprehensive evaluation.

Response: A public emergency with short-term, immediate consequences of the action. This includes prompt actions to save lives, protect property, and meet basic humanitarian needs; it also includes the implementation of emergency plans and disaster prevention and mitigation actions designed to reduce loss of life, injury to persons, damage to property, and other adverse consequences. Its contents can be divided into emergency event assessment, hazard control, personnel protection and incident management.

Recovery: refers to the development, coordination and implementation of service and site recovery plans; Rebuilding the government's operational capacity and service functions; Implementing assistance projects for individuals, the private sector, non-governmental and public to provide housing and promote recovery; Provide long-term care and treatment for those affected; and implementation of social, political, environmental, and economic recovery measures, assessment of the outbreak for lessons learned, and completion of incident reports; Proactive measures to mitigate the consequences of future events. Its components include disaster assessment, short-term recovery and reconstruction, long-term recovery and reconstruction, and recovery and reconstruction management.

(3) Emergency management "a case of three systems"

The content of our emergency management is summarized as "a case of three systems". "A case" refers to the emergency plan, that is, according to the occurrence and possible emergencies, prior research and development of response plans and programs. Emergency plans include overall plans, special plans and departmental plans of governments at all levels, as well as plans of grass-roots units and individual plans of large-scale activities. The "three systems" refer to the management system, operation mechanism and legal system of emergency work.

Emergency Preparedness: According to the definition of "Emergency Response Law of the People's Republic of China, Emergency plan is a pre-developed program to control, mitigate and eliminate the serious social hazards caused by emergencies and regulate emergency response activities. Specifically, on the basis of identifying and assessing the potential major hazards, the type of event, the likelihood of occurrence and the process of occurrence, the consequences of the event and the severity of the impact, the emergency response agencies and responsibilities, personnel, technology, equipment, facilities (equipment), materials, rescue operations and their command and coordination, etc., make specific arrangements in advance, which clarify before, during and just after the occurrence of a public emergency It clarifies who is responsible for doing what and when, as well as the corresponding disposal methods and resource preparation.

Emergency management system: mainly under the unified leadership of the Party Central Committee and the State Council, adhere to the principle of hierarchical management, hierarchical response, the combination of block, local management is the main; Establishing a sound centralized, unified and strong command structure; giving full play to our political and organizational advantages to form a strong social mobilization system; Establish and improve the leadership responsibility system based on the party committee and government of the place of occurrence, with the coordination and cooperation of relevant departments and related regions. The basic structure includes a decision-making body, an executive body, an operational body, an advisory team and an expert group.

Emergency operation mechanism: mainly to establish and improve the social early warning system, the formation of a unified command, fully functional, responsive, coordinated, orderly and efficient operation of the emergency mechanism. Its classification is currently divided in two different ways, governmental level and academic level. From the government level can be divided into prevention and emergency preparedness mechanism, monitoring and early warning mechanism, emergency decision-making and disposal mechanism, information dissemination and public opinion guidance mechanism, social mobilization mechanism, post-recovery and reconstruction mechanism, investigation and evaluation mechanism emergency security mechanism; The academic level can be divided into event management mechanism, process management mechanism, resource management mechanism, monitoring and management mechanism, and cooperative participation mechanism.

Emergency management legal system: mainly in accordance with the law of administration, efforts to make the emergency response to public emergencies gradually towards standardization, institutionalization and legalization track. And pay attention to the summary of practice to promote the continuous improvement of laws, regulations and rules. China published the "Emergency Response Law of the People's Republic of China" on August 30, 2007, to provide a basic framework for the legal system of emergency management and to establish the legal basis of the rule of law for emergency response in China, which is of great significance.

2.3 Grid Sensing Technology

2.3.1 Machine Vision Technology

The human visual system is composed of tens of thousands of nerve cells with different morphological functions, according to certain connection rules, forming a complex and advanced information processing system, which is the main component of the human body and is the main part of people's understanding of the complex unknown world and the colorful objective world. The retina is a key component of the human visual system and is an important way for people to experience the 3D world. The working principle of the retina is relatively simple, but the process is more complex. Light information is transformed into various neural impulses by the action of photoreceptor cells, and then the visual system, such as the optic nerve and the visual center, realizes deep processing of the acquired information, and people realize the understanding of 3D objects through the acquired processing information. For intelligent robots, they also have an advanced vision system. Machine vision is commonly known as a way for robots to obtain image information of external objects, that is, according to the principle of optics, using sensors to automatically obtain an image of a real object, and through the computer to carry out the corresponding processing and give a certain judgment to control the robot movement. That is to say, robots are using computers and various sensors to achieve human-like vision functions, and through computers, sensors and other core equipment to carry out objective cognition of the 3D world, including the acquisition and understanding of the surrounding environment in which they are located, the identification and positioning of target objects, etc. Machine vision is a discipline that integrates a variety of scientific theories and technologies, focusing on image acquisition, image processing and analysis, output, and display. In other words, the surface information of the object to be measured is first converted into 2D image data or 3D point cloud data, etc., and then various features of the image are extracted and later converted according to the requirements until it can be processed by the computer. At present, many research institutions and many scholars at home and abroad have conducted in-depth and systematic research on vision robots, and have achieved rich results.

The current rapid development of machine vision, but there is still no universal algorithm for accurate recognition of arbitrary objects, recognition algorithms face challenges in terms of robustness, computational complexity and scalability. Many domestic and foreign experts and scholars have conducted comprehensive and in-depth research on object recognition methods. Feature learning and classifier design have received a lot of attention, and these types of algorithms work well for object recognition in general categories. Currently the use of features to achieve object-specific recognition is a widespread and effective method, with feature matching and geometric verification being the key techniques of the recognition algorithm. The MOPED system developed by Carnegie Mellon University, USA, is a typical example of object recognition using local features. Target recognition is a key step in the application process of intelligent robots, and is the key for robots to sense their surroundings, recognize objects and understand them. The robot analyzes and identifies the target by image recognition technology through the image information of the actual object surface acquired by its vision system, as shown in Fig. 2.2. And image recognition technology can be generally divided into three stages, firstly the text recognition stage, then transition to 2D image recognition, and finally deep image recognition. At this stage, text recognition technology is relatively well developed, but its application areas also have significant limitations; 2D image recognition technology after recent decades of rapid development, the technology is relatively mature has a wide range of applications, but for image deformation, image rotation, scale scaling and other situations whose recognition efficiency is greatly reduced. In addition, 2D image recognition does not give the exact spatial location of the identified target; deep image recognition is the direction of image recognition technology development, this recognition technology can not only accurately identify the target, but also give the spatial location and direction of the target, so it can be better applied to intelligent robots. At the same time, with the development of technology and processing technology, depth sensors are developing rapidly and occupy a certain share in the sensor market. Such as ATOS and Microsoft's Kinect and other depth sensors make it easy to obtain depth images, 3D point clouds, and other 3D information data on the surface of objects. Therefore, the current trend of object recognition technology development is to use 3D information such as 3D point cloud data of the object surface for target recognition.

With the rapid development of computer vision technology, the research of target recognition based on 3D point cloud data has received more and more extensive attention. The target recognition of 3D point cloud data generally includes two parts: feature representation and feature matching strategy, and the matching recognition algorithm is a key component and a difficult point that needs to be tackled urgently. Object features can be classified as global features and local features, and the feature matching algorithms can be divided into direct feature point matching and indirect feature point matching methods. Therefore, there are various methods of target identification based on 3D point cloud data, and many domestic and foreign experts and scholars have done a lot of in-depth research on this, and achieved fruitful results.

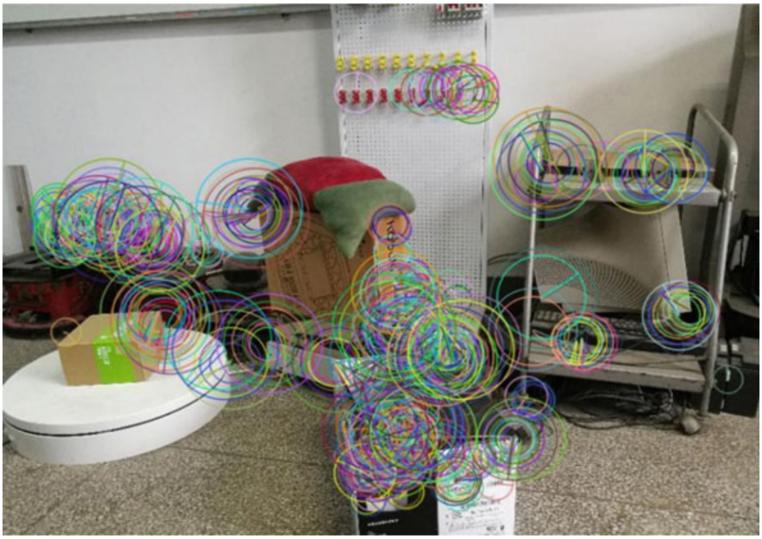

Fig. 2.2 Machine vision point cloud recognition feature point matching process diagram

2.3.2 Sensor Network Technologies

Sensing technology has a long history and the development of sensor networks has gone through four stages. The first generation sensor network is a simple measurement and control network, using wired transmission, with only a simple point-to-point transmission function, and complex wiring, poor anti-interference. The second generation sensor network is a measurement and control network composed of intelligent sensors and field control stations, and the biggest difference with the first generation sensor network is the realization of digital communication between control stations. The third generation sensor network refers to the intelligent sensor network based on fieldbus, fieldbus control system replaces the centralized control system, which is conducive to the development of sensor network in the direction of intelligence. After mankind enters the twenty-first century, the development of microelectromechanical systems technology, low-energy analog and digital circuit technology, low-energy radio frequency technology and sensor technology has made it possible to develop small, low-cost, low-power microsensors, while the development of radio, infrared, acoustic and other wireless communication technologies, especially the emergence of IEEE802.15.4 as the representative of the short-range radio communication standards, further gave birth to the fourth generation of sensor networks, namely Wireless Sensor Networks (WSN).

Wireless sensor networks are composed of a large number of small, low-cost sensor nodes with wireless communication, sensing and data processing capabilities deployed in the monitoring area. And each sensor node has the ability to store, transmit and process data. The nodes can exchange information with each

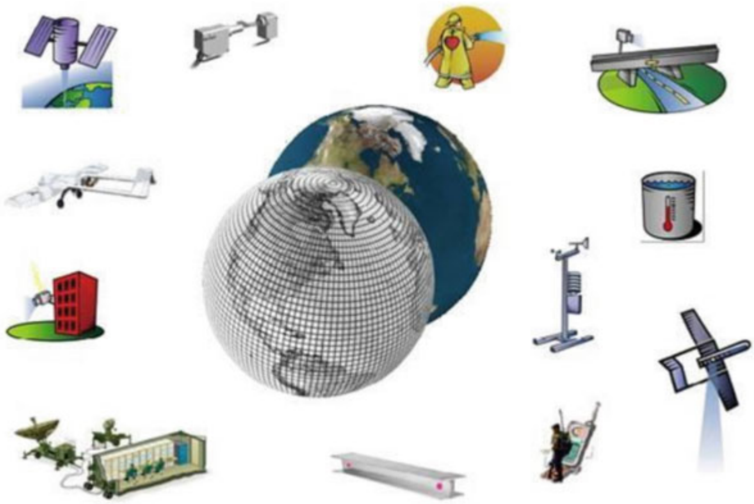

Fig. 2.3 Wireless sensor collection network application deployment diagram

other through the wireless network, and can also transmit information to the remote terminal. Figure 2.3 shows the deployment diagram of wireless sensor collection network application.

2.3.3 Multiple Information Fusion Technology

The concept of multifaceted information fusion first originated from the need for warfare and was dependent on military applications. The U.S. Department of Defense JDL (Joint Directors of Laboratories) defines information fusion in terms of military applications as the process of combining, correlating, combining, and valuing data from many sensors and information sources to achieve accurate location and identity estimates, as well as a timely and complete evaluation of battlefield conditions and threats and their significance. However, with the development of information fusion, it has become an independent discipline, no longer influenced by a particular application apparently, but with the help of reasoning, generalization of concepts, and specialization of synthesis to ask its own questions. Edward Waltz and James Linas have added and modified the above definition by replacing the position estimation with state estimation and adding the function of detection, thus giving the following definition: Information fusion is a multi-layered, multi-faceted process that involves detecting, combining, correlating, estimating, and combining multiple data to achieve accurate status estimates and identity estimates, as well as complete and timely situational assessments and threat estimates. China's research work in multi-sensor technology started late, in the early 1990s, a number of domestic universities and research institutes began to engage in research work on this technology, and achieved a large number of theoretical research results, such as Sichuan University developed a multi-tube radar information fusion system, the system performance reached the world's leading level. From the late 1990s to the present, multifaceted information fusion technology has developed into a common key technology of concern to many parties in China, and many scholars have devoted themselves to research on maneuvering multi-target tracking, distributed information fusion, identity recognition, situational estimation, threat determination, warning systems, and decision information fusion. In summary, multivariate information fusion technology is increasingly broadening the engineering application scenarios in military and non-military fields, but multivariate fusion technology for distribution network operation state sensing data is still in its initial stage. The operation, control and analysis of the distribution system rely on various types of sensors installed in the distribution network, which are analyzed and processed under certain criteria to obtain the real-time conditions of the distribution network, so that the multiple information fusion technology can be introduced into the simulation of the real-time and future states of the distribution network.

2.4 Grid Emergency Technologies and Methods

2.4.1 Critical Incident Risk Assessment Techniques

Risk is the product of the probability and consequences of an event, and its basic characteristics are objectivity, suddenness, variability, and intangibility, which ISO refers to as the "uncertainty effect of the target". The basic process of risk assessment is: ① Data collection and collation. Collect and organize the geographic information data, demographic statistics, economic statistics, emergency rescue resources distribution data, key infrastructure distribution data, etc. of the risk-prone area.② Comprehensive analysis of risk. Combined with the formation mechanism of the risk of emergencies, comprehensive analysis of the causative factors of emergencies, disaster-pregnant environment and other factors, providing information on the causative factors and disaster-pregnant environment that lead to emergencies, and grasp the causes of emergencies and their influencing factors. The GIS technology is used to generate the distribution map of disaster-causing factors, disaster-predisposing environment, causative factors, and comprehensive analysis of risk, etc. ③ Comprehensive analysis of vulnerability. Comprehensive analysis of the vulnerability of various disaster carriers (population, property, environment and infrastructure, etc.) in the risk-prone area provides information on the vulnerability of disaster carriers, and grasps the distribution of disaster carriers that may cause damage in the assessment area. GIS technology is used to generate information distribution maps of disaster carriers (population distribution map, property distribution map, critical infrastructure distribution map, etc.), distribution maps of possible event chains, and comprehensive vulnerability analysis maps, etc. ④ Comprehensive analysis of disaster prevention capability. Comprehensive analysis of various government and social disaster prevention capabilities to prevent emergencies and reduce the damage of disaster-bearing carriers, provide information on disaster prevention capabilities in response to emergencies, and grasp the distribution of various social resources and disaster prevention facilities in response to emergencies. GIS technology is used to generate emergency relief resources distribution map, disaster prevention facilities distribution map, and comprehensive analysis map of disaster prevention capacity. ⑤ Comprehensive analysis of secondary disasters. Comprehensive analysis of the secondary events that may be induced by the destruction of disaster-bearing carriers within the impact area of the emergency, providing information about secondary events and even event chains that may be induced by the emergency, and grasping the possible occurrence of event chains. GIS technology is used to generate information on possible secondary events, distribution maps of secondary event impact factors, and comprehensive analysis maps of induced secondary disasters.

Risk assessment can be divided into single-hazard risk assessment and multi-hazard integrated risk assessment according to the number of risk source types.

(1) Single-hazard risk assessment

Common types of single-hazard risk assessment methods are based on indicator systems, based on predictive models (i.e., event evolution dynamics), and based on accident analysis. Currently, the familiar risk assessment methods based on indicator systems mostly use statistical principles and methods, as well as other mathematical methods to quantify the value of indicators and synthesize them into a systematic index. Due to the simplicity of the principle, easy to understand and operate, etc., it has become a more widely used method in the field of assessment at present. The method consists of three main parts: assessment indicators, weighting coefficients and mathematical statistical methods. Each indicator portrays a certain characteristic affecting the risk from different aspects, and each indicator corresponds to a weighting coefficient reflecting the degree of influence of the indicator on the total risk. Finally, the assessment values of multiple indicators are synthesized into an overall assessment value by mathematical methods, and the mathematical statistical methods often resorted to in their assessment include hierarchical analysis, fuzzy comprehensive evaluation method, and gray theory-based methods.

1) Hierarchical analysis steps

① Establishing a recursive hierarchical structure: constructing a hierarchical structural model, the complex problem is decomposed into components of elements, which are further divided into several levels according to their attributes and relationships, and the elements of the previous level act as criteria to govern the relevant elements of the next level; ② Constructing a two-by-two comparison judgment matrix; ③ Calculating the relative weights of elements under a single criterion: generally obtained by the eigenroot method of ranked weight vector calculation; ④ Calculating the synthetic weights of the elements of each level relative to the target level.

2) Steps of fuzzy comprehensive evaluation method

Considering that there are a large number of fuzzy factors in various risk assessments, fuzzy evaluation of these factors can increase the reliability and scientificity of risk assessment results. ① Establish the fuzzy affiliation function of each index; ② Convert the results of literal linguistic estimation of risks by risk analysts and relevant experts to numerical descriptions by corresponding to the affiliation function; ③ Combine each risk factor according to the fuzzy relational operation rules to obtain the total risk degree fuzzy logical numerical description; ④ Compare the results with the affiliation function and reconvert them to literal linguistic risk degree descriptions.

3) Gray theory-based method steps

Gray theory is applicable to gray systems where the information is partially known and partially unknown, while risk information is usually not completely known, so the method based on gray theory can also be applied. ① The original data is processed by the cumulative generation method and the cumulative subtraction generation method; ② A gray model is built based on the generated numbers; ③ The determined model is tested for accuracy by the residual test, posterior difference test or correlation test; ④ When the accuracy meets the requirements, the model is used for risk analysis.

In addition, risk assessment methods based on predictive models/evolutionary dynamics of events simulate the evolutionary process of possible emergencies, analyze the scope and extent of their possible impact, examine the risk to human life, possible economic loss, environmental damage, and the risk compensation role of emergency rescue within that impact area, and thus calculate the total risk value. Risk assessment methods based on accident analysis include safety checklist method, advance hazard analysis, failure type and impact analysis method, event tree analysis method and accident tree analysis method.

(2) Integrated multi-hazard risk assessment

Currently, research on single risk sources natural disasters or accidental catastrophes is more mature, but risk sources are often coupled, so the results of such risk analysis are often inaccurate and incomplete. Only when all relevant threats are considered and analyzed is it possible to reduce effective risk reduction. However, compared with the risk analysis of a single hazard or accident, the risk analysis of multiple hazards and accidents appears to be more complex and variable, mainly because the characteristics of various types of hazards and accidents are different, so the analysis methods may also differ significantly, and the interrelationships between multiple hazards and accidents may be very complex when they are concurrent, so it is not simply possible to superimpose different hazards. At the same time, many different research methods have been proposed by different researchers at home and abroad, and multiple analysis methods need to be adjusted and unified in order to be applicable to more general situations.

Comprehensive multi-hazard risk assessment generally takes natural disasters and accidental catastrophes as research objects, focusing on the risk assessment and zoning of the coupling of these emergencies. According to different disaster-incident interrelationships to distinguish different multi-hazard scenarios, multi-hazard scenarios are classified into 3 major categories of disaster-incident mutual enhancement, disaster-incident mutually exclusive weakening, and disaster-incident mutually unaffected, where disaster-incident mutual enhancement is divided into: ① Cross-category disasters: Natech events and human-initiated disasters. ② Disaster mutual enhancement (compound disaster): disaster chains and parallel disasters. ③ Accident mutual enhancement: Domino effect, parallel accident. The disaster-accident mutual enhancement includes both disaster-accident sets and disaster-accident episodes. Meanwhile, the parallel occurrence of disasters and accidents is also called parallel disaster accidents. Disaster-incident mutual enhancement is the part of multi-hazard risk assessment that focuses on. Because of the existence of interrelationship between hazard types, the risk of multi-hazard types cannot be treated as a simple linear sum of single-hazard risks. For the mutual reinforcement between hazard incidents, one is that one or more hazard incident processes triggers another or more hazard incident processes, resulting in an increase in the number, deepening and expansion of the damage; the other is that the state process of a hazard incident is changed due to the action of another or more hazard incidents, resulting in an increase in the intensity of the hazard incident and more serious consequences.

This section specifies the meaning of Natech event and domino effect in the scenario of mutual reinforcement of disaster incidents and the steps of risk assessment.

1) Natech event risk assessment

Natech refers to natural hazard events that trigger technological emergencies, accidents and disasters caused by natural disasters. In practice, natural disasters such as earthquakes, storms, floods and lightning are more likely to cause Natech events, and at the same time, it is easy to find that chemical parks are the key areas of concern for Natech events, and their key process equipment is vulnerable to natural disasters. Natural disasters such as storms, earthquakes and floods cause damage to the relevant structures in chemical parks through external impacts, resulting in the leakage of storage tanks containing toxic substances, which is the main evolutionary pattern of Natech events. At the same time, crush collisions between equipment units may also cause vessel pressure destabilization and lead to explosions.

Taking the chemical Natech event caused by flooding as an example, we introduce the steps of Natech event risk assessment: ① Assess the frequency and intensity of flooding. The frequency of flooding is expressed in terms of return period, and the intensity indicator is usually chosen to characterize the maximum water velocity and inundation height. These data are easily accessible and can be collected at the disaster site. ② Identification of equipment that may be damaged in a flood disaster. The type of disaster scenario is related to the following three factors: 1) the properties of the hazardous material; 2) the containment measures of the equipment; and 3) the possible forms of structural damage. Commonly damaged equipment in floods are: pipes, flanges, reaction units, storage tanks, etc. In this section, common atmospheric storage tanks are chosen as the main object of study. ③ Assumptions are made for disaster scenarios. The flood causes the storage tank to fail and rupture, and a chemical leak occurs, which in turn contaminates the water or air. ④ The probability of loss of the target equipment in a flood. Vulnerability of storage tanks in a flood is analyzed. ⑤ Quantitative risk assessment of hypothetical scenarios. By means of event tree analysis, the consequences of a disaster can be expressed in the form of individual risk and social risk.

2) Domino accident risk assessment

The domino effect is a phenomenon that occurs in an accident disaster when the initial accident occurs and the spread of the accident leads to an accident in one or more adjacent devices, resulting in a total accident that is more severe than the initial accident. There are many studies on the concept of domino effect, but in general, its core is “initial accident-propagation path-target equipment or unit”, which is essentially a “accident chain”. In industrial production, domino accidents are usually fires, explosions and toxic spills, where fire heat radiation, explosion fragments and explosion shock waves are the three main factors leading to accident propagation. Generally speaking, toxic spills do not further cause “fire and explosion poison” accident, so it is usually as the domino effect of the last accident.

Taking the Tianjiayi chemical enterprise in Ringshui County, Jiangsu Province as an example, we introduce the steps of applying Monte Carlo simulation method to carry out Domino accident risk assessment: ① Preparation stage. In the preparation stage of quantitative risk assessment of Domino accidents, a detailed hazard source analysis is required, including site construction, accident category identification and base model selection, and the most common method is process hazard analysis (PHA). ② Determine the initial accident. The LOC (Loss-of-containment) event is introduced to the random chemical plant in the accident scenario, and the initial accident of fire, explosion and poison can be triggered according to the corresponding event tree model, so that the frequency of the corresponding initial accident, the physical effect field of the accident and the accident escalation probability matrix can be calculated by the corresponding accident analysis model. ③ Accident escalation simulation. Based on the escalation probability matrix of the initial accident, the damage probability of the chemical plant in the accident scenario under the influence of the initial accident can be analyzed, and this analysis process is realized by generating random numbers. The accident escalation probability of each undamaged chemical plant in the accident scenario needs to be determined based on its accident escalation probability. ④ Iterative accident simulation. The purpose of this step is to carry out an iterative simulation of the accident escalation process in unit time steps until the end of the domino accident development process. ⑤ Monte Carlo simulation. The implementation of Monte Carlo simulation requires a large number of repetitions of steps two to four. Through Monte Carlo simulations, the initial accident occurrence frequencies of all possible accident scenarios for this domino accident and the large-scale physical effect fields can be obtained. ⑥ Analysis of results. Based on the large-scale physical effect fields and the application of the accident injury analysis model, the dynamic distribution of human mortality in the region can be calculated to obtain the regional individual risk distribution.

2.4.2 Emergency Monitoring and Warning Technology

Emergency monitoring and early warning technology is based on monitoring and monitoring data, prediction and analysis of emergencies, according to the analysis results of the early warning information release process, including the monitoring and monitoring of emergencies and their related information, emergency prediction and early warning, etc.

Monitoring and control is to observe, measure, record and analyze the collected data and propose control measures for various safety and environmental parameters of the emergency and its related things and phenomena. In the emergency before, during or after the event, can be performed as needed to perform a variety of monitoring and surveillance tasks. The monitoring route can be divided into contact and non-contact two. The purpose of monitoring and surveillance is to obtain a variety of data and information related to the prevention and disposal of emergencies, in peacetime, this data and information can be used as the basis for risk identification, risk assessment, prediction and warning, while in wartime, it is an important source of information for emergency decision-making and will become an important basis for decision analysis.

Pre-event monitoring and warning refers to risk analysis, risk assessment, prediction of the possibility of emergencies, and the release of various early warning information to emergency staff or the public (such as the occurrence of emergencies warning information the duration and scope of emergencies, secondary and derivative events occurring risk, etc.); in-event monitoring and warning refers to the development trend and impact of emergencies through scientific methods (such as model simulation extrapolation). This prediction also includes the pre-evaluation of intervention measures, i.e., the prediction of the expected effect of the disposal behavior to be taken. In view of the positioning and functions of the power grid emergency platform, the emergency platform focuses more on the monitoring of the comprehensive risk potential of emergencies and comprehensive prediction and early warning, using the data aggregation and departmental synergy advantages of the emergency platform to conduct a comprehensive analysis of the conception, occurrence and development of emergencies.

(1) Monitoring and control technology of risk and potential hazards

Risk monitoring and control technology includes risk identification technology, risk source monitoring technology, comprehensive risk assessment technology, risk prevention and control technology, etc. Risk identification is the basis of risk assessment, which is to systematically categorize and comprehensively identify various potential risks that have not yet occurred, and to determine which potential factors will lead to the occurrence of events, or under certain specific conditions will further expand the events that have occurred, or even cause secondary and derivative events, resulting in greater losses. Risk source monitoring is the application of the principles and methods of systems theory, cybernetics, information theory, combined with automatic monitoring technology, sensors, computers, communications and other modern high-tech, real-time monitoring of the safety of risk sources, speed collection of a variety of digital and non-digital information, especially those that may make the safety of the risk source to the non-normal state of the trend of change of various parameters, to give the results of risk assessment. Timely issuance of early warning information, the hidden danger in the nascent state. Common monitoring and surveillance methods are video monitoring and surveillance methods, wireless monitoring and surveillance methods and 3S monitoring and surveillance methods.

1) Video monitoring and surveillance methods. Widely used in the field of security, divided into closed-circuit television monitoring system and remote network video surveillance system. Video surveillance system mainly consists of monitoring front-end, management center, monitoring center, PC client, and wireless network bridge.
2) Wireless monitoring and surveillance method. The prototype is a distributed sensor network, the main components of which are data acquisition network, data distribution network, nodes integrated with sensors, data processing units and communication modules, each node forms a distributed network through a protocol, and transmits the collected data to the information processing center via radio waves after optimization.
3) 3S monitoring methods. 3S includes Global Positioning System (GPS), Remote Sensing System (RS) and Geographic Information System (GIS). GPS monitors the deformation information of space objects, such as the deformation of landslides, the deformation of bridges and dams, etc. RS remote sensing images can pick up all kinds of characteristic information and detect the change of risk factors through sequence images, and GIS can dynamically display and analyze the data and maintain and manage them.

Risk assessment is divided into quantitative comprehensive risk assessment under single disaster and comprehensive risk assessment under multi-disaster coupling disaster. The quantitative comprehensive risk assessment in the case of single disaster is to give the corresponding risk assessment method based on a certain hazard source, while the comprehensive risk assessment of single emergency is mainly based on index system. The general idea of multi-hazard risk assessment based on emergent event chain is briefly introduced in this paper. The mathematical model of hazard comprehensive risk assessment based on induction probability matrix is used. Risk prevention and control refers to the prevention and control of risks by means of risk avoidance, risk prevention, risk control, risk tolerance, risk transfer and other methods based on the monitoring information of potential risks. When carrying out risk prevention and control, appropriate risk treatment methods shall be selected according to the characteristics of different risks, and the risk control methods shall be selected accurately and reasonably according to the results of risk forecast, identification, assessment and analysis as far as possible, and the risk treatment plan shall be adjusted timely according to the changes of risk monitoring information.

(2) Comprehensive forecasting and early warning technology

Comprehensive Forecasting and Early Warning Technology. The qualitative and quantitative forecasting methods shall be adopted to simulate and analyze the development of the situation and the consequences, predict the possible secondary and derivative events, determine the scope, mode, duration and degree of harm of the event, and put forward early warning and grading suggestions in combination with the relevant early warning grading indicators. The difficulty of comprehensive forecast and early warning is that we need to combine the historical and statistical data of different fields closely to make statistical analysis, mathematical and physical modeling and numerical calculation.

The research methods of predictive model include deterministic research method, stochastic research method, information-based research method, system science research method and compound research method. Deterministic research methods mainly refer to experimental simulation, theoretical analysis and numerical simulation; stochastic research methods mainly study the laws of time series, spatial distribution and space–time coupling of public security science by means of probability, statistics and analysis, such as time series analysis method, spatial statistics analysis method and space–time coupling analysis method; information-based research methods mainly refer to the supplement of deterministic research methods and stochastic research methods, such as the acquisition of data in the experimental simulation of deterministic methods, the determination of some parameters, initial parameters and boundary parameters in theoretical analysis and numerical simulation, and the modification of intermediate results, etc.; for stochastic research methods, it is also necessary to have sufficient and effective data or information to conduct statistical analysis of the results of stochastic research methods, which will have an impact on the results of stochastic research methods, and these are inseparable from information-based research methods; systematic scientific research methods include non-linear scientific research methods such as synergistic research methods, mutation theory, etc., and research methods of complexity science such as Based on Methods, cellular automata and complex network dynamics, etc.; compound research methods are comprehensive methods formed by using several of these four methods when studying a public security scientific problem.

The prediction and analysis models of typical emergencies in power grid emergency platform include earthquake disaster damage model, landslide disaster damage model, typhoon disaster damage model, rainstorm flood disaster damage model, snow freezing disaster damage model, etc. At present, based on the understanding of the formation mechanism, disaster-causing mechanism and evolution law of some unexpected events, some scientific models and algorithms have been established to predict and analyze power grid disasters and accidents, but some models are not mature and perfect. According to the needs of emergency platform construction, some models with high input parameters, difficult to obtain parameter information, complicated steps and complex algorithms need to be improved.

2.4.3 Emergency Information Interaction and Integration Technology

Information technology is the basis for the development of the emergency system, and many developed countries have already established a relatively complete emergency platform system, and various emergency equipment technology has been quite mature. In the construction of the emergency platform system in the United States, Japan and other developed countries, all attach great importance to the application of digital information technology, the United States is more concerned about the investment in software platforms, while Japan is more concerned about the smooth flow of information and communication, all of which have good significance for the planning and construction of China's digital emergency system.

(1) Emergency Geographic Information Technology

Geographic information belongs to the basic information of national economic construction, and plays an important role in the process of disaster prevention and emergency disposal. In the process of emergency response, it is often necessary to realize geographic information exchange and sharing between relevant emergency management departments. In the construction of emergency platform system, both government emergency platforms at all levels and professional departmental emergency platforms need the support of basic geographic information data. In order to avoid duplicate construction, facilitate the subsequent updating and maintenance of basic geographic information, and meet the demand for real-time and consistent on-site geographic information data for emergency disposal, it is necessary to study the interoperability between emergency platforms, insufficient information in the emergency disposal environment, and establish an integrated system of geographic information services for emergency management.

As a new direction in the development of GIS technology, geographic information service has become a new solution for geographic information sharing and processing in a distributed environment in recent years. How to use geographic information service technology to realize the sharing and exchange of geographic information between emergency management departments is one of the key technical problems that need to be solved for the interconnection of emergency platform system. The key technologies involved in emergency geo-information technology include: emergency geo-information service integration, emergency geo-information service resource discovery, geo-information integrated service optimization, etc.

The current primary approach to resource discovery for World Wide Web (Web) services provides only a general solution for Web service users to discover and access services. Geographic information services have their own characteristics, which require special analysis and research. In addition, given the special characteristics of the public safety field, it is necessary to study the typical service resource query requests of emergency management users and research the discovery and access algorithms of emergency geographic information services applicable to the business needs of emergency management. Web element service (WFS) is an important way to carry out vector geographic information data sharing, and WFS service often causes large transmission cost when integrating query because it adopts geographic identity language (GML) as the carrier of spatial data, and it is necessary to study the optimization strategy of WFS integrated service connection query.

(2) Information integration technology

Information integration is a concept of organizing and managing information for a certain goal or for a specific service, and the core of integration is to take resources as a large system and adopt technical means to integrate and share resources. The information of subsystems and users in the system adopts a unified standard, specification and code to achieve system-wide information sharing, which in turn can realize the interaction and orderly work between the software of users. The basis of information integration is standardization, which mainly includes communication protocol standardization (e.g. MAP/TOP, Manufacturing Automation Protocol/Technical Office Protocol, etc.), product data standardization (e.g. STEP, Standard for exchange of product model data, etc.), as well as regulation network standardization, electronic document standardization, interactive graphics standardization, etc. The integration platform is a powerful tool for information integration and is an application of object-oriented open integration technology, for example, there are N applications that need to interact, and as long as each application is connected to the integration platform separately, the integration of N applications can be realized with the support of a group of integration servers, thus the complexity of integration is reduced from multiple to one. The key technologies involved in emergency geo-information technology include: heterogeneous database integration technology, middleware-based information integration technology, XML-based information integration technology, etc.

1) Heterogeneous database integration technology

There are mainly two options for heterogeneous database integration: multi-database language system and schema integration. The former only provides a unified multi-database operation language and a common interface to access member databases, and each member database is highly autonomous, but does not address semantic heterogeneity and achieve access locality transparency, the user must specify the database to be accessed, and the constraints or dependencies between databases must be defined and maintained by the user and the application. This method is more suitable for integrating a small number of databases. The schema integration system provides a global schema that allows clients to access each member database transparently, with the member databases still maintaining a high degree of autonomy. Schema integration is more suitable for integrating a large number of databases or databases with high access transparency requirements.

2) Middleware-based information integration technology

With the wide application of information technology in various industries, there is an urgent need to integrate information from a large number of semi-structured or unstructured data sources, such as Web information, and the system is required to be scalable to integrate additional data sources. Traditional database integration methods based on schema integration are no longer applicable to this new requirement, and middleware-based information systems have been proposed. Middleware-based information system architecture can improve concurrency of query processing and reduce response time by splitting processing tasks between middleware and wrappers. A wrapper encapsulates a specific data source, converts its data model to the common model adopted by the system as its output model, and provides a consistent physical access mechanism. The middleware focuses on global query processing and optimization, with a global schema described using a common model. It resolves data redundancy and inconsistency by calling wrappers or other middleware to integrate information from data sources, providing consistent and coordinated views of data and a unified query language. The wrapper can be either in the same location as the middleware or in the same location as the data source, depending on the performance requirements of the system, the attribution of the data source and its access control privileges.

3) XML-based information integration technology

XML, the Extensible Markup Language, is SGML (Standard Generalized Markup Language), as is HTML. XML is a cross-platform, content-dependent technology in the Internet environment and is a powerful tool for handling structured document information today. Extensible Markup Language XML is a simple data storage language that describes data using a series of simple tags that can be built in a convenient way. XML has great potential to become a new generation of data exchange standards, but because database management systems have more powerful data management functions, efficient data access, data consistency automation guarantee mechanism, powerful data integrity guarantee mechanism, and multi-user concurrent access control mechanism than XML, in practical applications, the storage management of large amounts of data still relies on database management systems, and the core role of XML is reflected in the implementation of shared data exchange, which has three roles: modeling of complex product data objects, exchange of shared data, and direct operation of the Web.

(3) Grid information integration platform

Grid enterprise information integration platform can use grid heterogeneous database integration technology, middleware-based information integration technology, XML-based information integration technology to realize grid enterprise information integration services. The overall architecture of grid enterprise information integration can be integrated from both horizontal and vertical aspects, horizontal is mainly the integration of data information between different information systems within the grid enterprise level, vertical information integration is mainly the integration of data information between the upper and lower level units of the grid enterprise, horizontal and vertical information through the grid enterprise information integration platform constitutes the grid enterprise information interweaving, forming the grid enterprise information exchange horizontal and vertical exchange integration system.

Horizontal information integration of grid enterprises can use heterogeneous database and XML integration technology to form a grid enterprise bus for horizontal information integration of data. Vertical information integration of power grid enterprises can use heterogeneous database integration technology and middleware information integration technology to build a vertical exchange platform for power grid enterprises to realize vertical information exchange between upper and lower level units of power grid enterprises.

2.4.4 Emergency Command and Decision-Making Integrated Research and Diagnosis Technology

Emergency command and decision-making comprehensive research and analysis is after the occurrence of an emergency, in order to control the situation, reduce the loss of life and property and carry out the analysis and decision-making work, including information receiving, on-site information acquisition and display, query and analysis, situational mapping, intelligent auxiliary program production, resource scheduling and tracking, etc. In the emergency command and decision-making process, how to organize cross-field, cross-level, cross-departmental consultation and decision-making, and carry out collaborative disposal, which is a key link and a key issue in the face of emergency management of emergencies. On the basis of modern communication technology, GIS and other modern technologies, we can realize online collaborative meetings between multiple parties and different locations by integrating text, voice, video and other media interaction means, as well as "emergency one map" theory and technical research results. Emergency decision-making techniques include model chain methods, digital preplanning methods, knowledge rule-based reasoning, case-based reasoning, multi-type knowledge coupling methods, scenario evolution methods, etc. Among them, the emergency decision-making model based on human–computer interaction technology provides an important support for scientific decision-making and efficient disposal of emergency management. Decision support systems are computer applications that assist decision makers in making semi-structured or unstructured decisions through data, models and knowledge in a human–computer interactive manner. It is an advanced information management system resulting from the development of management information systems to a higher level. It provides decision makers with an environment to analyze problems to build models, simulate decision-making processes and scenarios, and call on various information resources and analytical tools to help decision makers improve the level and quality of their decisions.

(1) Online meeting technology

In the emergency disposal of emergencies, it often requires cross-regional and cross-departmental collaborative emergency command and consultation, and for serious incidents, an on-site emergency command will be set up, which requires timely transmission of on-site information (such as the latitude and longitude of the accident site, type of disaster, casualty statistics, the scope of the incident, resource requirements, etc.) back to the rear, which, with the support of a powerful database and professional analysis system, will provide timely feedback to the front after comprehensive analysis of disaster prediction and warning results, emergency resource distribution and dispatch information to assist in the emergency disposal of the site. The online consultation technology of "Emergency One Map" can solve the problem of asymmetric information of multiple parties and incomplete information of a single party.

Traditional multi-party online conferencing is mostly based on video conferencing technology, through computer networks, in the form of voice, text and video conferencing. Videoconferencing, because of its lack of processing and support of spatial geographic information, often makes it difficult for participants to understand the location of the incident, the surrounding geographic environment, the distribution and damage of the road network at the scene, the spatial distribution of emergency resources and the location of the deployment of emergency rescue forces, and other information, making it difficult to accurately describe the spatial relationship between objects. Based on GIS technology, communication technology and computer technology, we can build a multi-party online consultation system for emergency response, which can support participants to map on the same map, exchange information in the form of graphics and text, and superimpose professional prediction and warning results of disasters from various departments, and jointly discuss and analyze the disposal measures for disasters with the support of professional database.

" Emergency One Map" means that the initiator of the online meeting or other data owners participating in the meeting provide the basic map data, and the participants of the meeting map out the basic map and discuss disaster response measures through the interaction of text, map drawing symbols, voice and video information. The consistency of data source, data accuracy, spatial reference, and map symbol expression of "Emergency One Map" ensures that all participants can negotiate and make decisions in the same semantic environment during online meetings, and ensures the accuracy of information transmission and expression. “The “Emergency One Map” needs to solve three key technical problems: ① how to quickly build an online consultation “base map”, which consists of digital maps, on-site images (remote sensing images, aerial images, photos, etc.), hazard sources, key protection targets and emergency resources; ② how to quickly distribute the “base map” to all parties involved in the online consultation; ③ how to eliminate the semantic differences between the geographic identifiers used by the parties in the multi-party consultation and create a unified graphical language.

(2) Emergency decision-making technology

Emergency decision-making is the process of studying and selecting emergency response processes and action plans in order to carry out prevention, disposal and rescue work quickly and effectively. The emergency command and decision making of power grid enterprises mainly realize the process of dealing with emergencies to provide comprehensive and accurate assistant decision analysis capability, through the analysis of information and data reasoning, to make the fastest response to emergencies in the shortest time and provide suitable auxiliary measures plan, with the help of reliable network and telephone and other communication tools to convey the decision information in a timely manner, and use advanced display technology to better express the decision information.

The research on emergency decision-making techniques is based on traditional operations research and artificial intelligence techniques on the one hand, considering the special needs and constraints of emergency decision-making, and extending and improving the traditional techniques to adapt them to the needs of decision-making activities in the emergency event environment. For example, the traditional model library system, case-based reasoning, rule-based reasoning and other methods and theories can be introduced into the system construction of emergency decision-making to establish corresponding emergency decision-making support models; on the other hand, in recent years, some researchers have introduced scenario planning, scenario evolution and other theories into the emergency decision-making system of various major emergencies and proposed the “scenario-response” emergency decision-making model based on scenario reproduction and situational projection.

Emergencies are characterized by suddenness, complexity, diversity, relevance, timeliness and uncertainty, etc. For emergency decision-making, two issues need to be addressed: first, the response to primary events and their secondary and derivative events; second, the multiparty collaborative response across departments and regions. For these two problems, we can use the traditional “prediction-response” model to maximize the multi-event prediction and early warning capability to solve some of the problems based on people’s knowledge of the laws of emergencies, and at the same time, we can use the multi-party collaborative consultation model to make decisions on the difficult-to-understand parts. At the same time, a reasonable “man–machine” relationship should be established and an effective method of integrating various emergency technologies should be proposed. Human–computer interaction-based emergency decision-making technology is a kind of technology that combines the two modes of "prediction-response" and "scenario-response" and effectively integrates various emergency technology methods by establishing a reasonable "human–computer" relationship in response to the dual laws of certainty and randomness of emergencies. Based on the emergency platform system, this technology can better solve the integration and balance of the two modes of "prediction-response" and "scenario-response" in the emergency platform system, and better serve the disposal of emergencies.

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Chapter 3
Multiple Information Collection Technology of Power Network Disaster Loss

3.1 Research Status of Information Collection Technology

In the field of wireless sensor network in the application and research and development, foreign countries such as the United States, Europe, Japan, South Korea and other countries started earlier, and their overall strength is strong. The United States "smart grid", "smart Earth", the European "Internet of Things Action Plan" and the "U Society" strategy based on the Internet of Things in Japan and South Korea have been implemented, and the Internet of Things has become an important means to seize the "post-crisis" era to enhance the comprehensive competitiveness of countries. In China, wireless sensor networks began to develop after the concept of intelligent dust was put forward, and with the deepening of research on it, it has gradually expanded from the application of national defense and military fields to environmental monitoring, medical health, seabed exploration, forest fire fighting and other fields, and it is included in the future emerging technology development plan, and focus on the application of biotechnology, chemistry and other aspects. After that, the scientific community focused its research on secure and scalable networks, sensor systems and other networks, which prompted scholars from all walks of life to gradually participate in the research and development process of wireless sensor networks.

The development of wireless sensor networks in China started at the same time as in developed countries, and the related research work has gradually received extensive attention from the government,. As a key research project, its basic theories and key technologies are included in the planned research. In recent years, the research of wireless sensor networks in our country has been developing continuously, and more achievements have been obtained. At the same time, with the continuous development and improvement of communication technology and electronic technology, wireless sensor networks have also been rapidly developed, and their application scope is more and more extensive, and their development prospects are broad.

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3.2 Disaster Loss Collection Technology of Power Equipment Based on Internet of Things

3.2.1 Summarize

The research on the rapid collection and automatic collection of multiple information of power equipment disaster loss focuses on the field environment and equipment perception collection technology, including machine vision intelligent identification collection and wireless sensor collection technology. Firstly, the method of machine vision is used to create an indoor environment map, and the damage state of power equipment is identified from the perspective of emergency treatment to realize the accurate perception and information correlation of the field environment; Secondly, it studies the identification of power field equipment based on mobile terminals to realize the identification of power grid equipment and related components. Finally, wireless communication module is used to realize the fast networking and data acquisition of power equipment sensors.

3.2.2 Intelligent Recognition and Acquisition Technology of Machine Vision

By using machine vision intelligent recognition and collection technology, the main task is to identify the overall damage of equipment in power facilities. A typical internal damage scenario of a power facility is shown in Fig. 3.1. The research of the identification algorithm will be carried out mainly from the perspective of emergency disposal needs, both the results of the algorithm identification will be used to complete the estimation of the number of resources required for the maintenance of power equipment and the subsequent research work, which will provide direct reference information for emergency decision-making.

Firstly, the RGB-D (RGB image + depth image fusion) sensor is used to obtain visual information about the indoor environment in real-time, and the feature extraction is performed separately for each subspace of the RGB image using ORB (an algorithm for fast feature point extraction, which can be used to quickly create feature vectors for key points in the image, and these feature vectors can be used to identify objects in the image) feature operators in binary form; then the image features are described as visual words in binary form according to the characteristics of ORB algorithm and stored in a tree structured model to construct a visual dictionary in binary form incorporating spatial information; closed-loop detection of the visual information acquired in real-time incorporating both temporal continuity and geometric consistency constraints, to determine whether the closed-loop condition is satisfied; if the closed-loop conditions are not met, then the image is stitched together with the depth information and through spatial mapping using the RANSAC algorithm

Fig. 3.1 Internal damage scene of power facilities

(an algorithm that calculates the parameters of a mathematical model of the data to obtain valid sample data based on a sample data set containing anomalous data); if the closed-loop conditions are met, the intelligent identification of on-site power equipment can be realized, and the equipment background operation data can be quickly retrieved after obtaining the equipment number. Field operators need to use the equipment to intelligently identify grid equipment and related components, thus laying the foundation for data collection.

Some physical quantities or states in power equipment can be obtained by visual methods, therefore, using image processing technology to analyze the object under test can realize the measurement or identification of physical quantities characterizing power equipment or its state, and discover abnormal phenomena and potential faults in time, meanwhile, using multi-band image technology can discover changes in subtle images that are difficult to be distinguished by human eyes, and realize equipment fault diagnosis and state early warning. In general, the principle of using machine vision intelligent recognition acquisition technology is shown in Fig. 3.2.

The process of identification of electrical equipment using image information is as follows: Image pre-processing: The image acquisition process and transmission process cause images with noise and other unfavorable factors for image analysis, so the first step of image analysis is pre-processing work to improve the quality of images. It mainly uses low-pass filtering to remove image noise and improve the quality of images. Image alignment: Not only does the electrical equipment need Image registration to recognize the infrared image to the visible image. In the comparison between the image obtained during patrol inspection and the image in

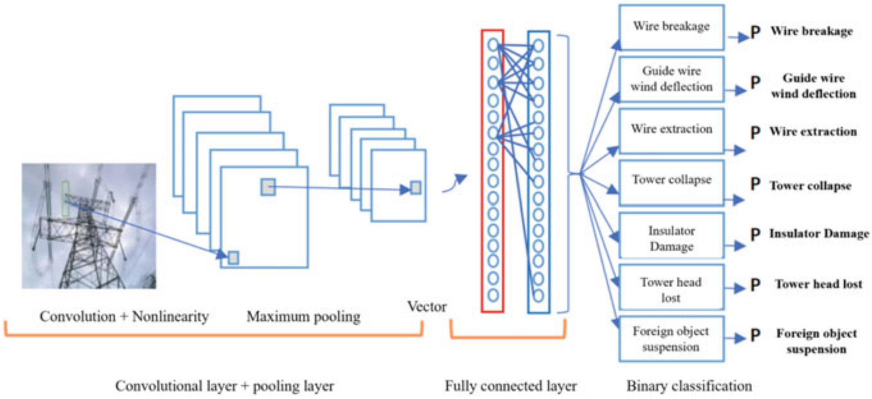


Fig. 3.2 Machine vision intelligent recognition acquisition technology principle

the historical database, due to the difference in angle and local area in shooting, in order to facilitate the later feature extraction work, it is also necessary to register these images with deviation. The method based on feature matching can be used, and the sift algorithm can extract stable feature points, and deal with the matching problems in the case of translation, rotation, affine transformation, perspective transformation, etc. between two images, which has good robustness to light changes and can match with a high probability. Image feature extraction: Image features are the original characteristics or attributes of the image field. Some of these are natural features that are directly perceived by the image, and some are artificial features that need to be transformed or measured to be obtained. In the walk-through, the color, shape and texture of the image can be used as natural features, while grayscale, histogram and infrared temperature differences can all be used as artificial features for recognition. Feature extraction should focus on the benefits that the extracted features bring to the accuracy and speed of the recognition process that follows.

An image is distinguished from other images mainly by its features, which include color features, texture features, shape features, etc.

(1) Color features

Color is the most significant feature of the image, and different electrical devices have different colors. Some electrical devices have obvious color features, which can be used as a basis for judgment. When the color feature of the electrical equipment is obvious, recognition analysis, the color can be used as a feature of recognition. For example, for transformers close to red, gray transformers, etc., the color range of the electrical equipment image is first extracted to obtain the range in which it is located as the main basis for identification, and the identification target in the image is located and analyzed.

The color feature expresses the global properties of the image is its shortcoming, and the local characteristics of the object are not well expressed. Therefore, color feature methods usually have to be used in combination with other methods to provide sufficient image information well. The extraction of color features mainly involves the following key issues: The choice of color space should be appropriate (other color spaces are not all consistent with all with human perception); defining and quantifying color features; similarity metrics and matching, how to define the similarity of color features and match them quickly.

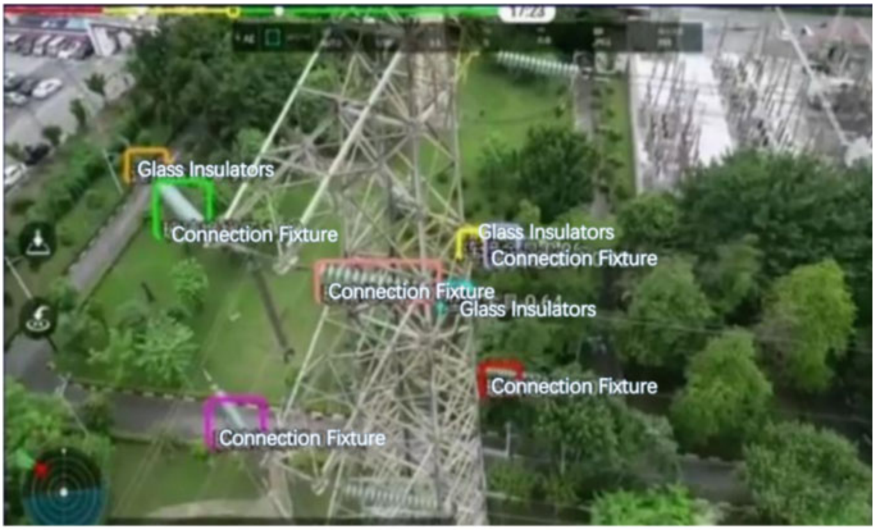
(2) Texture features

A texture feature is a global feature of an image that describes the surface properties of the scene corresponding to the image or image region. Unlike color features, texture features are not pixel point-based features, which require statistical calculations in regions containing multiple pixel points. As a statistical feature, texture features are often rotationally invariant and have a high resistance to noise. Insulators and porcelain sleeves of electrical equipment have special textures. In pattern matching, such regional characteristics are superior and will not fail to match successfully due to local deviations.

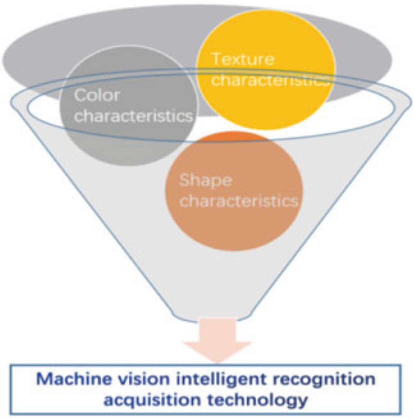
(3) Shape features

The target in an image generally has its specific shape, and there are two types of representation for shape features, one is contour features and the other is area features. The contour features of the image mainly target the outer boundary of the object, while the area features of the image relate to the whole shape region. The general lightning tower is in the shape of a tall tower, for instance. The alignment of the visible light of the electrical equipment is also the basis of the initial recognition of the image, if the matching to the feature points is relatively sparse, it can be considered that this image does not match the database image or is not conducive to analysis, and this image can be discarded and the next image is taken again.

The difficulty of image processing and analysis methods used for machine vision is that machine vision is affected by multiple factors such as environment, lighting, production process and noise, etc. The signal-to-noise ratio of detection is generally low, and weak signals are difficult to detect or cannot be effectively distinguished from noise. How to build a stable, reliable and robust detection method to adapt to the interference of light changes, noise and other adverse external environments to complete the detection and identification of targets is the problem to be solved. When the target to be identified is complex, it is necessary to achieve it through several links, integrated from different sides. The first thing to consider when recognizing and extracting targets is how to automatically separate them from the background. The complexity of target extraction generally lies in the fact that the features of targets and non-targets are not very different, and after the target extraction scheme is determined, the target features need to be enhanced. The effect of machine intelligence recognition using feature recognition is shown in Fig. 3.3.



(a) Machine intelligence recognition effect



(b) Machine vision intelligent recognition acquisition technology features

Fig. 3.3 Machine vision intelligent recognition

3.2.3 Multiple Information Collection Technology for Power Equipment

(1) Power sensor technology and applications

Sensor technology can convert analog signals to digital signals to support the computer to complete the processing of data and information. The role of sensor technology for the Internet of Things, just like the five senses in the human body, is a class of sensory systems.

1) Under the power IoT architecture, the application of sensor technology includes six main types:

a) Liquid level sensor

The main principle of the liquid level sensor is hydrostatics, which is a kind of pressure sensor and is suitable for liquid monitoring of power equipment.

b) Speed sensor

The speed sensor can transform the non-electricity change to the electricity change, thus achieving speed based monitoring. In addition, speed sensors also include acceleration sensors, electronic devices to measure acceleration forces and mainly used for monitoring electrical environments.

c) Humidity sensor

The humidity sensor functions mainly through the moisture-sensitive material applied to the substrate to form a moisture-sensitive film. When humidity sensitive materials adsorb water molecules in the air, the performance of components such as impedance and dielectric constant will change, resulting in humidity sensitivity. It is suitable for humidity monitoring in the environment where power equipment is located. At present, humidity sensors are mainly divided into resistors and capacitance.

d) Gas-sensitive sensor

Gas-sensitive sensors monitor specific gases and are suitable for carbon monoxide monitoring of components such as transformers.

e) Infrared sensor

Infrared sensors mainly utilize the physical properties of infrared light to achieve non-contact monitoring, monitoring objects such as temperature and gas composition.

f) Vision sensor

Vision sensors are suitable for high pixel capture, and are mostly used in industry for measurement orientation and defect detection, and in power equipment management for theft prevention, tower tilt prevention, breeze vibration prevention, and fault location and diagnosis .

(a)Equipment composition (b) Equipment installation

Fig. 3.4 Transmission line three-span monitoring device

2) Overview of common sensor devices for the power IoT

a) Transmission line three span monitoring device

The transmission line three-span monitoring device is a field data collection device installed on the towers of high-voltage transmission lines, as shown in Fig. 3.4. The device is mainly composed of camera, solar panel and main chassis. The camera is responsible for real-time video and the master control is responsible for on-site communication, which is transmitted in real-time through wireless so that the administrator can grasp the situation around the monitored tower in real-time and effectively ensure the safety of the line.

b) Distributed fault diagnosis device

The distributed fault diagnosis device adopts distributed traveling wave measurement technology, and the monitoring terminals are distributed and installed on the transmission line conductors, as shown in Fig. 3.5. High potential acquisition line fault moment near the point of the frequency fault signal and traveling wave fault signal can be comprehensively analyzed by the data center to achieve fault interval positioning, accurate fault location, fault cause identification, and lightning stroke characteristic monitoring.

c) Ice cover online monitoring device

Transmission line ice-covering online monitoring device is mainly used to monitor the ice-covering situation of conductors, towers and insulator strings on transmission line sites, as shown in Fig. 3.6. The monitoring means used by the transmission line ice cover online monitoring device include micro-meteorological monitoring, image monitoring and conductor equivalent ice cover thickness monitoring. Monitoring of the conductor equivalent ice thickness is achieved by monitoring parameters such as insulator string wind deflection angle, tilt angle and axial tension. Wire equivalent ice

(a) Equipment composition (b) Equipment installation

Fig. 3.5 Distributed fault diagnosis device

thickness monitoring: The device can collect on-site insulator string wind deflection angle, tilt angle and axial tension data according to preset time, and then transmit the wire equivalent ice thickness, unbalance tension and other data back to the backend server through the power IOT after calculation.

d) Video surveillance device

The video surveillance device is mainly designed to achieve a comprehensive understanding of the surrounding environment such as the transmission line corridor area and tower base area, and can perform preset timing capture monitoring and real-time retrieval of video data according to needs. It supports horizontal 360° and vertical 180° rotation, and is currently mainly installed in areas prone to mountain fire hazards, as shown in Fig. 3.7.

e) Weather online device

The meteorological online device can measure the meteorological data (temperature, humidity, wind speed, wind direction, rainfall, air pressure, light radiation, etc.) and its change condition in the transmission line area, and transmit it to the main station system of the monitoring center in real-time through GPRS/4G network, and the main station system will conduct accurate analysis, and if abnormal conditions occur, the system will immediately issue early warning information in various ways, and the management personnel will make early decision on the warning area based on the early warning information in order to carry out key maintenance, and the device is shown in Fig. 3.8.

f) Transmission line fusion-type intelligent terminal

The transmission line fusion-type intelligent terminal applies the image monitoring device installed on the tower, obtains the monitoring point information in real-time through 4G wireless communication technology, applies the image intelligent analysis to the collected image intelligent analysis, and pushes it to the panoramic intelligent monitoring center personnel in the first time through the platform alarm method, as shown in Fig. 3.9.

(a) Equipment composition

(b) Equipment installation

(c) Showing the effect of use

Fig. 3.6 Online monitoring device for ice cover

3) The application of electric power IOT sensor technology in online monitoring of electric power equipment is mainly reflected in the monitoring application management for transmission equipment and substation equipment, specifically analyzed as follows:

a) For online monitoring applications of power transmission equipment

For the transmission equipment online monitoring application, is the key content of the power IOT sensor technology in the application of online monitoring of power equipment, the main monitoring content to the transmission equipment operating conditions and operating environment, effectively enhance the perception and early warning ability of the transmission line when the ice, tower tilt, wire wind deflection

(a) Equipment composition

(b) Equipment installation

(c) Showing the effect of use

Fig. 3.7 Video surveillance device

droop arc, etc., for the realization of the transmission equipment operating state dynamic full-time monitoring has an important role in promoting.

b) For online monitoring application of substation equipment

The online monitoring application of substation equipment mainly includes transformer core current, oil chromatography, GIS local discharge and arrester insulation. Online monitoring based on electric power IOT sensor technology can realize highly sensitive collection of equipment operation information on one hand, and online management of substation equipment pre-testing project on the other hand, so as to carry out online diagnosis and evaluation of equipment operation status. It is important to promote the development of substations in the direction of intelligence and enhance the monitoring capability of substation safety performance.

(a) Equipment composition

(b) Equipment installation

(c) Showing the effect of use

Fig. 3.8 Weather online device

(2) Information collection, automatic collection

The rapid power equipment information collection function can build a power equipment ledger database and a backend transmission server through sensor nodes deployed in the smart grid, and use a dedicated power network to quickly and effectively collect the status of smart grid equipment operation and environmental information, which are power equipment information, temperature, humidity, oxygen, carbon dioxide, carbon monoxide, sulfur dioxide and methane and other related information of the power equipment operation environment, and then transfer them to the system and realize the sensing of ambient air quality information. Power equipment information collection and sensing is also the most basic function of the system. In order to be able to save the energy of the wireless sensor system, the relevant sensor deployment nodes need to be optimized to save the energy of the system, and the collected information is saved to the relevant database server so that it can help the logical business processing system to analyze the data and predict whether the associated collected data exceeds the pre-set warning value so that it can be displayed on the monitoring interface of the power equipment information system to facilitate the analysis by the power system managers.

(a) Equipment composition

(b) Equipment installation

(c) Showing the effect of use

Fig. 3.9 Transmission line fusion-type intelligent terminal

(3) Information transmission

After the power equipment sensor nodes collect the relevant equipment operation information and environmental information, they can use the wireless network to transmit the data to the convergence node to ensure that the power equipment environmental information is accurately saved in the backend database server The specific power equipment information transmission process is described in detail as follows: The sensor nodes are deployed on the power equipment and use the sensors' own temperature control, humidity control, and equipment status control functions to collect the power equipment data information and transmit it to the aggregation node, which can transmit it to the server through 4G wireless network and fiber optic network to be able to carry out logical business processing.

Table 3.1 Distributed ledger

No	Voltage level (kV)	Line name	Tower number	Phase
1	220	Column new 4P12 line	Tower no. 43	B phase
2	220	Column new 4P12 line	Tower no. 1	B phase
3	220	Column new 4P12 line	Tower no. 43	C phase
4	220	Column new 4P12 line	Tower no. 43	A phase
5	220	Column new 4P12 line	Tower no. 1	A phase
6	220	Column new 4P12 line	Tower no. 1	C phase
7	220	Column day 4P15 line	Tower no. 11	A phase
8	220	Column day 4P15 line	Tower no. 10	B phase
9	220	Column day 4P15 line	Tower no. 10	C phase
10	220	Column day 4P15 line	Tower no. 11	B phase

(4) Information processing

After the power equipment and its environment data collected by the power IoT sensors are transmitted to the server, the power equipment information processing module can be responsible for processing the collected equipment information. If the sensor server finds that the relevant power device information to exceed the warning value set by the administrator, the sensor detection device can send control commands to the power device through the ZigBee network and store the collected information in the server database. In power equipment there are many sensors working together in a coordinated manner, and the information sensed by each sensor usually has different characteristics: fuzzy, wrong, mutually dismantling, complementary, competitive, etc. The presence of these various information may lead to the difficulty of accurately judging the real state of the measured object with any single information, so it is often necessary to have multiple sensors of the same type or multiple different types of sensors for cooperative sensing to achieve comprehensive and accurate detection of the target, and further processing of sensor information through cooperative sensing technology can eventually lead to different equipment ledger information and complete information acquisition. As shown in Tables 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, respectively, are some of the disaster damage multi-information collection equipment ledgers of power equipment in Wenzhou, Zhejiang.

3.2.4 Disaster Damage Multiple Information Collection Technology

Targeted at the system fusion scheme of multiple IoT sensors deployed in the power grid and in the need for rapid collection of disaster loss information, callback functions can be designed on the terminal node to achieve emergency data collection at the disaster loss site. The collected data can be transferred back to the main node by

Table 3.2 Micro-meteorological accounts

No	Voltage level (kV)	Line name	Tower number
1	AC 550	Lotte 5449 line	127#
2	AC 500	Lotte 5449 line	92#
3	AC 500	Lotte 5449 line	89#
4	AC 500	Lotte 5449 line	55#
5	AC 500	Lotte 5449 line	40#
6	AC 500	Lotte 5449 line	30#
7	AC 500	Lotte 5449 line	20#
8	AC 500	Lotte 5449 line	10#
9	AC 500	Lezhu 5450 line	95#
10	AC 500	Lezhu 5450 line	87#

Table 3.3 Mountain fire video ledger

No	Voltage level (kV)	Line name	Tower number	Large/small size side
1	220	Longyang 2Q80 line	025#	Large size side
2	500	Baidu 5863 line	136#	Large size side
3	500	Zhuhai 5468 line	006#	Large size side
4	500	Dutang 5861 line	034#	Large size side
5	500	Lezhu 5450 line	095#	Large size side
6	500	Lianou 5489 line	215#	Large size side
7	500	Lianhai 5490 line	185#	Large size side

Table 3.4 Converged intelligent terminal wire genie ledger

No	Voltage level (kV)	Line name	Tower number
1	AC 500	500 kV Lezhu 5450 line	104#
2	AC 500	500 kV Lezhu 5450 line	104#
3	AC 500	500 kV Lezhu 5450 line	002#
4	AC 500	500 kV Lezhu 5450 line	002#
5	AC 500	500 kV Ninghua 5916 line	221#
6	AC 500	500 kV Ninghua 5916 line	221#
7	AC 500	500 kV Ninghua 5916 line	143#
8	AC 500	500 kV Ninghua 5916 line	143#
9	AC 500	500 kV Ningjin 5906 line	221#
10	AC 500	500 kV Ningjin 5906 line	221#

Table 3.5 Image surveillance ledger

No	Voltage level (kV)	Line name	Tower number	Large/small size side
1	500	Lotte 5449 line/ Lezhu 5450 line	3	Large size side
2	500	Lotte 5449 line/ Lezhu 5450 line	5	Large size side
3	500	Lotte 5449 line/ Lezhu 5450 line	7	Large size side
4	500	Lotte 5449 line/ Lezhu 5450 line	8	Large size side
5	500	Lotte 5449 line/ Lezhu 5450 line	12	Large size side
6	500	Lotte 5449 line/ Lezhu 5450 line	15	Large size side
7	500	Lotte 5449 line/ Lezhu 5450 line	17	Large size side
8	500	Lotte 5449 line/ Lezhu 5450 line	18	Large size side
9	500	Lotte 5449 line/ Lezhu 5450 line	20	Large size side
10	500	Lotte 5449 line/ Lezhu 5450 line	22	Large size side

Table 3.6 Ice cover online monitoring device account

No	Voltage level (kV)	Line name	Tower number
1	AC 500	500 kV Lezhu 5450 line	104#
2	AC 500	500 kV Lezhu 5450 line	104#
3	AC 500	500 kV Lezhu 5450 line	002#
4	AC 500	500 kV Lezhu 5450 line	002#
5	AC 500	500 kV Ninghua 5916 line	221#
6	AC 500	500 kV Ninghua 5916 line	221#
7	AC 500	500 kV Ninghua 5916 line	143#
8	AC 500	500 kV Ninghua 5916 line	143#
9	AC 500	500 kV Ningjin 5906 line	221#
10	AC 500	500 kV Ningjin 5906 line	221#

using a remote function call machine callback scheme. Through the existing multiple online monitoring sensors for a unified data integration, fusion of UAV acquisition image data, unified access to the data center to complete the analysis and processing of data, can be realized with the field power equipment each sensor for networking control, and finally in the form of graphics and reports to display the processing results, and according to the need to store or forward data to other system interfaces.

ZigBee standard is used to achieve wireless data collection and sharing among wireless sensors of power equipment. The ZigBee standard is a proximity-oriented, low-rate, low-power, low-cost wireless sensor network standard. The ZigBee protocol uses the IEEE 802.15.4 standard at the physical and link layers and adds to it the network layer, security module, and application support sub-layer modules, among others, to enable large area groups. Devices in IEEE 802.15.4 networks are classified into two device types, based on their communication capabilities: Full-Device (FFD) and Reduced-Function-Device (RFD). FFD devices have all the features defined by IEEE 802.15.4 and can play any role in the network, while RFDs can only communicate with FFDs because of their limited functionality.

The ZigBee transmission network and data center upper computer can communicate with wireless sensors of on-site power equipment through networking, ZigBee has three standards. ZigBee coordinators, ZigBee routers and ZigBee end devices. The coordinator is responsible for initializing, maintaining and controlling the network; routers are responsible for data collection, relaying messages and providing routing information; The terminal nodes are responsible for data collection. Each network must have only one coordinator, the coordinator and router must be FFD, and the end nodes can be FFD or RFD. The ZigBee standard supports network topologies such as star, tree, and mesh. ZigBee tree network is the most commonly used topology type in which the coordinator initializes the network, routers form the network branches and relay messages, and end nodes as leaf nodes do not participate in message routing. The collection terminal is responsible for collecting and preprocessing the power information of the switchgear in the substation, and sending the data to the data center host computer using ZigBee's multi-hop technology. The data center completes the analysis and processing of the data, displays the final results in the form of graphs and reports, and stores the data as needed.

The wireless ZigBee data acquisition in this project consists of a ZigBee data acquisition node and a master node (coordinator) responsible for communication with the computer, OPC server, and force control configuration software. The ZigBee data acquisition node is developed using the SNAP network protocol stack, which is a ZigBee protocol stack with an embedded Python virtual machine that can write application layer scripts, compile and download script files over the air. It provides a simple, reliable, intelligent and complete networking solution for complex ZigBee digital transmission module networks, with significant power optimization and excellent redundancy performance due to the "peer-to-peer network" concept. The function of the end node is ZigBee data acquisition and data transmission. In the SNAP network stack, data transfer is achieved through remote function calls. In the terminal node, the callback function is designed to realize the emergency data collection at the disaster damage site, and the collected data should be passed back to the master node, which is realized by using remote function call machine transfer.

3.2.5 Collection Data Processing

(1) Causes of missing data and bad data

The communication capacity of wireless sensor network nodes is limited, so in power system tests or specific production operations, temporary disconnection of the link may be caused by obstacles, or packet loss during data transmission. In addition, since wireless sensor networks are battery-powered, lack of energy or exhaustion of energy may cause abnormal or missing data. Also, the nodes can be damaged due to human reasons, which can cause missing data. Besides, the instability of the working environment may also cause missing and abnormal data in the wireless sensor network. Therefore, due to the above inherent characteristics of wireless sensor networks, missing data and bad data generation are inevitable. Missing data and bad data can affect the results of data analysis, so in order to solve this problem, it is necessary to pre-process the missing data and bad data, that is, to clean them. For missing data, the missing data are processed by estimating the data and filling the missing values with the estimated values, and for bad data, the bad data are detected and corrected.

(2) Relevant definitions

1) Bad data: these deviations or corrupted data are referred to as bad data because of deviations or corruption caused by the network and equipment. Bad data detection and identification is to find out whether the data sequence to be tested contains bad data, and to determine the location of the bad data, and finally to correct the bad data. Bad data detection is important in the operation of power systems and even affects the corresponding decisions of power personnel.
2) Bad data detection: determining whether there is bad data during sampling for a specific measurement is called bad data detection.
3) Bad data identification: bad data identification occurs after bad data detection, when the presence of bad data is detected, the location of the data is determined, and this process is called bad data identification.
4) Bad data estimation: the estimation of bad data occurs after the identification of bad data, and the corresponding estimate is given for the bad data. The smaller the error between the estimated value and the true value is, the higher the accuracy of the estimation is.

Based on the understanding of the definitions of bad data detection, bad identification, and bad data correction through the above definitions, Fig. 3.10 gives the specific processing flow.

(3) Missing data interpolation algorithm

In the power wireless sensor network due to the characteristics of the wireless sensor network itself so the phenomenon of missing data is unavoidable, so the study of algorithms for processing missing data is very meaningful. Data interpolation originally

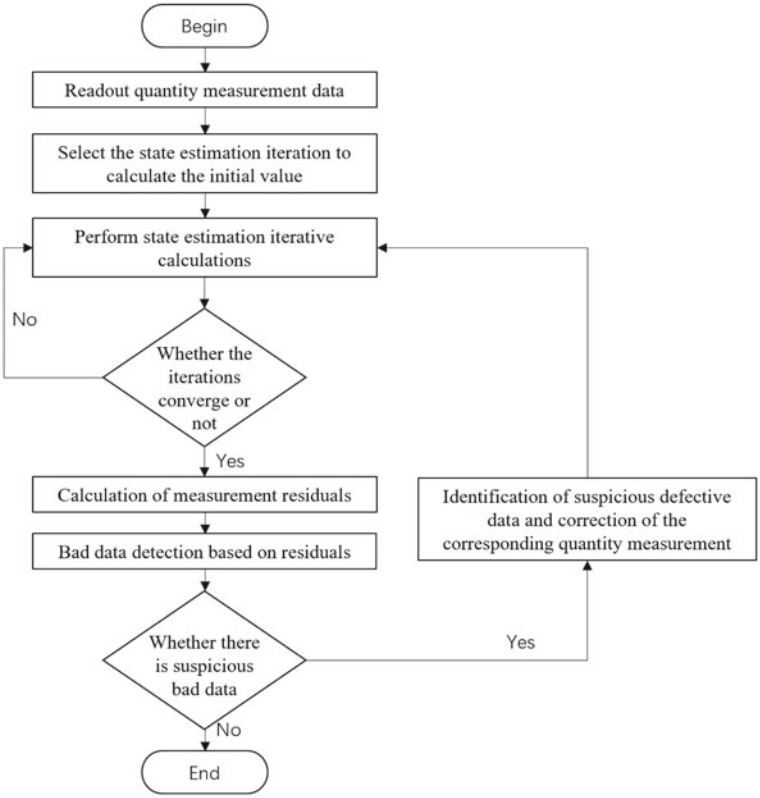


Fig. 3.10 Flowchart of defective data detection and identification

originated from the function in mathematics, the actual production and measurement can only get some discrete data, only through the function to express the relationship between the variables more intuitive, so the function will be discrete data into a continuous model, data interpolation in essence, that is, approximating the function, its theory has been gradually improved after the emergence of calculus. Data interpolation is now widely used in geology, meteorology, image processing, wireless sensor networks, etc.

Interpolation of missing data, i.e., establishing a functional correspondence based on the known information, and then estimating the unknown value by the function. There are many methods for interpolation of missing data, mainly: mean, plurality, linear interpolation, nearest neighbor interpolation, kriging interpolation, etc.

1) Mean method

The mean method, which means that all missing values in the series are filled with the mean. For example, for a known series $\{a_1, a_2, a_3, \ldots\ldots, a_{19}, a_{20}\}$, if the values of a_1, a_{19} are missing, then find the average of the non-missing values in the series, and if the result of the average is b, then a_1, a_{19} are assigned the value b. This method is simpler and has lower time complexity, and can be used when the data series are smoother and the accuracy of the estimated values is higher. However, when the data series is unstable, there may be a large deviation between the estimated value and the true value. The results estimated using this method not only do not yield useful information but may interfere with the results of the data analysis.

2) Plurality method

The plurality method, which is also a frequently used estimation algorithm in missing data. The algorithm selects the most frequently occurring value in the series to interpolate the missing data. Simply put, for the series $\{5, 4, 5, 7, 6, 5, 5, 8, 9, 5, x\}$, x is the missing value, and according to the plurality method, the data with the highest frequency in the series is 5, then assign a value of 5 to x. The plurality method precisely uses the principle of probability in mathematics, using the data with the highest probability of occurrence to estimate the missing value. It is similar to the mean method, which is simple and easy to implement, but when there is oscillation in the data series, there is a large deviation between the estimated and actual values.

3) Linear interpolation method

Linear interpolation uses the values of the data adjacent to the missing data to estimate the size of the current missing data. The calculation is as follows: $y_{ij}^{*} = y_{im} + \frac{y_{in} - y_{im}}{n-m}(j - m)$, where y_{ij}^{*} is the estimate of the missing data y_{ij}, y_{im} and y_{in} are the two non-missing data that are nearest neighbors to y_{ij} and $m \le j \le n$.

Like the plurality method and the mean method, the linear interpolation method is also simple to compute and has a low time complexity, using only the values of the two moments closest to the missing data. However, it is also only applicable to smooth time series, and if the series is unstable or has serious data missing, the bias is larger and the estimation accuracy is not enough.

4) Kriging interpolation method

Kriging interpolation is a better method to interpolate data that can achieve linear optimality and has unbiased nature. This method mainly uses the distribution of space to solve the data, and it is suitable for solving the estimation of missing data between some variables that are spatially correlated. The Kriging method has an early origin, but in recent years many experts have studied the method in more depth and combined it with other disciplines, and finally developed and formed some new methods. Some of these methods were combined with fuzzy theory in mathematics, culminating in the fuzzy kriging method; some of them are combined with trigonometric functions in mathematics, a method called trigonometric kriging.

5) Nearest neighbor interpolation method

The nearest-neighbor interpolation method exploits the property that physically neighboring nodes have similarity, an analysis proposed by Dutch meteorologist A.

H. Thiessen. This method is mainly used in meteorology, where it is developed from the application of rainfall data from various dispersed weather stations to calculate the average rainfall, and is often used in GIS for fast assignment of nearest neighbor interpolation. In fact, theoretically, the application of the nearest neighbor interpolation method defaults to the fact that the data value of any grid point $p(x, y)$ can be replaced by the data value of the nearest location point (which is its implicit condition). This means that it takes the value of the closest node in each grid node as its node value. The interpolation algorithm can be applied to data that is distributed at uniform time intervals and has been converted to a grid file, and it can also be applied to files that contain only a small number of no values, i.e., data points that have no values are filled with the nearest values.

Based on the performance analysis of the above interpolation method, this project uses the nearest neighbor interpolation method to interpolate the grid data.

(4) Detection and identification of bad data

1) Traditional bad data detection and identification methods

The commonly used methods for detecting bad data are: target extreme value detection method, weighted residual method, standard residual method, and quantity measurement mutation method. Among them, both the target extreme value detection method and the weighted residual method have certain disadvantages, namely residual contamination and residual flooding; quantity measurement mutation detection method can basically solve the phenomenon of residual contamination and flooding, but it has certain restrictions on the sampling samples, for example, it requires that the structure of the system must not change between two adjacent samples, and there must not be a sudden change in the quantity of the phenomenon either. Where residual contamination is commonly referred to as: In addition to the residuals of bad data points in addition to identifying bad data as such, normal values are also identified as bad data; residual flooding refers to the interaction between multiple bad data, resulting in residuals close to normal residual values at some bad data points. The presence of residual contamination and residual flooding can cause missed detection of bad data as well as false detection (i.e., normal values as bad data). Other bad data detection methods include the pseudo-measurement mutation detection method.

The traditional methods commonly used for bad data identification include estimation identification method and residual search algorithm as well as zero-residual method. The principles of traditional bad data identification methods are similar, i.e., weighted residuals or standard residuals are used as a standard value, and then a threshold value is calculated at a certain confidence level using the principle of hypothesis testing, followed by a judgment on the measured value.

2) New method of bad data detection and correction

At present, with the deepening of the research on the detection and correction of bad data, some scholars have proposed to apply some algorithms in data mining, machine learning neural network and statistics algorithms to the detection and identification of bad data.

After preliminary analysis of the collected images, the project team found that the data had an unbalanced distribution and some of the disaster samples were small, mainly with the following problems: Firstly, the unbalanced distribution of the data set and the long-tail problem, especially the small number of negative samples of abnormal defects, will affect the convergence of model training and the process of data clustering and analysis, which is not conducive to the training of disaster damage identification models; Second, the problem of target detection for small targets with few samples requires a certain degree of data enhancement and data expansion, which can also cause a decrease in model accuracy; Third, server resources and arithmetic problems, large-scale image video data acquisition needs to support high-bandwidth multiple concurrent transmission, high requirements for server throughput, and data cleaning also requires the corresponding arithmetic resources; Fourth, the conflict and contradiction between the coverage of data collection and the generalization of the model, the accuracy of the model will be reduced if migrating to other regions or using other weakly related data. Therefore, the project team adopted a "multi-legged" approach. First, it conducted several rounds of field collection in October, November, December 2020 and January 2021 in Zhejiang to accumulate normal pictures of equipment; second, it visited grassroots units and directly contacted Wenzhou Transmission and Transformation Company to collect disaster damage images of power equipment collected by front-line power sensors and mobile terminals; third, it called on resources from other provincial companies to assist in obtaining disaster damage data of power equipment. In the end, 5620 valid images were obtained for training, completing the multi-dimensional information collection of grid damage and supporting the construction of subsequent damage recognition models.

3.3 Disaster Identification Technology of Power Grid Line Based on UAV

3.3.1 Summarize

In this section, the automatic detection system of UAV is used to identify the power disaster scene and realize the automatic identification and survey of the disaster scene. Uav route survey mainly involves UAV automatic detection system and UAV image recognition technology. To achieve a wide range of power facilities and equipment damage quickly acquired.

The UAV automatic detection is mainly to quickly detect the damage of power facilities and equipment from a distance, and quickly identify serious scenarios such as UHV collapse and substation flooding at the UAV end, as shown in Figs. 3.11 and 3.12.

Fig. 3.11 Flooding scenario of power facilities

Fig. 3.12 Damage scene of power tower

The UAV automatic inspection system consists of two major parts: digital airborne component performance inspection subsystem and analog airborne component performance inspection subsystem. After DJI M300RTK model is used to carry airborne parts for flight survey, ground-based automatic testing equipment can be used for testing and analysis, and automatic testing equipment is a device for test control, data acquisition and fault inference built on PXI bus architecture, including 8-slot PXI chassis assembly, PXI-8106 type zero-slot controller, DA card, AD card, relay control card, serial communication card and multimeter card, totaling 6 PXI-type plug-in cards; the interface adapter consists of an integrated control box that combines power supply, filtering, driving, and level conversion. The device under test is excited by the excitation system and converges the response signal to the interface adapter, which is then used by the automatic detection equipment to collect and process and analyze the display.

UAV target image recognition mainly uses image segmentation (threshold judgment) based, classifier based, feature point based, inter-frame difference method, and background difference method for target image segmentation and recognition. The so-called "threshold" is the boundary of a field or a system, and its value is called threshold, using threshold for image segmentation is a region segmentation technique, especially effective for the segmentation of images with strong contrast between objects and background. It is simple to calculate and always possible to define non intersecting regions with closed and connected boundaries. Threshold segmentation is performed using methods such as grayscale histogram peak and valley localization and image filtering, as shown in Fig. 3.13, the basic principle is to select one or more grayscale thresholds in the grayscale image range, and then compare the grayscale value of each pixel in the image with the threshold, and according to the result of the comparison, the corresponding pixels in the image are divided into two or more classes, so as to divide the image into a collection of non-overlapping regions and achieve the purpose of image segmentation. As shown in the Fig. below, in some simple images, the grayscale distribution for the target is more regular, and the background and the individual targets each form a wave in the grayscale histogram of the image, i.e., the region and the wave correspond one-to-one. Since a trough is formed between each peak, the two regions can be separated by selecting the gray value corresponding to the trough between the two peaks as the threshold value. The subject realizes the pre-processing and segmentation recognition of the UAV target image based on image segmentation (threshold judgment) and achieves the automatic survey and recognition of the disaster site. The recognition image effect is shown in Fig. 3.14.

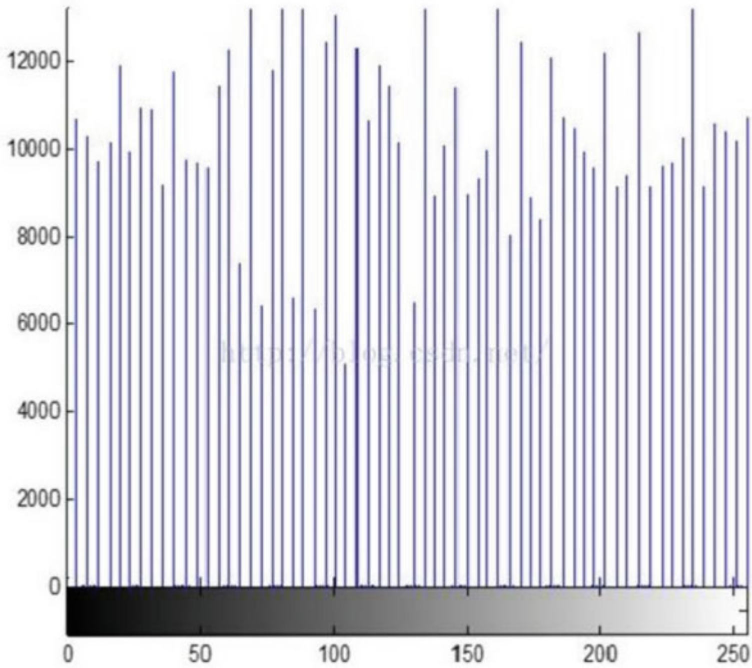


Fig. 3.13 Grayscale histogram peak and valley method

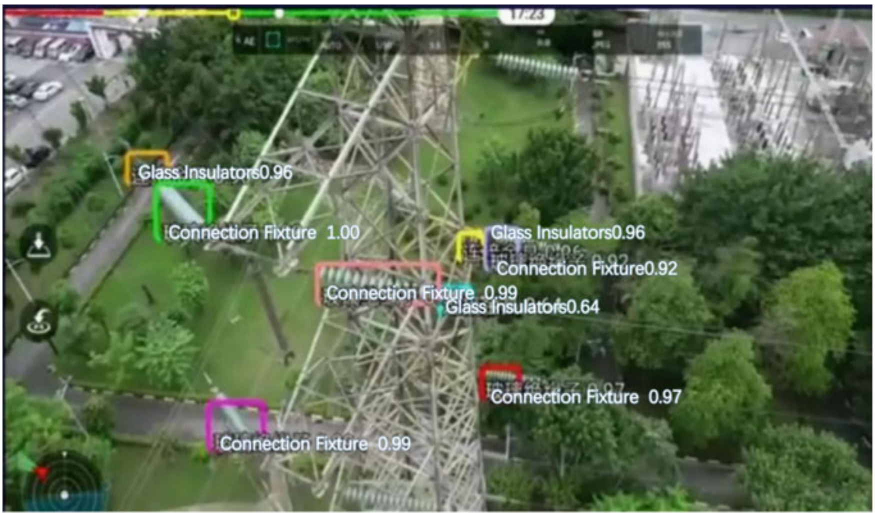


Fig. 3.14 UAV target recognition

3.3.2 *Principle of Intelligent Analysis Algorithm for UAV Main Network Disaster Detection*

A mixture of intelligent algorithms will be used to achieve the best results for each type of disaster damage pattern. The following addresses the proposed different classes of algorithms to be used are described below.

(1) Contrastive Learning

Contrastive Learning is a model for deep learning, which is used to describe the task of similar and different things. Using this approach, we can train machine learning models to distinguish between similar and different images. The basic concepts are as follows.

1) An unsupervised representation learning of images/text.
2) Motivation analysis: Analysis algorithms often learn to distinguish things by comparison. As shown in Fig. 3.15. The model does not need to learn too specific details (image: pixel level; text: word level), but only features at a high enough level to distinguish between objects.

The difference from the previous supervised/unsupervised approach is shown in Fig. 3.16.

(2) Contrast learning in the image field

Contrast learning is widely used for unsupervised representation learning in the image domain, based on MoCo (ICML2020) and SimCLR (2020), and has achieved significant improvements on the ImageNet dataset. The core of contrastive learning lies in how to construct a set of positive and negative samples. In the image field, image operations such as rotation and cropping are generally used, while in the text

(a) Before comparative analysis (b) High level features after comparison

Fig. 3.15 Contrast learning does not require learning overly specific details

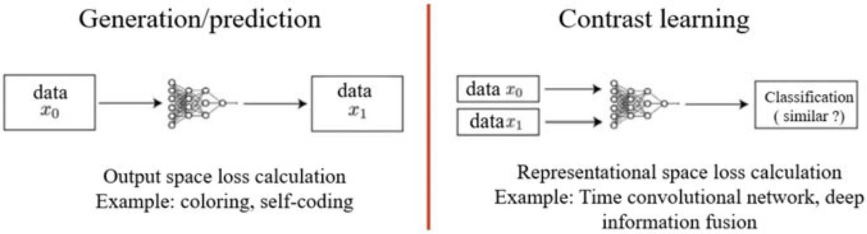


Fig. 3.16 Difference between supervised/unsupervised methods

field, methods such as backtranslation and character insertion and deletion are often used. These methods rely on domain experience and lack diversity and flexibility; Perform data augmentation through adversarial attacks to obtain positive and negative samples.

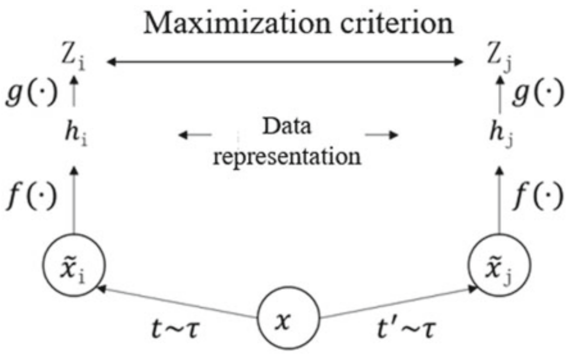
SimCLR uses a simple comparison learning framework that allows views sampled from the same image to be as close as possible in the representation space, and views sampled from different images to be as far apart as possible. Contrast loss is the crossover within batch Entropy loss:

$$l_{i,j} = \frac{\exp\left(\frac{sim(z_i,z_j)}{\tau}\right)}{\sum_{k=1}^{2N} 1_{[k \neq i]} \exp\left(\frac{sim(z_i,z_j)}{\tau}\right)} \tag{3.1}$$

The numerator is a positive pair; the denominator is 1 positive pair and 2N−2 negative pairs model structure, as shown in Fig. 3.17.

In addition to this various image enhancement methods are used, which include cropping, flipping, rotating, Gaussian noise, masking, color transformations, filters, etc.

Fig. 3.17 simCLR contrastive learning model structure



Different enhancement methods have different effects on the image in the same environment, and the reasonable and timely selection has an important role in the subsequent image disaster recognition, as shown in Fig. 3.18.

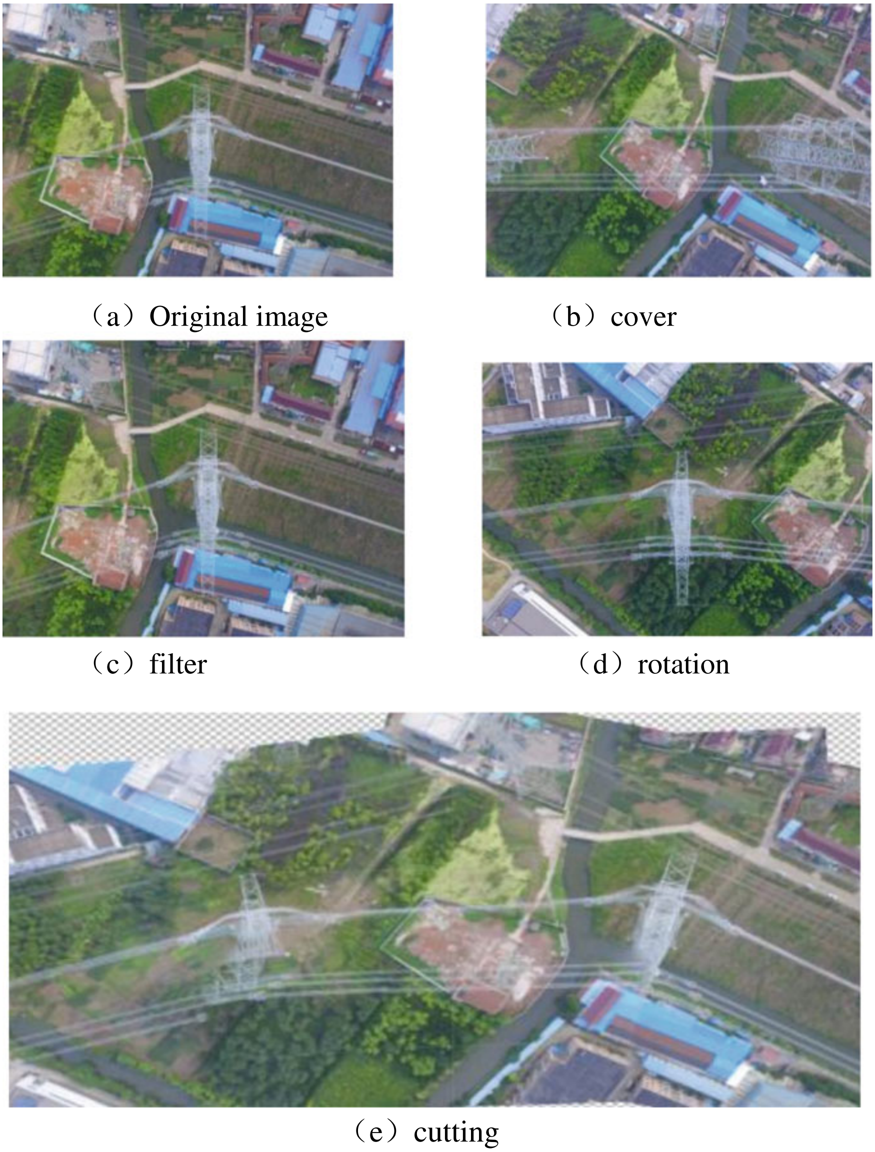


Fig. 3.18 Various image enhancement methods

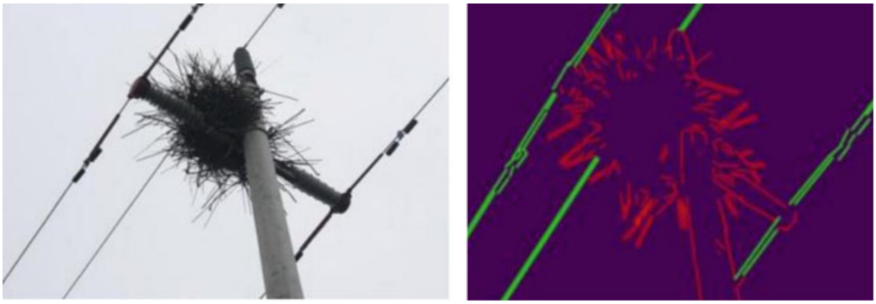


Fig. 3.19 Comparison of before and after semantic segmentation

(3) Front and rear view separation

Semantic segmentation techniques in machine vision are used to separate the front and back views of images.

1) Semantic segmentation definition

Semantic segmentation is a classification at the pixel level. It groups pixels of the same class into one category. So semantic segmentation understands the image from the pixel level. For example, in the following photos, pixels belonging to tower poles are divided into one category. Pixels belonging to cross-arms, insulators, and bird's nests are also grouped into one category. In addition, the background pixels are also classified into one category. Semantic segmentation is different from instance segmentation. For example, if there are more than one person in a photo, for semantic segmentation, simply group all the pixels of those people together. But instance segmentation also puts different people's pixels into different classes. This means that instance segmentation goes further than semantic segmentation. Figure 3.19 shows the before and after comparison of semantic segmentation.

2) Deep learning for semantic segmentation scheme

Deep learning methods have been used well for semantic segmentation, and the use of deep learning methods to solve semantic segmentation problems can be summarized in several ideas. Below is a detailed introduction.

a) Full convolution method

Full Convolutional Network (FCN) replaces the fully connected layers of the network with convolution, thus making input of any image size possible. This makes it possible to use any image size as input, and it is much faster than the patch classification method.

Despite the removal of the fully connected layer, there is a problem with CNN models for semantic segmentation, which is the downsampling operation (e.g., pooling). Pooling can expand the receptive field and integrate contextual information well. The popular understanding is that more information is integrated to make decisions, which is very effective for high level tasks (such as classification). However, at the same time, the pooling downsampling operation reduces the resolution and therefore weakens the location information. And the semantic segmentation requires score map and original map alignment, so rich location information is needed.

b) Encoder-decoder architecture

The encoder-decoder is based on the FCN architecture. Encoder gradually reduces the spatial dimension due to pooling, and decoder gradually restores spatial dimensionality and detail information. Usually there is also a shortcut connection from encoder to decoder (aka cross-layer connection). This is shown in Fig. 3.20.

c) Null convolution (Dilated/atrous)

Void convolution architecture replaces pooling. On the one hand, it can maintain spatial resolution. On the other hand, it can integrate contextual information very well because it can expand the field of perception. As shown in Fig. 3.21.

This service technology project will verify the actual use effect of the above solutions one by one, and adopt the optimal solution to solve the problem of intelligent analysis of disaster damage.

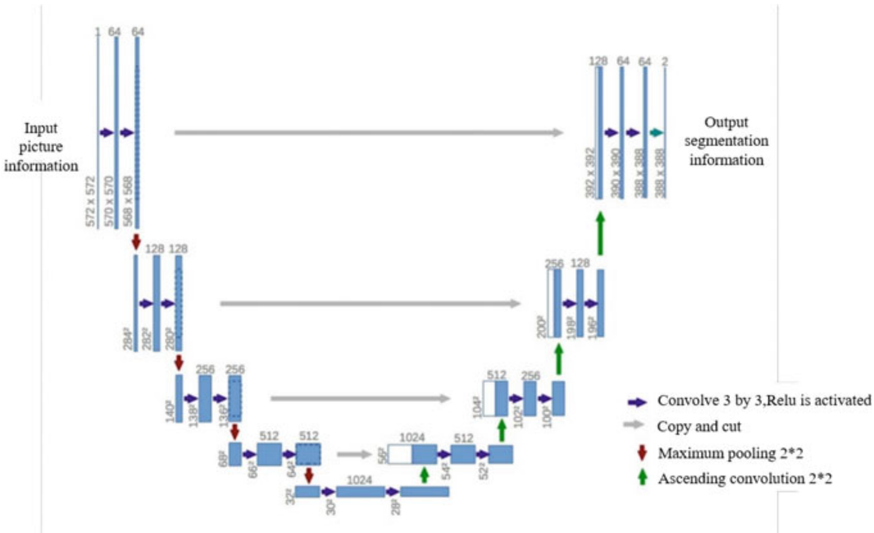


Fig. 3.20 Shortcut connection

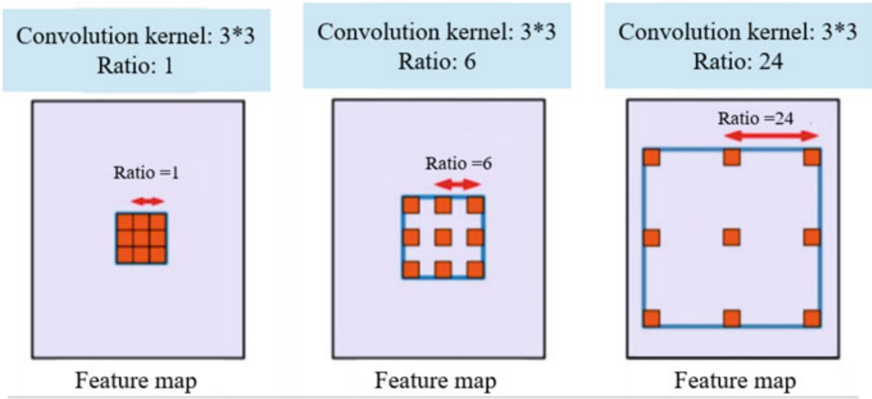


Fig. 3.21 Null convolution

(4) Target detection

Target detection is a more practical and challenging computer vision task that can be seen as a combination of image classification and localization. Given a picture, the target detection system has to be able to identify the target of the picture and give its location. Since the number of targets in the image is variable and the exact location of the target is to be given, target detection is more complex than the classification task.

1) A review of commonly used Object Detection algorithms

The common classical target detection algorithms are shown in Fig. 3.22.

The basic idea of target detection: localization + recognition is solved simultaneously. It belongs to multi-task learning with two output branches. A branch is used to do image classification by full concatenation + softmax to determine the target class. The difference between this branch and simple image classification is that an additional "background" class is needed here. Another branch is used to determine the target location, and the regression task is completed by outputting four numbers to mark the enclosing box location (e.g., centroid horizontal and vertical coordinates and enclosing box length and width). The output of this branch is only used when the classification branch is not judged to be "background". The detailed structure is shown in Fig. 3.23.

A traditional target detection framework that consists of three main steps:

1) Use sliding windows of different sizes to frame a certain part of the image as a candidate area;

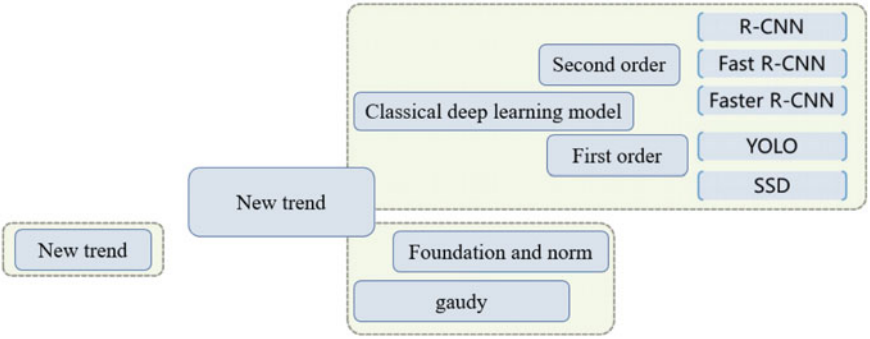


Fig. 3.22 Classical target detection algorithm

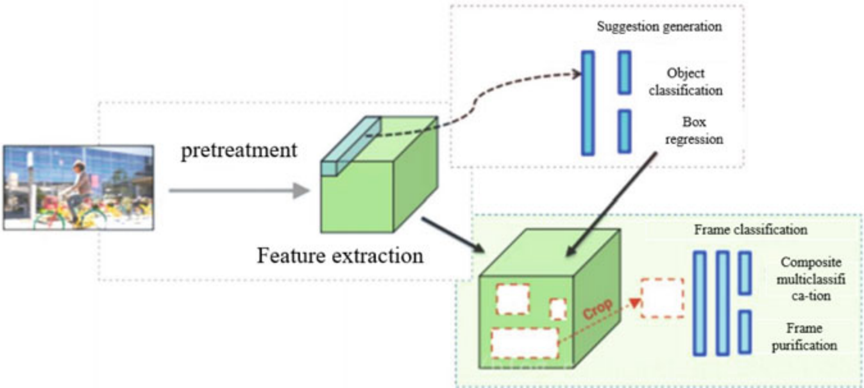


Fig. 3.23 Multi-task learning

2) Extract visual features related to candidate regions. For example, the commonly used Harr features in facial detection; The commonly used HOG features for pedestrian detection and ordinary object detection;
3) Use classifiers for recognition, such as commonly used SVM models. The current deep learning methods in the field of target detection are mainly divided into two categories: Two Stages target detection algorithms and One Stage target detection algorithms.

Two Stages: First, the algorithm generates a series of candidate frames as samples, and then the samples are classified by convolutional neural network.

Common algorithms are R-CNN, Fast R-CNN, Faster R-CNN, etc.

One Stage: This class of methods does not require the generation of candidate boxes, and directly converts the problem of target box location into a regression problem processing (Process).

Common algorithms are YOLO, SSD, etc.

Based on candidate regions (Region Proposal), such as R-CNN, SPP-net, Fast R-CNN, Faster R-CNN, R-FCN.

End-to-End based, no candidate region (Region Proposal), such as YOLO, SSD SSD.

For both approaches, the Region Proposal-based approach is superior in terms of detection accuracy and localization precision, and the End-to-End-based algorithm is superior in speed. Compared with the R-CNN series YOLO only requires a "look" compared to the "look twice" of the R-CNN series (candidate frame picking and classification). In summary, for now, the Region Proposal-based approach still prevails, but the speed of the end-to-end approach has a clear advantage. We will wait and see the subsequent development.

2) Target detection candidate frame generation mechanism

Nowadays, deep learning is developing rapidly, and articles such as RCNN/SPP-Net/Fast-RCNN talk about candidate edge Bounding boxes are generated and filtered. So how are the candidate boxes created? And how is filtered? In fact, object candidate frame acquisition currently mainly uses image segmentation and region growing techniques. Region growth (merging) is mainly due to the detection of objects present in the image with local region similarity (color, texture, etc.). The development of target recognition and image segmentation techniques further promotes the effective extraction of information from images.

According to the different ways of target candidate region extraction, traditional target detection algorithms can be divided into sliding window-based target detection algorithms and selective search-based target detection algorithms. Sliding window method as a classical object detection method, individuals believe that the probability of the presence of objects after the convolution operation when sliding windows of different sizes on the image with the already trained classifier discriminate. Selective search is the main use of image segmentation techniques for object detection.

a) Sliding Window target detection

The sliding window approach is a simple target detection algorithm that transforms the detection problem into an image classification problem. The basic principle is to slide windows of different sizes and aspect ratios (width-to-height ratios) over the entire image with a certain stride. Then, image classification is performed on the corresponding regions within these windows, enabling detection of objects in the entire image. However, this method has a fatal drawback: you do not know the scale of the target object that needs to be detected. Therefore, you need to set windows of different sizes and aspect ratios to slide, and also choose an appropriate stride. This approach generates many sub-regions that all need to be passed through the classifier for prediction, which requires significant computational power. Hence, the classifier cannot be too complex to ensure speed. Next, let's take a look at the flowchart of the object detection process using the sliding window method, as shown in Fig. 3.24.

The specific steps of the sliding window method can be analyzed through the flowchart as follows: First, the input image is subjected to sliding window operation

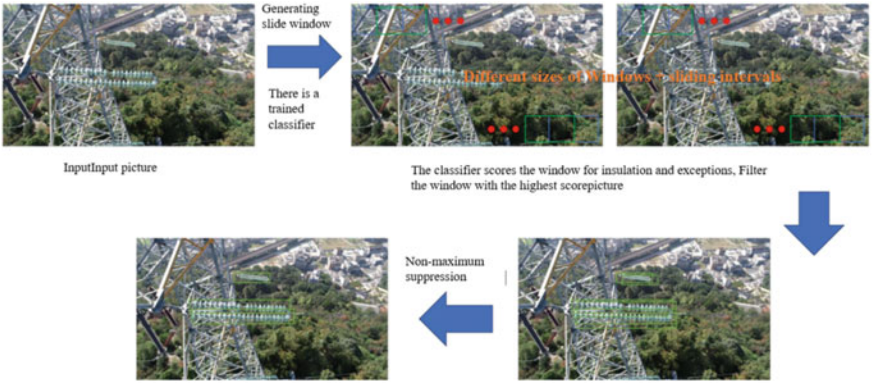


Fig. 3.24 Sliding window method object detection flow chart

with different window sizes, sliding from left to right and top to bottom. Each time the window slides, the classifier (pre-trained) is applied to the current window. If the current window obtains a high classification probability, it is considered as detecting an object. After detecting with different window sizes, there will be overlapping regions with high repetitions among the detected windows. Finally, non-maximum suppression (NMS) is applied to filter out redundant detections. As a result, the detected objects are obtained after the NMS filtering.

The sliding window method is simple and easy to understand, but searching the entire image using windows of different sizes results in low efficiency, and designing window sizes also requires consideration of the aspect ratio of the object. Therefore, for classifiers with high real-time requirements, the use of the sliding window method is not recommended.

b) Selective Search

The sliding window method is similar to an exhaustive search of image sub-regions, but in most cases, the majority of sub-regions in the image do not contain objects. Researchers naturally thought of searching only in the regions most likely to contain objects in order to improve computational efficiency. The chosen search method is the widely known algorithm for extracting image bounding boxes, which is shown in Fig. 3.25.

The main idea for selecting a search algorithm is that regions in the image where objects may exist should exhibit some similarity or continuity. Therefore, a method based on the merging of sub-regions is chosen to extract candidate bounding boxes. Firstly, the input image is segmented using a segmentation algorithm, resulting in numerous small sub-regions (approximately 2000 sub-regions). Secondly, based on the similarity between these sub-regions (measured by criteria such as color, texture, size, etc.), region merging is performed iteratively. During each iteration, bounding boxes are generated for the merged sub-regions, which are referred to as candidate boxes.

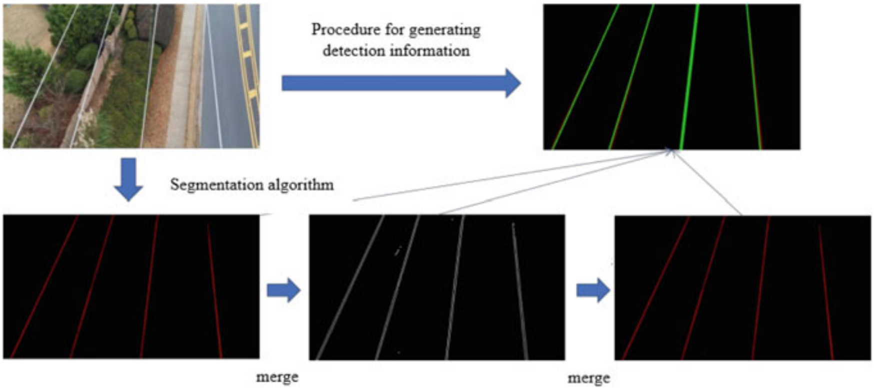


Fig. 3.25 Selective search method object detection flow chart

c) Select Search Benefits

① The computational efficiency is better than that of the sliding window method.
② Since the sub-region merging strategy is used, it can contain various sizes of suspected object frames.
③ The diversity of similar indicators in merged regions improves the probability of detecting objects.

3) Overlap of the predicted and manually labeled boxes

To evaluate the annotation performance of the Bounding-box Regression model for target objects, we introduce the concept of Intersection over Union (IOU). Let's provide a brief definition: Object detection requires localizing the Bounding-box of the object, as illustrated in Fig. 3.26. It is not only about locating the Bounding-box of the vehicle but also identifying the object within the Bounding-box, which is the vehicle itself. When it comes to the localization accuracy of the Bounding-box, an essential concept arises because our algorithm cannot perfectly match the manually annotated data. Hence, there exists an evaluation formula for localization accuracy known as IOU (also referred to as Intersection Over Union). IOU defines the degree of overlap between two Bounding-boxes, as depicted in Fig. 3.26.

One overlap IOU of rectangular boxes A and B is calculated as:

Fig. 3.26 Overlap between the predicted and manually labeled boxes

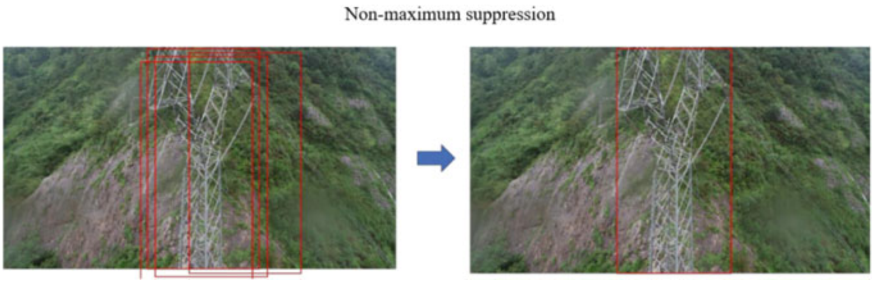


Fig. 3.27 Non-extreme value suppression

$$IOU = \frac{(A \cap B)}{(A \cup B)} \tag{3.2}$$

The ratio of the overlapping area of rectangular boxes A and B to the area of the concatenation of A and B is defined as:

$$IOU = \frac{SI}{(SA + SB - SI)} \tag{3.3}$$

4) Non-Maximun Suppression (NMS)

When studying the R-CNN algorithm, it is crucial to understand a significant concept called Non-Maximum Suppression (NMS). For example, we aim to identify numerous Bounding-boxes that potentially contain objects from an image. Subsequently, we compute the probabilities of each rectangular box belonging to a specific category, as shown in Fig. 3.27.

As shown in the above image, if we want to locate a vehicle, the algorithm ultimately finds a pile of boxes, each corresponding to a probability of belonging to the car category. We need to determine which rectangles are redundant. The method employed is Non-Maximum Suppression (NMS): let's assume there are six bounding boxes, and we sort them in ascending order based on the probabilities of belonging to the vehicle class, denoted as A, B, C, D, E, and F.

Starting from the maximum probability rectangle F, we can determine whether the overlap IOU between A~E and F is greater than a set threshold.

If the overlap between B, D and F exceeds the threshold, throw away B, D; and mark the first rectangular box F that we keep.

From the remaining rectangles A, C and E, select E with the highest probability, and then determine the overlap between E and A and C. If the overlap is greater than a certain threshold, then throw it away and mark E as the second rectangle we keep.

This cycle is repeated until there are no remaining rectangles, and then all the rectangles that are kept are found, which is the rectangle we think is most likely to contain the car.

a) The specific approach of NMS in R-CNN algorithm:

Suppose there are 20 categories and 2000 suggestion boxes, and the final output vector dimension is 2000 * 20, then each column corresponds to one category. One row is the score of each suggestion box, and the NMS algorithm steps as follows:

① Sorting each column in the 2000 × 20 dimensional matrix from largest to smallest;
② Starting from the largest scoring suggestion box in each column, perform IoU calculation with the scoring suggestion boxes following that column, respectively. If IoU > threshold, the suggestion box with smaller score is excluded, otherwise, it is considered that there are multiple objects of the same class in the image;
③ Repeat step ② starting with the next largest scoring suggestion box in each column;
④ Repeat step ③ until all suggestion boxes in that column are traversed;
⑤ Iterate through all columns of the 2000 × 20 dimensional matrix, i.e., do non-maximal suppression for all object categories;
⑥ Finally, eliminate the remaining suggestion boxes in each category that have scores less than the threshold value of that category.

5) Region Proposal Suggested Boxes for Crop/Wrap Specific Practices

In the R-CNN paper, anisotropic scaling with padding = 16 achieved the highest accuracy. The authors employed a simple transformation where, regardless of the size of the candidate region, a context region (referring to the surrounding pixels of the Region of Interest or RoI in the image) with a padding of 16 pixels, filled with the average pixel value of the RoI, is added. Then, the region is directly transformed to a size of 227 × 227.

a) Anisotropic scaling (non-isometric scaling)

This method is simple, regardless of the aspect ratio of the image, whether it is distorted or not, it is scaled and all scaled to the size of the CNN input 227 * 227, with proportional distortion of the shape.

b) Isotropic scaling

Because the distortion of the image has an impact on the training accuracy of the subsequent CNN, the authors also tested the "isotropic. The authors also tested the "isotropic scaling" scheme. There are two ways to do this.

① Directly in the original image, extend the bounding box border into a square, and then crop it; if it already extends to the outer boundary of the original image, then use the color in the bounding box the average value of the bounding box;

② First crop out the bounding box image, then fill it with a fixed background color to form a square image (the background color is also the pixel color average of the bounding box).

6) Bounding-box Regression Method

The regressor used in R-CNN is linear, with the input being the output of AlexNet's pool5 layer. Bounding-box regression assumes a linear relationship between the candidate regions and the ground truth bounding boxes (as the regions selected from the SVM closely approximate the ground truth). The input for training the regressor consists of N pairs of values, representing the coordinates of the candidate regions' bounding boxes and the corresponding coordinates of the ground truth bounding boxes. In the following explanation, the index "i" is omitted unless necessary. Here, the proposals used must have an IoU (Intersection over Union) with the ground truth greater than 0.6 to be considered positive samples. Bounding-box pairs and input characteristics are as follows input characteristics are as follows:

Bounding box for $\left\{\left(P^i, G^i\right)\right\}_{i=1,\ldots,N}$ central location (x, y):

$$P^i = \left(P_x^i, P_y^i, P_w^i, P_h^i\right) \tag{3.4}$$

$$G = \left(G_x, G_{yx}, G_w, G_h\right) \tag{3.5}$$

And the width and height dimensions (w, h) and the Conv5 feature $\varphi_5(P)$ of CNN.

The basic idea of going from the candidate box P to the prediction box is as follows:

After obtaining the candidate boxes P following classification, we define the representation of the boxes using the variables x and y for the center coordinates, and w and h for the width and height of the boxes. In the following explanation, all box localization is defined using this representation. Once we have the representation of the candidate boxes, we can estimate the translation and scale factors between the candidate boxes and the ground truth boxes. With these factors, we can compute our estimated boxes.

The training phase of the regression model is represented as:

$$w_* = arg \min_{\widehat{w}_*} \sum_i^N \left(t_*^i - \widehat{w}_*^T \varphi_5(P^i)\right)^2 + \lambda \|\widehat{w}_*\|^2 \tag{3.6}$$

$$t_x = (G_x - P_x)/P_w \tag{3.7}$$

$$t_y = (G_y - P_y)/P_h \tag{3.8}$$

$$t_w = \log\left(\frac{G_w}{P_w}\right) \tag{3.9}$$

$$t_h = \log\left(\frac{G_h}{P_h}\right) \tag{3.10}$$

Based on the aforementioned loss function model, we can solve for the optimal weight W. Multiplying the weight with the features from pool 5 yields the translation and scale parameters. During the testing phase of bounding box regression, the weight parameters have already been trained and the results are obtained.

$$d_*(P) = w_*^T \Phi_5(P) \tag{3.11}$$

The above equation is the characteristic of pool5 output, so the four transformations can be derived. Then, using the following algorithm flowchart to find the predicted bounding box that contains the object.

$$\widehat{G}_x = P_w d_x(P) + P_x \tag{3.12}$$

$$\widehat{G}_y = P_h d_y(P) + P_y \tag{3.13}$$

$$\widehat{G}_w = P_w \exp(d_w(P)) \tag{3.14}$$

$$\widehat{G}_h = P_h \exp(d_h(P) \tag{3.15}$$

$$d_*(P) = w_*^T \varphi_5(P) \tag{3.16}$$

(5) Image Recognition

Image recognition technology is an important field in the information age, with the aim of allowing computers to replace humans in processing a large amount of physical information. With the advancement of computer technology, our understanding of image recognition has deepened. The process of image recognition involves information acquisition, preprocessing, feature extraction and selection, classifier design, and classification decision-making. This text briefly analyzes the introduction of image recognition technology, its technical principles, and pattern recognition. It also discusses neural network-based image recognition techniques, nonlinear dimensionality reduction techniques, and the applications of image recognition technology. From this, we can conclude that image processing technology has wide-ranging applications, and human life has become inseparable from image recognition technology. Therefore, researching image recognition technology holds significant importance.

1) Introduction of image recognition technology

Image recognition is an important field of artificial intelligence. The development of image recognition has gone through three stages: text recognition, digital image processing and recognition, and object recognition. As the name suggests, image recognition involves various processing and analysis of images to ultimately identify the objects of interest. Today, image recognition refers to the use of computer technology to perform recognition, rather than relying solely on human visual perception. Although human recognition capabilities are powerful, they are insufficient to meet the demands of a rapidly developing society. Thus, computer-based image recognition technology has emerged. It is similar to how humans study biological cells. It is unrealistic to rely solely on naked-eye observation for accurate cell examination, which is why instruments like microscopes have been invented for precise observation. When inherent techniques in a field cannot address certain demands, new technologies are developed accordingly. Image recognition technology is no exception. Its purpose is to enable computers to process large amounts of physical information, solving problems that are difficult or nearly impossible for humans to recognize.

2) Principle of image recognition technology

In fact, the underlying principles of image recognition technology are not very difficult. It's just that the information it deals with can be complex. Any processing technique in computer science is not created out of thin air but rather inspired by practical experiences of scholars, who then simulate and implement them through programs. The principles of computer-based image recognition technology are fundamentally similar to human image recognition. The main difference is that machines lack the influence of human sensory and visual perception. Human image recognition is not solely based on memorizing the entire image in our minds. Instead, we recognize images by identifying the inherent features of the images themselves and categorizing them based on these features. However, we are often unaware of this process. When we see an image, our brain quickly senses whether we have seen the image before or if it resembles similar images. In fact, there is a rapid recognition process that occurs between "seeing" and "sensing," which is similar to searching. During this process, our brain recognizes the image by comparing it with the stored memories and checking for similar or identical features. Machine image recognition works in a similar way, where it categorizes and extracts important features while excluding irrelevant information to identify the image. The features extracted by machines can sometimes be very distinctive, while other times they may be quite ordinary, which greatly affects the speed of machine recognition. In computer vision, the content of an image is typically described using image features.

3) Pattern Recognition

Pattern recognition is an important component of artificial intelligence and information science. It refers to the process of analyzing and processing different forms of information that represent objects or phenomena in order to obtain descriptions, recognition, classification, and other outcomes related to those objects or phenomena.

Computer's image recognition technology simulates the human process of pattern recognition. Pattern recognition is originally a fundamental ability of humans.

However, with the development of computers and the rise of artificial intelligence, human pattern recognition alone cannot meet the demands of daily life. Therefore, humans have sought to use computers to replace or augment human cognitive abilities. This gave rise to computer-based pattern recognition. In simple terms, pattern recognition involves classifying data and is a science closely integrated with mathematics, with a significant focus on probability and statistics. Pattern recognition can be broadly categorized into three types: statistical pattern recognition, syntactic pattern recognition, and fuzzy pattern recognition.

4) The process of image recognition technology

Since computer image recognition technology follows the same principles as human image recognition, their processes are quite similar. The process of image recognition technology can be divided into the following steps: information acquisition, preprocessing, feature extraction and selection, classifier design, and classification decision.

Information acquisition refers to the process of capturing the basic information of the research object, such as light or sound, and converting it into electrical information through sensors. It involves obtaining the fundamental data about the object of study and transforming it into information that can be understood by the machine through certain methods.

Preprocessing mainly refers to the operations in image processing, such as denoising, smoothing, and transformation, to enhance the significant features of the image. It aims to improve the quality and extract relevant information from the image.

Feature extraction and selection refer to the process of extracting and selecting relevant features in pattern recognition. In simple terms, when dealing with various types of images, we need to identify and differentiate them based on their inherent features. The process of obtaining these features is called feature extraction. However, not all the features extracted may be useful for the specific recognition task at hand. In such cases, feature selection is performed to choose the most relevant and informative features. Feature extraction and selection are critical techniques in the image recognition process, and understanding this step is essential in image recognition.

Classifier design refers to the process of training a recognition rule that enables the image recognition technology to achieve high recognition accuracy. It involves developing a classifier model that can effectively categorize and classify the extracted features of the objects being studied. On the other hand, classification decision refers to the process of assigning the recognized objects to specific classes within the feature space. This step helps determine the exact category or class to which the studied objects belong.

5) Analysis of image recognition technology

With the rapid development of computer technology and advancements in science and technology, image recognition technology has been applied in various fields. On February 15, 2015, Sina Technology reported: “Microsoft recently published a research paper on image recognition, and in a benchmark test of image recognition, the computer system has surpassed humans. The human error rate in classifying images in the ImageNet database is 5.1%, while Microsoft's research team achieved an error rate of 4.94% with their deep learning system." This news indicates that image recognition technology has shown a trend of surpassing human capabilities in image recognition. It also highlights the significant research significance and potential of image recognition technology in the future. Furthermore, computers have advantages that surpass human capabilities in many aspects, which is why image recognition technology can bring more applications to human society.

6) Neural networks for image recognition

Neural network image recognition technology is a relatively new approach that combines neural network algorithms with traditional image recognition methods. Here, neural network refers to artificial neural networks, which are generated by humans to mimic the neural networks found in animals. In neural network image recognition technology, the fusion of genetic algorithms and backpropagation (BP) networks is a classic neural network image recognition model that finds applications in various fields. In an image recognition system that utilizes neural networks, the general process involves first extracting features from the images and then mapping these features to the neural network for image recognition and classification. Let's take the example of automatic license plate recognition technology for vehicles. When a vehicle passes by, the detection devices installed on the vehicle will sense its presence. The image acquisition device is then activated to capture images of the front and rear sides of the vehicle. Once the images are obtained, they need to be uploaded to a computer for storage and further processing. The license plate localization module will extract the license plate information and recognize the characters on the license plate, displaying the final result. In the process of character recognition on the license plate, both template matching algorithms and artificial neural network algorithms are used.

7) Nonlinear dimensionality reduction for image recognition

Computer image recognition technology is an exceptionally high-dimensional recognition technique. Regardless of the resolution of the image itself, the data generated from it often exhibits a high degree of dimensionality, which poses significant challenges for computer recognition. To enable efficient recognition capabilities in computers, the most direct and effective approach is dimensionality reduction. Dimensionality reduction can be classified into linear and nonlinear methods. For example, Principal Component Analysis (PCA) and Linear Discriminant Analysis (LDA) are common linear dimensionality reduction methods, known for their simplicity and ease of understanding. However, linear dimensionality reduction methods operate on the entire dataset and seek the optimal low-dimensional projection for the entire dataset. After verification, it has been found that linear dimensionality reduction strategies have high computational complexity and consume relatively more time and space. As a result, image recognition techniques based on nonlinear dimensionality reduction have emerged as highly effective methods for feature extraction. These techniques can discover the nonlinear structure of images and perform dimensionality reduction without disrupting their intrinsic structure. This allows computer image recognition to be conducted in as low-dimensional space as possible, thereby improving the recognition speed. For example, face recognition systems typically require a high number of dimensions, which presents a significant "curse" in terms of complexity for computers. Due to the uneven distribution of face images in high-dimensional space, humans can utilize nonlinear dimensionality reduction techniques to obtain compactly distributed face images, thus enhancing the efficiency of face recognition technology.

8) Application and prospect of image recognition technology

Computer image recognition technology has applications in various fields such as public safety, biology, industry, agriculture, transportation, and healthcare. For instance, in transportation, there are license plate recognition systems. In public safety, there are technologies like facial recognition and fingerprint recognition. In agriculture, there are seed recognition and food quality inspection technologies. In the medical field, there are techniques like electrocardiogram recognition. With the continuous development of computer technology, image recognition technology is being optimized, and its algorithms are constantly improving. Since images are a primary source of information acquisition and exchange for humans, it is evident that image recognition technology related to images will be a major focus of future research. Computer image recognition technology is likely to make further advancements in various fields, with limitless potential for applications. Human life will become increasingly dependent on image recognition technology.

Although image recognition technology is a relatively new field, its applications are already quite extensive. Furthermore, image recognition technology continues to evolve, and with the progress of science and technology, our understanding of it will deepen. In the future, image recognition technology will become even more powerful and intelligent, making significant contributions to various domains of human society. In this era of information technology in the twenty-first century, it is unimaginable how our lives would be without image recognition technology. It is an indispensable technology for our present and future lives.

(6) Edge detection

Edge detection is a fundamental problem in image processing and computer vision, and its goal is to identify points in a digital image where there is a significant change in brightness. Prominent changes in image properties often reflect important events and variations in the attributes, including (i) discontinuities in depth, (ii) discontinuities in surface orientation, (iii) variations in material properties, and (iv) changes in scene illumination. Edge detection is a research area in image processing and computer vision, particularly in the context of feature detection.

Image edge detection significantly reduces the amount of data and eliminates potentially irrelevant information, while preserving the important structural attributes of the image. There are various methods for edge detection, most of which can be categorized into two types: the class of lookup-based methods and the class of zero-crossing-based methods. Lookup-based methods detect edges by searching for the maximum and minimum values in the first-order derivatives of the image, typically locating edges in the direction of maximum gradient. Zero-crossing-based methods detect edges by identifying the zero-crossings of the second-order derivatives of the image, often through the use of Laplacian zero-crossings or zero-crossings represented by nonlinear differences.

1) Edge Properties

Edges can be viewpoint-dependent, meaning that they may vary with different perspectives. This is typically reflected in the occlusion of one scene or object by another, or in the presence of attributes such as surface texture and shape of the observed object. In 2D or higher-dimensional spaces, the effects of perspective projection need to be considered. A typical boundary might be the edge between a red region and a yellow region, for example. Conversely, an edge might consist of a few differently colored points against a background that remains constant. Edges have significant importance in many applications of image processing. However, in recent years, computer vision processing methods that do not heavily rely on explicit edge detection as a preprocessing step have achieved substantial research progress and success.

2) Simple Edge Model

The edges of natural images are not always ideal stepped edges. Instead, they are usually affected by one or more of the following factors listed below:

a) Focus blur from limited scene depth;
b) Penumbra blur from shadows produced by non-zero radius light sources;
c) Shadows at the edges of smooth objects;
d) Local specular or diffuse reflections near the edges of objects.

Although the following model is not perfect, the error function erf is often used in practical applications of edge blur modeling the effect of edge blurring.

Thus, a one-dimensional image at the boundary of position 0 can be represented by the following model:

$$f(x) = \frac{I_r - I_l}{2}\left(\operatorname{erf}\left(\frac{x}{\sqrt{2}\sigma}\right) + 1\right) + I_l \tag{3.17}$$

3) Detecting edges is not a simple problem

If we consider an edge to be a location where there is a significant change in brightness across a certain number of points, then edge detection can be seen as computing the derivative of this brightness variation. To simplify the explanation, let's analyze edge detection in one-dimensional space. In this example, our data consists of a series of brightness values along a line. For instance, in the 1D data below, we can intuitively say that there is an edge between the fourth and fifth points, as shown in Fig. 3.28.

Unless the objects in the scene are very simple and the lighting conditions are well-controlled, it is not an easy task to determine the threshold for what constitutes a significant change in brightness between two adjacent points to be considered an edge. In fact, this is one of the reasons why edge detection is not a straightforward problem.

4) Methods of edge detection

There are many methods for edge detection, which can be broadly categorized into two types: search-based and zero-crossing-based.

Search-based edge detection methods first compute edge strength, often represented by the first-order derivative, such as the gradient magnitude. Then, they estimate the local direction of the edge, typically using the direction of the gradient, and use this direction to find the maximum value of the local gradient magnitude.

Zero-crossing-based methods locate edges by finding the zero-crossing points of the second-order derivative obtained from the image. Typically, the zero-crossings of the Laplacian operator or zero-crossings of nonlinear diffusion equations are used. We will describe these in later sections.

Filtering, often using Gaussian filtering, is commonly performed as a preprocessing step in edge detection.

Published edge detection methods utilize measures of boundary strength, which are fundamentally different from smoothing filters. Just as many edge detection methods rely on computing image gradients, they use different types of filters to estimate gradients in the x- and y-directions.

a) Calculating the first order derivative

Many edge detection operations are based on the first derivative of brightness, which yields the gradient of the original data's brightness. With this information, we can search for peaks in the brightness gradient of the image.

If $I(x)$ represents the brightness of point x, $I'(x)$ represents the first derivative (brightness gradient) of point x, then we find:

$$I'(x) = -\frac{1}{2} \cdot I(x-1) + 0 \cdot I(x) + \frac{1}{2} \cdot I(x+1) \tag{3.18}$$

For higher-performance image processing, the first derivative can be computed through convolution with a masked raw data (1D).

Fig. 3.28 One-dimensional spatial analysis edge detection example

5	7	6	4	152	148	149

+1	−2	+1

Fig. 3.29 Example of a convolutional mask representation

b) Calculating the second order derivative

Other edge detection operations are based on the second derivative of brightness. This essentially measures the rate of change of the brightness gradient. In the ideal continuous case, detecting zero crossings in the second derivative will yield local maxima in the gradient.

On the other hand, peak detection in the second derivative is edge line detection, as long as the image operation uses an appropriate scale representation. As mentioned above, an edge line is a double edge, so we can observe a brightness gradient on one side and an opposite gradient on the other side. If there is an edge line in the image, we will see a significant change in the brightness gradient. To find these edge lines, we can search for zero crossings in the second derivative of the image brightness gradient.

If $I(x)$ I represents the brightness of point x, and $I''(x)$ represents the second derivative of the brightness of point x, then:

$$I''(x) = 1 \cdot I(x-1) - 2 \cdot I(x) + 1 \cdot I(x+1) \tag{3.19}$$

Similarly, many algorithms use convolution masks to process image data quickly. Figure 3.29 illustrates an example of a convolution mask.

c) Threshold determination

Once we have computed the derivatives, the next step is to apply a threshold to determine the edge locations. A lower threshold will detect more edge lines, but it is also more susceptible to noise in the image and can pick up irrelevant features. On the other hand, a higher threshold will result in the loss of fine or short line segments.

One commonly used approach is thresholding with hysteresis. This method employs different thresholds to search for edges. It starts by using an upper threshold to locate the beginning of an edge line. Once a starting point is found, the algorithm tracks the edge path point by point on the image, recording the edge positions as long as they are above the lower threshold, and stops recording when the value falls below the lower threshold. This method assumes that edges are continuous boundaries and allows us to track the fuzzy parts of edges observed earlier without labeling noise points in the image as edges.

5) Edge Detection Operators

There are several commonly used edge detection operators:

First-order operators: Roberts Cross operator, Prewitt operator, Sobel operator, Canny operator, Compass operator.

Second-order operators: Marr-Hildreth operator, which detects zero-crossings in the second derivative along the gradient direction.

Among these, the Canny operator (or its variants) is the most commonly used edge detection method. In Canny's groundbreaking work, he studied the problem of designing an optimal pre-smoothing filter for edge detection. He later demonstrated that this filter could be effectively optimized using a first-order Gaussian derivative kernel. Additionally, Canny introduced the concept of non-maximum suppression, which states that edges are defined as points with the maximum gradient value in the gradient direction.

In a discrete matrix, non-maximum suppression can be implemented by using a method that involves predicting the direction of the first-order derivative, approximating it to a multiple of 45°, and then comparing the gradient magnitude in the predicted gradient direction.

An improved implementation to obtain subpoint accuracy edges is achieved by detecting the trans-zero of the second-order directional gradient in the gradient direction points to achieve:

$$L_x^2 L_{xx} + 2L_x L_y L_{xy} + L_y^2 L_{yy} = 0 \tag{3.20}$$

Its third-order directional gradient in the direction of the gradient satisfies the sign condition:

$$L_x^3 L_{xxx} + 3L_x^2 L_y L_{xxy} + 3L_x L_y^2 L_{xyy} + L_y^3 L_{yyy} < 0 \tag{3.21}$$

where $L_x L_y L_{xy}$ represents the partial differential calculated from the scale-space representation obtained using the Gaussian kernel to smooth the original image. According to this method, continuous curve edges with subpoint accuracy can be obtained automatically. Following this method, continuous curve edges with subpoint accuracy can be obtained automatically.

The hysteresis threshold can also be used for these differential edge slices.

3.3.3 Intelligent Analysis Algorithm Architecture of UAV Power Grid Disaster Loss Detection

We propose an intelligent analysis algorithm for UAV power grid disaster detection, and the main detection categories include insulators and towers 7 types of fault conditions, such as body, tower head, foreign body, broken wire, wind deviation, tower tilt, etc., are divided by the survey image before and after Separation and image enhancement processing, combined with the normal and abnormal image libraries of training, using comparative learning, anomaly labeling and other means to realize the investigation and identification of line disasters. The algorithm pre-training phase flow is shown in Fig. 3.30.

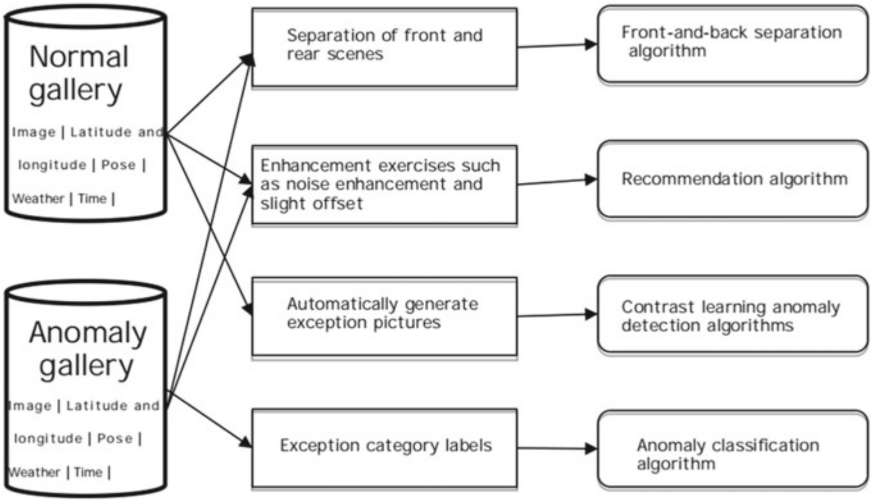


Fig. 3.30 Algorithm pre-training stage flowchart

Figure 3.31 shows the process of running the stage after the algorithm is deployed.

Here it is proposed to use two ways to collect and produce datasets, one is web crawler + data cleaning, and the other is drone on-site shooting and collection. When it is inconvenient to go to the site to shoot, the first method is preferred to collect and sort out to ensure that enough sample photos are collected and verified with the actual disaster photos on site.

There are certain requirements for the amount of data involved in researching related systems. The construction of the resource library adopts "unified planning and classified construction. "Libraries, libraries are associated, fully shared, redundant growth", the overall design capacity is about 5 million sheets. That Included in:

1) Build a tower foundation image library
   For the data of several tower types commonly used in high voltage power lines, the image upload and query function is opened to users, and the image comparison service interface is opened to the background service system. Users can use the actual needs and business needs of the tower image resource library on the basis of targeted image contrast and image detection services.
2) Establish the negative sample image library of the pole and tower, establish the negative sample image of the pole and tower with the same target at each shooting angle according to the type of the pole and tower, and establish the corresponding index position in the background database to facilitate the image retrieval and comparison, and make full preparation for the subsequent sample training.
3) The data is updated to the image library
   Supporting the update of business data sources, the system supports the loading and updating of dynamic incremental templates, so that the dynamically updated

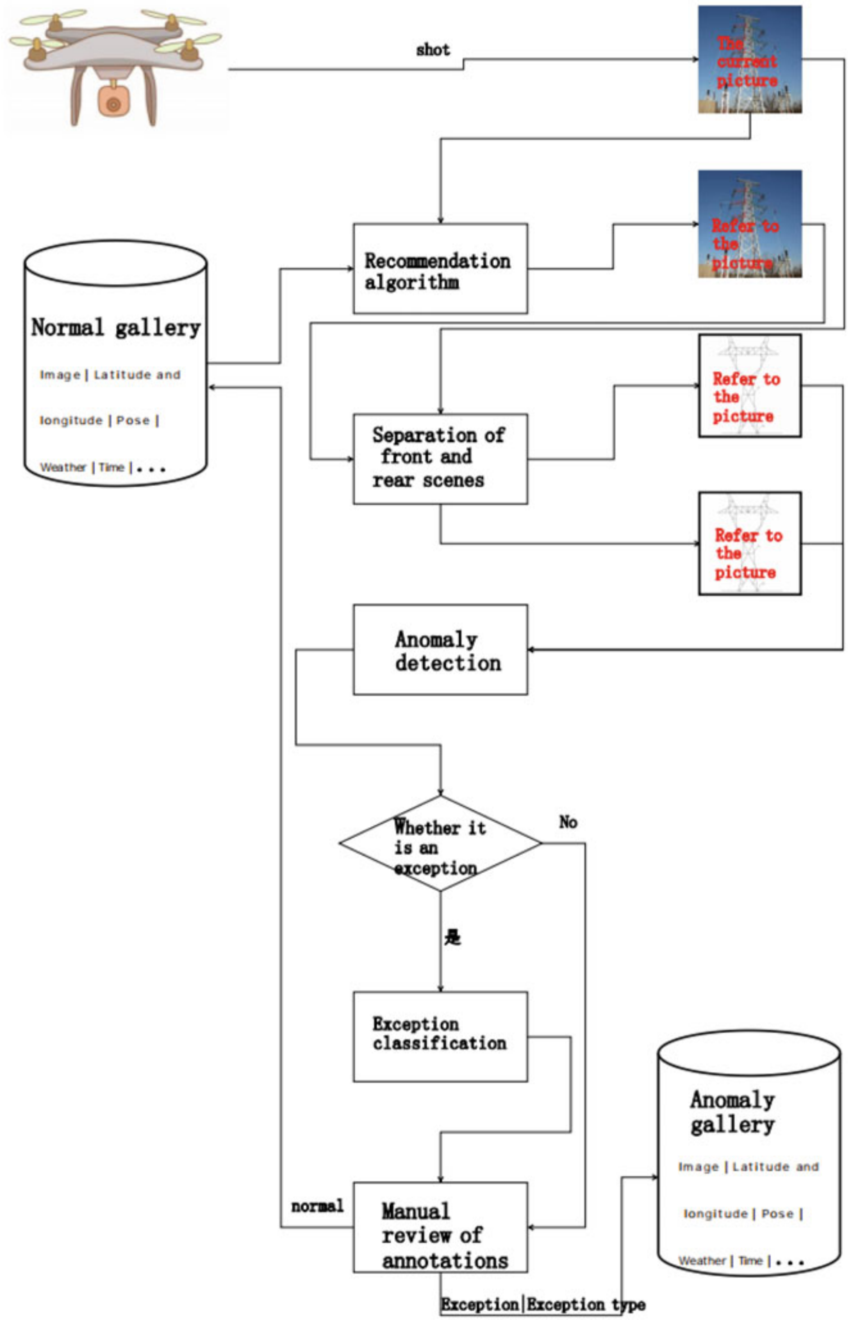


Fig. 3.31 UAV power grid disaster image collection process

(a) Original image (b) Image after separation of front and back scenes

Fig. 3.32 Image front and rear separation

inbound photo data can participate in the comparison in time; The system automatically detects all kinds of business photo databases, and if there is an update, it automatically takes photos according to the update time set by the user, and compares them with the existing image feature database to ensure uniqueness before entering the database.

(1) Separation of front and rear scenes

The semantic segmentation technology in machine vision is used to separate the front and back scenes of the image. This is shown in Fig. 3.32.

(2) Recommended image retrieval

When the **wide&deep** recommendation model is adopted, the UAV's pose (relative position in space), camera's internal parameters (imaging effect parameters), weather, time, and other sensor information are used as wide features when collecting pictures, and picture information is used as deep features. Through a large number of verification and training, the algorithm model and data will be fitted and approximated from the two dimensions of wide and deep. Train a picture retrieval model. During anomaly detection, the image taken at the moment is used to retrieve the most similar image from the normal image library. The **wide&deep** model connects the wide part of the single-input layer with the deep part consisting of the Embedding layer and the multi-hidden layer to input the final output layer. The wide part of the single layer is good at handling a large number of sparse different fault class characteristics; The deep part uses the characteristics of the neural network with strong expression ability to carry out deep feature crossover and mine the data patterns hidden behind the features. Finally, using the logistic regression model, the output layer combines the wide part and the deep part to form a unified model. The wide & deep (wide and deep) recommended model is shown in Fig. 3.33.

(3) Manual labeling

Through comparative learning, train an anomaly detection model. Reasonably design the positive example, negative example, and loss function in comparative learning, and then train it. The final model can determine whether there is a significant difference between the current pictures based on the images retrieved in the previous step. This is shown in Fig. 3.34.

Then, according to the classification standard, the collected sample data pictures are classified and labeled.

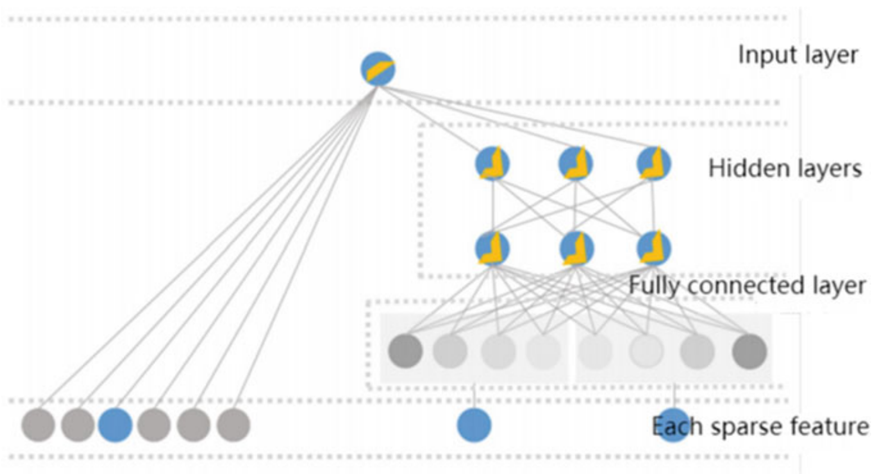


Fig. 3.33 Wide and deep recommendation model

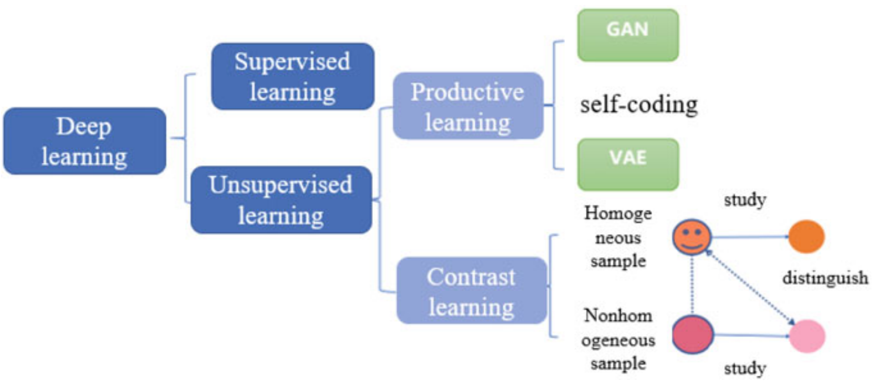


Fig. 3.34 Anomaly detection model

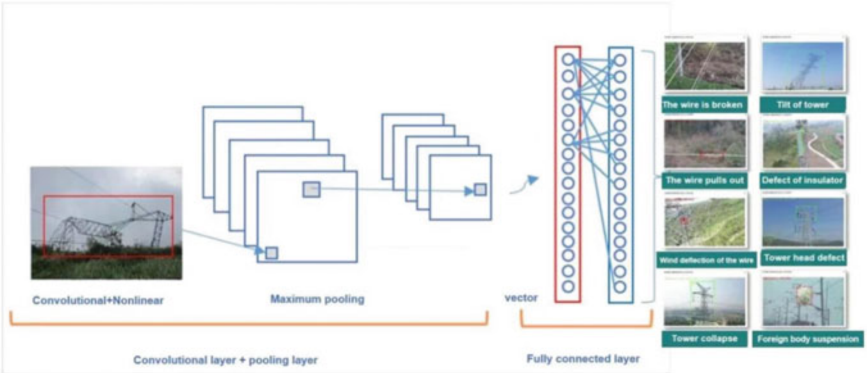


Fig. 3.35 Abnormal situation identification model

(4) Classification of abnormal scenarios

The pictures of various abnormal situations marked manually are used as training data. The amount of such data is expected to be small, so the transfer learning method is adopted to fine-tune the latest classification model of machine vision, and the abnormal situation recognition model is obtained. Figure 3.35 shows the abnormal situation identification model.

3.3.4 Typical Disaster Loss Scenario Identification

We have developed a drone-based main grid disaster detection algorithm and a typical disaster investigation plan for unmanned aerial vehicles (UAVs). The algorithm primarily detects various types of disaster scenarios, including wire breakage, conductor deviation, tower collapse, insulator damage, tower top loss, and foreign object suspension, totaling seven categories. Intelligent analysis and explanations are provided for each type of disaster. The recognition rates and examples corresponding to the functionalities of each algorithm are shown in Table 3.7.

(1) Wire break identification solution

1) Testing ideas

The detection of wire breakage, which refers to the breakage of wires between towers due to aging or external forces, can be performed in several steps. As the wires on towers are typically connected to insulators, the first step is to train a deep learning object detection model specifically for insulator detection. This model is used to locate the starting point of the wire by identifying the position of the insulators. Since wires are thin and may lose their distinctive features when downscaled in a large-scale view, we perform image cropping after detecting the insulator positions,

Table 3.7 Recognition rate for each type of algorithm function

Serial number	Identification item	Data source	Recognition rate	Example
1	Wire breakage	Wenzhou and Xiamen Data set 200 cases in total	More than 86%	
2	Wire stock drawing	Wenzhou and Xiamen Data set 1000 cases in total	More than 85%	
3	Wire deviation	Wenzhou and Xiamen Data set 304 cases in total	More than 85%	
4	Tower collapse	Wenzhou and Xiamen Data set 958 cases in total	More than 95%	
5	Insulator damage	Wenzhou and Xiamen Data set 1367 cases in total	More than 90%	
6	Loss of tower head	Wenzhou and Xiamen Data set 845 cases in total	More than 90%	
7	Foreign body hanging	Wenzhou and Xiamen Data set 1555 cases in total	More than 95%	

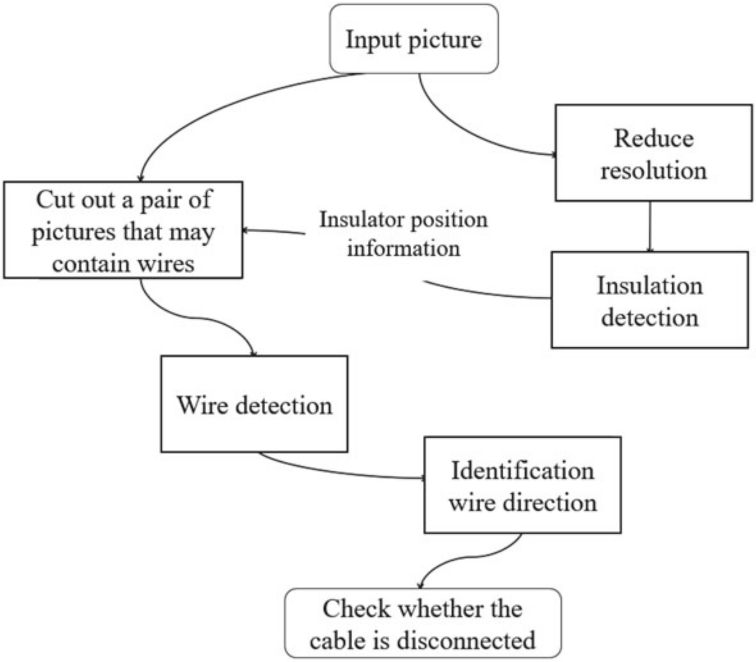


Fig. 3.36 Wire break detection process

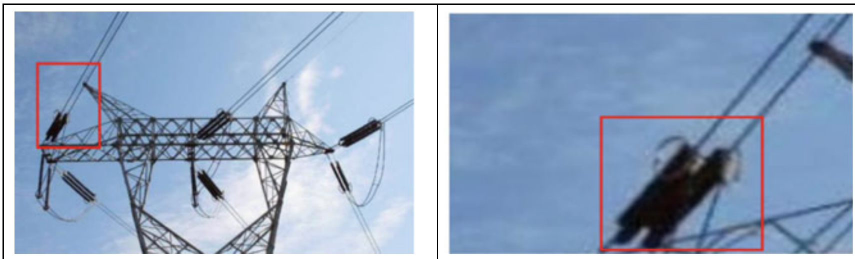
preserving the original resolution and extracting regions where wires may appear. Next, a wire detection model is developed to detect the wires within the cropped images. Finally, by analyzing the orientation of the detected wires, we can determine if there is a wire breakage. The specific workflow is illustrated in Fig. 3.36.

2) Insulator labeling instructions

The insulator labeling is divided into two steps: first, the general location of the insulator is marked in the original drawing, and then the detailed location is marked after pixel processing of the original drawing. This is shown in Fig. 3.37.

3) Insulator Inspection Model Introduction

The insulator detection is based on YOLOv4, which redefines object detection as a regression problem. It applies a single convolutional neural network (CNN) to the entire image, dividing it into a grid and predicting class probabilities and bounding boxes for each grid cell. For each grid cell, the network predicts a bounding box and probabilities corresponding to each class (e.g., car, pedestrian, traffic signal). Each bounding box is described using four descriptors: the mapped values of the center, height, and width of the bounding box, and the confidence of an object being present in the bounding box. If an object's center falls within a grid cell, that grid cell is responsible for detecting the object. There can be multiple bounding boxes



(a) Mark the general position of insulator

(b) Insulator detailed position marking

Fig. 3.37 Insulator labeling schematic

within each grid cell. During training, we want each object to be assigned to only one bounding box, so we assign a bounding box that has the highest overlap with the ground truth box to predict the object. Finally, a technique called "Non-Max Suppression" is applied to filter out bounding boxes with confidence scores below a threshold for each class. This gives us the final image predictions. YOLO is known for its speed. Since the detection problem is treated as a regression problem, it does not require a complex pipeline. It is 1000 times faster than "R-CNN" and 100 times faster than "Fast R-CNN". It can handle real-time video streams with a delay of less than 25 ms. Its accuracy is more than twice that of previous real-time systems. Equally important, YOLO follows the practice of "end-to-end deep learning".

4) Wire labeling instructions

Wire labeling starts with pixel dot labeling of the wires of the same line to identify abnormal lines. This is shown in Fig. 3.38.

（a）Wire pixel point labeling （b）Identify abnormal line labeling

Fig. 3.38 Wire labeling

5) Introduction to wire detection model

The wire line detection algorithm is an end-to-end detection approach that consists of two network models: LanNet and H-Net. LanNet is a multi-task model that combines semantic segmentation and pixel-level vector representation. Finally, it utilizes clustering to achieve instance segmentation of the lane lines. H-Net is a small network structure responsible for predicting the transformation matrix H. The transformation matrix H is then used to re-model all pixels belonging to the same wire line, with the y-coordinate representing the x-coordinate.

(2) Wire strand drawing identification scheme

In recent years, unmanned aerial vehicle (UAV) inspection technology has been developed as a solution to address the issues of low efficiency, poor reliability, and potential risks associated with manual inspections. Implementing UAVs for transmission line inspections can effectively reduce inspection costs and enable large-scale deployment across various levels of State Grid Corporation of China (SGCC). Additionally, it can significantly reduce the reliance on manpower and resources.

1) Basic requirements for UAV flight and shooting

a) The drone cannot shake;
b) The drone must fly to the bottom of the wire and try to be as level as possible with the wire, not too low or too high, if there is a block part try to bypass;
c) The wire must be shot toward the sky.

2) Detection idea

a) Based on the overall idea of LSD (Line Segment Detector) for line detection, the aerial wire sag detection based on unmanned aerial vehicles (UAVs) begins with the UAV capturing video images at specific locations. After the inspection is completed, the collected images are processed by recognition algorithms to obtain the inspection results.
b) Linear detection based on principal curvature and principal direction.

① Overview of principal curvature and principal direction principles

In 3D Euclidean space, if point X is any point on the differentiable surface, a unit normal vector of the surface can be taken through point X. The innumerable planes where the normal vector lies intersect the differentiable surface in a series of Plane curve. Except for some special shapes, the curvature radius of this curve on different cutting planes is often different, so the maximum or minimum curvature value can be obtained on some cutting planes, The radius of curvature that reaches the maximum

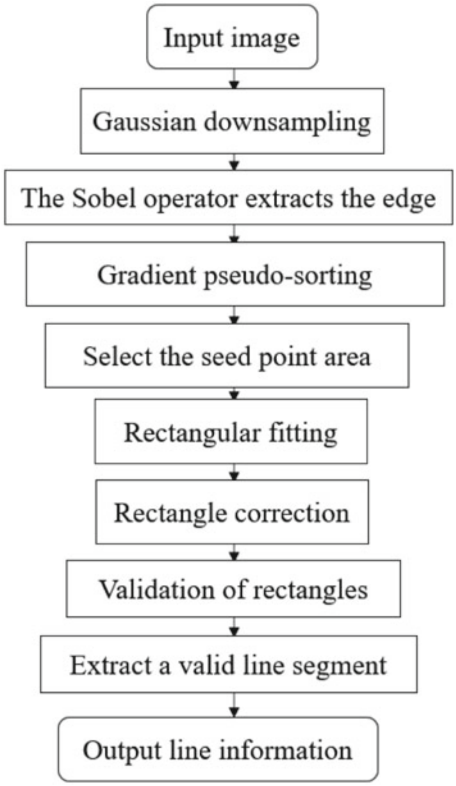


Fig. 3.39 Marking lines based on the main curvature and direction

is called the main radius of curvature, or the main curvature for short. The detection and annotation of power lines based on principal curvatures and principal directions are illustrated in Fig. 3.39.

Given the curve (C): $r = r[u(t), v(t)]$ on the surface S: $r = r(u, v)$, then:

$$dr = r_u du r_v dv \tag{3.22}$$

Order:

$$E = r_u \cdot r_u \tag{3.23}$$

$$F = r_u \cdot r_v \tag{3.24}$$

$$G = r_v \cdot r_v \tag{3.25}$$

Then the linear characteristics are shown in Table 3.8.

In addition, the ideal linear characteristics should satisfy:

Table 3.8 Shows the linear features

$\frac{k_1}{k_2}$	Geometric feature
Height (positive)	Bright line
Height (negative)	Dark line
Low (positive)	Bright spot
Low (negative)	Dark spots

$$|k_1| \gg |k_2| \tag{3.26}$$

$$k_2 \approx 0 \tag{3.27}$$

And:

$$L = r_{uu} \cdot n \tag{3.28}$$

$$M = r_{uv} \cdot n \tag{3.29}$$

$$N = r_{vv} \cdot n \tag{3.30}$$

$$\begin{bmatrix} dv^2 & -dudv & du^2 \\ E & F & G \\ L & M & N \end{bmatrix} = 0 \tag{3.31}$$

Or:

$$(EM - FL)du^2 + (EN - GL)dudv + (FN - GM)du^2 = 0 \tag{3.32}$$

Apart from:

$$\frac{E}{L} = \frac{F}{M} = \frac{G}{N} \tag{3.33}$$

c) Line segment detection extraction based on principal curvature and principal direction

① Potential linear target screening based on principal curvature:

The principal curvatures represent the bending behavior of a surface in two perpendicular directions. On a grayscale surface, the set of pixels that form a straight line typically exhibit minimal variations along the line direction, while significant variations are observed along the direction perpendicular to the line. As a result, the principal curvatures of image pixels on a straight line usually have significant differences, whereas the principal curvatures of background pixels are similar.

② Line segment detection based on main direction

The solution of the main curvature and the main direction is completed by calculating the eigenvalues and eigenvectors of the Hessian matrix. Wherein, D_m, the main direction corresponding to the smaller curvature, is the pixel direction vector, then the pixel direction Angle θ is:

$$\theta = arctan\ D_m \tag{3.34}$$

By selecting a seed point region, a group of pixels with similar principal directions can be merged to form a potential line region, achieving an initial segmentation of the line. In this case, the density of homogeneous points is computed as the criterion for region growing. Pixels whose principal direction deviation from the fitted rectangle direction is less than τ are considered homogeneous points. Let n be the number of homogeneous points in the rectangular approximation region r, then the density of homogeneous points in that region is defined as follows:

$$D(r) = \frac{n}{length(r) \cdot width(r)} \tag{3.35}$$

If the density of homogeneous points $D(r)$ in the rectangular region r exceeds a predefined threshold D_0, the region is considered to meet the requirements for a line region. The NFA (Number of False Alarms) calculation is performed to filter the line pixels and output the detected line segments. The flowchart for this process is shown in Fig. 3.40.

d) Screening fit for transmission lines

Through methods such as grayscale transformation, image preprocessing is carried out on the images collected during inspection, effectively reducing the interference of image background on the images. However, in the actual inspection process, the aerial images collected by the UAV inevitably will contain some background information with obvious line characteristics, such as the edge of artificial buildings, the edge of the road lane lines, etc. and power towers, etc., which cause interference to the detection of transmission lines in the video image sequence. In addition, due to factors such as complex backgrounds and lighting, the detected transmission lines may be incomplete, and the obtained straight line information may be screened for intermediate fractures. Therefore, it is necessary to fit the detected straight lines. By analyzing the aerial image information collected by the UAV inspection and the linear information obtained in the previous section, it can be found that the transmission lines are the main linear features in the image, and most of them run through the whole image and are parallel, with obvious directionality. After the set threshold is used to screen potential line segments based on Principal curvature, the long linear targets detected are mainly transmission line targets. Due to the small difference in inclination angles of transmission lines in the same image, it is possible to consider setting a slope inclination interval threshold to filter transmission line information

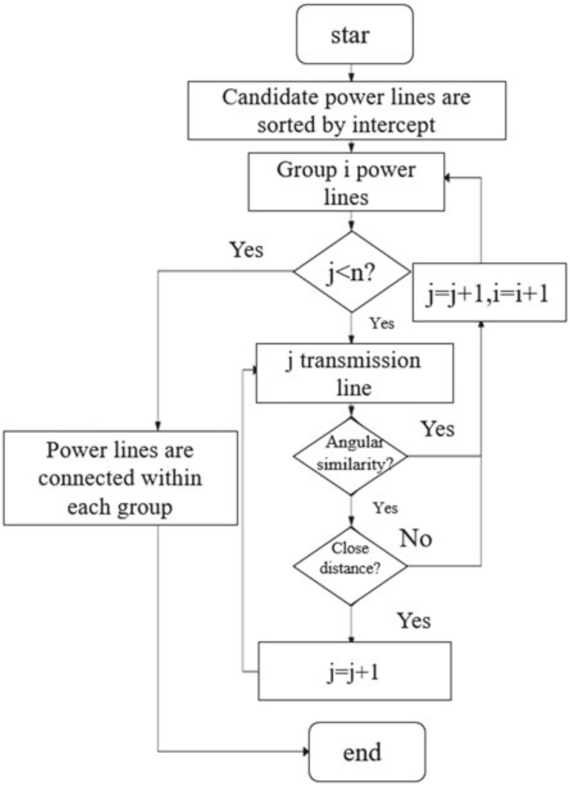


Fig. 3.40 Line segment detection based on main direction

based on the slope of the longest group of linear targets detected. Due to factors such as light and obstructions, the detected transmission line breaks, and needs to be fitted. Traverse all transmission lines, and if the detected transmission line information has the following characteristics, perform grouping fitting for the transmission line:

① The distance between adjacent transmission lines is less than a certain distance, i.e., two transmission lines are nearly on the same extension line.
② The angle between transmission lines is less than a certain threshold.

After filtering, the transmission lines are sorted based on intercept information. The adjacent transmission lines are then sequentially examined to determine if they belong to the same transmission line. In Fig. 3.41, transmission lines l_1 and l_2 are close in distance and have similar angles. According to the aforementioned criteria, it can be approximated that these two transmission lines are different parts of the same transmission line. Therefore, these two line segments are connected and fitted as a single transmission line. Continuing the search for other connectable lines, it is observed that l_3 is far from l_1, and there is a significant angle deviation between l_4 and l_3. Hence, in the graph, the four candidate transmission lines can be fitted into three separate transmission lines. The process flowchart for grouping and fitting the transmission lines is shown in Fig. 3.42.

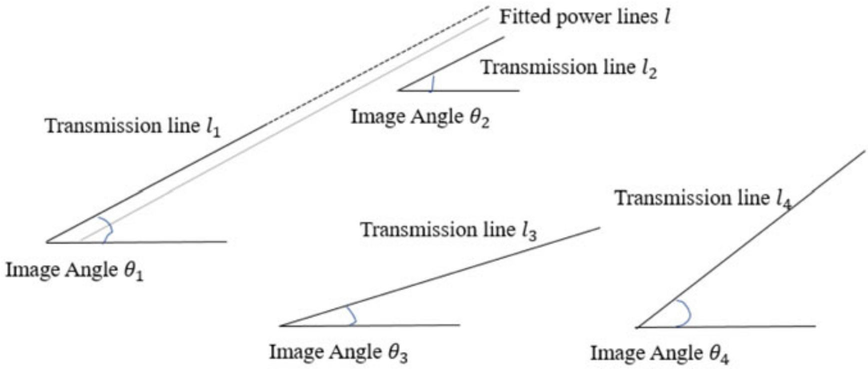


Fig. 3.41 Fitting judgment characteristics of transmission lines

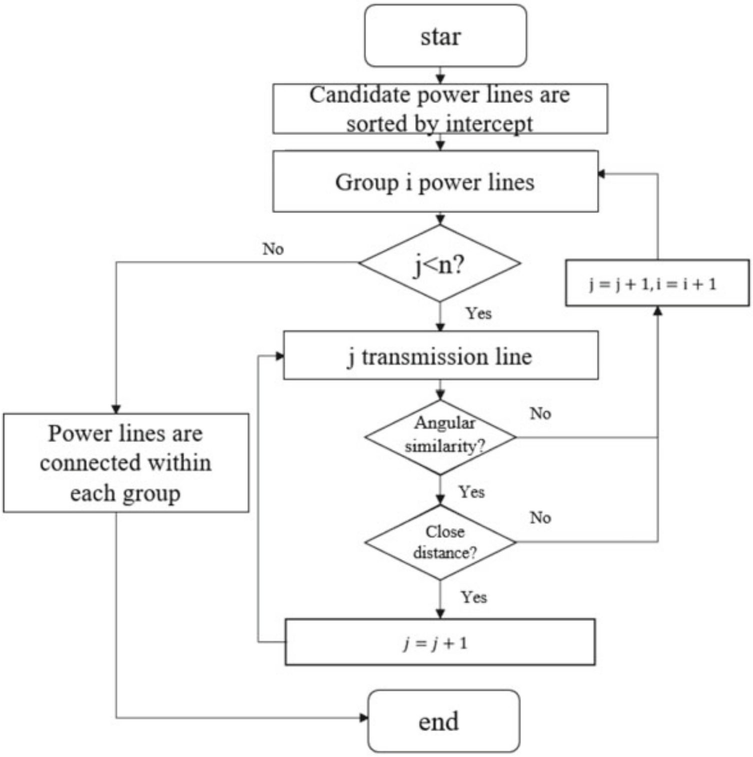


Fig. 3.42 Group fitting of transmission lines

3) Straight line or line segment extraction

Radon transform and Hough transform are combined with each other to extract the line segments.

4) Wire extraction detection foreign body extraction detection

a) Wire extraction strand detection methods are as follows:

① Line segment extraction to determine whether the broken line.
② Line segment extraction of abnormal bumps.
③ Extraction of edge maximization by edge detection.
④ Extracting continuous fast by binarization and judging whether the continuous block crosses the wire part.
⑤ By module matching.

Wire extraction pixel point judgment, wire abnormal image is relatively small, you can set the pixel point threshold as a benchmark. Foreign body detection The method is shown in Fig. 3.43.

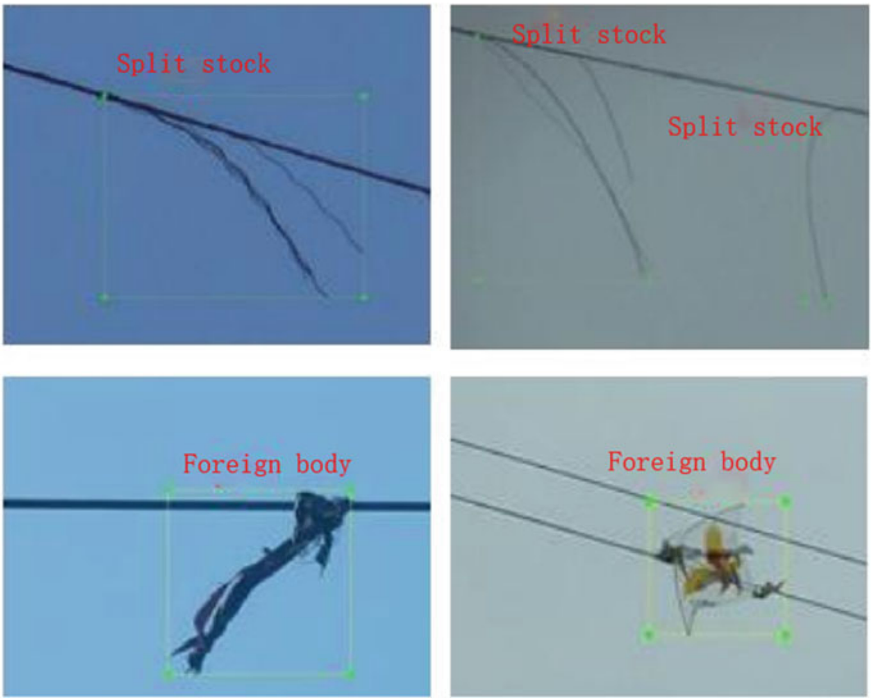


Fig. 3.43 Wire extraction foreign body extraction detection

5) Abnormal weather handling

Handling three types of abnormal weather conditions: overcast and rainy days, snowy days, and backlit situations.

Overcast and rainy days: Rain may create water droplets on the wires, which can cause interference during algorithm computation, leading to potential packet loss. In special cases, a water droplet removal algorithm is applied to eliminate the impact of water droplets.

Snowy days: Prolonged snowfall can result in ice formation or the accumulation of small snowballs on the wires, which can also cause interference during algorithm computation. Since these samples are relatively rare, they are processed when sufficient samples are available.

Backlit situations: When capturing images towards the sky, backlit conditions are often encountered. First, the brightness value is evaluated, and if it exceeds a specified threshold, it is considered as a backlit situation. Then, a white balance algorithm is used to reduce the brightness.

6) Algorithm verification and testing

Based on actual sampling, a portion of the samples are used as the algorithm tuning set, while another portion is used as the algorithm testing set. A 3:7 ratio is employed as the basis for algorithm validation. The detection criterion states that an accuracy rate of 80% or higher within 70% of the samples is considered acceptable. Otherwise, further algorithm optimization is required to achieve the desired results.

(3) Guide wire wind deflection identification program

1) Wind deflection overview

Wind-induced displacement fault, also known as wind deviation fault, is one of the most common types of wind-related hazards in power transmission lines. It occurs when the conductors and insulators sway under the influence of wind, leading to discharge and tripping due to inadequate electrical clearance. Wind-induced displacement faults are sometimes abbreviated as wind deviation faults.

Wind deviation detection primarily involves checking whether the distance between insulator strings and tower poles exceeds the limit of electrical air gap, as well as ensuring the normal distance between conductors. Drone-based wind deviation detection can be divided into two parts: detecting the suspended insulators on tower poles and detecting any abnormalities in the conductors during line inspection. The wind deviation detection model is illustrated in Fig. 3.44.

2) Testing ideas

The overall idea is shown in Fig. 3.45, where the UAV-based wind deflection detection of the conductor is firstly collected by the UAV at fixed points. After the inspection

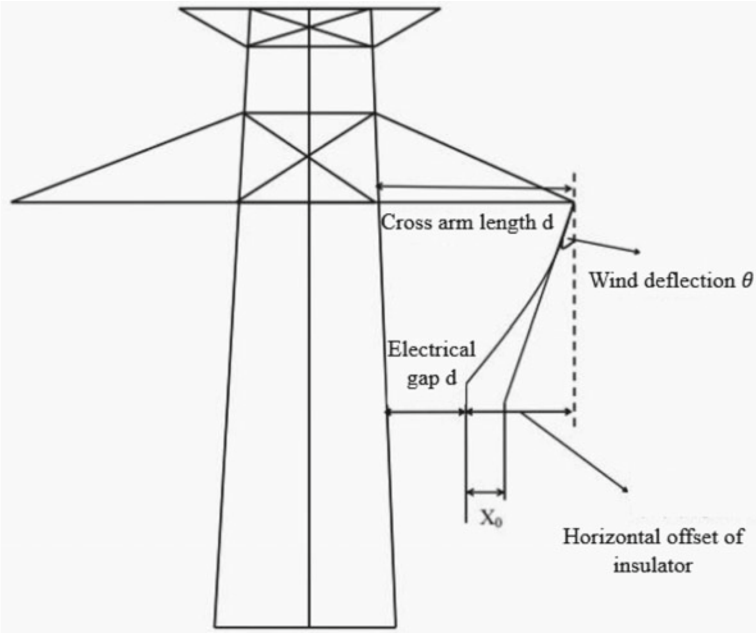


Fig. 3.44 Wind deflection detection of guide wire

is completed, the collected images are processed by the recognition algorithm and the inspection results are obtained.

The camera gimbal of the UAV is calibrated before the acquisition to reduce the influence of the senior distortion of the camera, improve the quality of the acquired images, and further increase the accuracy of recognition. The camera calibration uses the Zhang's calibration method, and the process is shown in Fig. 3.46.

The recognition is mainly divided into two stages: localization and judgment. Localization is based on a high-precision and lightweight deep learning target detection Algorithm model implementation, the images collected by the UAV are classified and labeled as samples, and the samples are read into the target detection network. The model can accurately detect the position of the overhanging insulator.

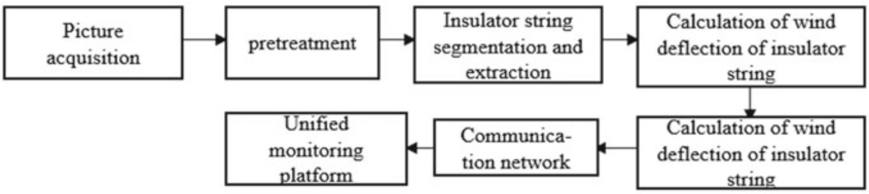


Fig. 3.45 Ideas for wind deflection detection of guide wire

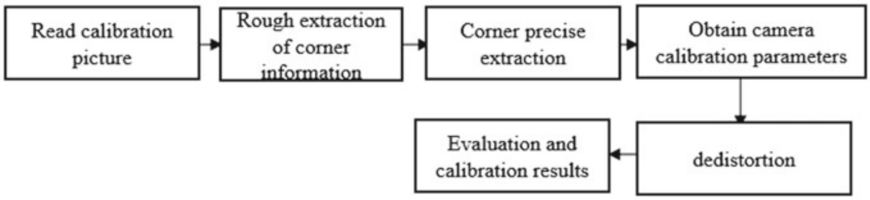


Fig. 3.46 Calibration process of guidewire wind deflection detection camera

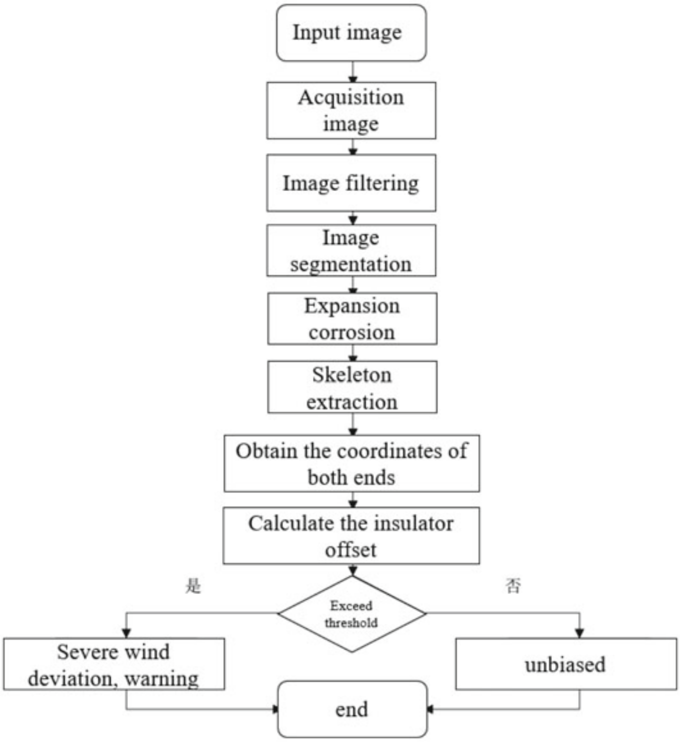


Fig. 3.47 Process of judging wind deflection of guide wire

After obtaining the position of the hanging insulator, the wind deflection can be determined by image processing. The main steps include image preprocessing, morphological processing and wind deflection Angle calculation. The detailed steps are shown in flow chart 3.47.

(4) Tower collapse identification program

The following is a block diagram of the overall process, as shown in Fig. 3.48.

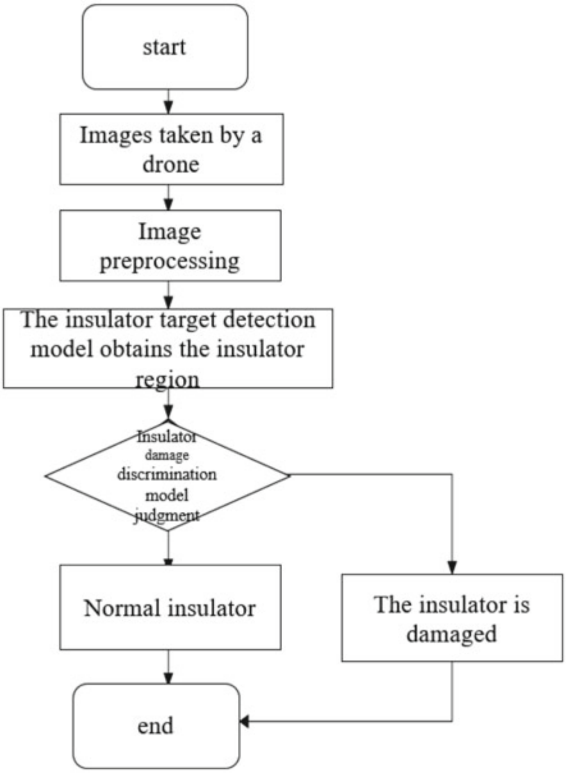


Fig. 3.48 Tower collapse identification process

1) Image segmentation algorithm

a) Feature encoder based

The self-encoder consists of two parts:

The encoder: this part can compress the input into a potential spatial representation, which can be represented by the encoding function $h = f(x)$.

The decoder: this part reconstructs the input from the potential spatial representation and can be represented by the decoding function $r = g(h)$ is represented.

Thus, the entire self-encoder can be described by the function $g(f(x)) = r$, where the output r is similar to the original input x.

Auto Encoder can be considered as a neural network with only one implicit layer, and the reconstruction of features is achieved by compression and reduction.

The input data serves as the features, and the encoder, from the input layer to the hidden layer, compresses the input into a latent space representation. The decoder, from the hidden layer to the output layer, reconstructs the input from the latent space representation. Both the input and output neurons of the autoencoder have the same number as the feature dimension. Training this autoencoder aims to make the output features as similar as possible to the input features. The autoencoder attempts to reproduce its original input, so during training, the output of the network should be the same as the input, i.e., $y = x$. Therefore, an autoencoder should have the same structure for its input and output. By training this network using training data, it learns the capability of $x \rightarrow h \rightarrow x$.

b) Regional proposal based

Regional proposal is a very common algorithm in the field of computer vision, especially in the field of target detection. The core idea is to detect the color space and similarity matrix, and based on these to detect the region to be detected. Then, based on the detection results, classification prediction can be performed.

c) Image segmentation applications

By using machine vision algorithms, the target subject can be identified, allowing for the separation of foreground and background. This enables image segmentation, where the target object in the image is distinguished from the background scene. As a result, background interference can be eliminated, and the focus can be solely on processing the objects of interest for recognition and detection.

2) Image retrieval algorithms

a) Image Library Retrieval Images

Image retrieval means to find images similar to the image to be matched from a pile of images, and this way is to find images by images. With the increasing and simultaneous updating of the image repository, an image retrieval database will gradually be formed between the images and the established information. The user can retrieve the required image from the existing image database according to the specific image.

b) Contrast image features

On the basis of the image retrieval library, users can retrieve the pictures of the nearest time period or a reference point when the UAV is taking aerial photographs of the inspection poles and towers according to the information in the background, so as to compare the captured pictures with the retrieved pictures in terms of similarity or feature great value, and use the comparison result as an evaluation parameter to provide anomaly detection algorithm for reference. If the evaluation parameter satisfies the set condition, the anomaly detection is not required and the recognition detection result is directly fed back . If the evaluation parameters satisfy the set conditions, then no anomaly detection is required and the recognition detection results are directly fed back.

3) Abnormal image detection algorithm

a) Abnormal image classification algorithm

We build the corresponding network model, train the image library in batches by deep learning network model, and output the weight file corresponding to the number of iterations after the training, on the basis of which the prediction is inferred according to the preset labeled classification, and in this way the classification information belonging to the abnormal image can be obtained.

b) Anomaly detection algorithm

In this case, the analysis is performed on the input using a residual network binary classification model. After obtaining the abnormal classification information, further anomaly detection is required to determine whether the tower has collapsed. Tower collapse is considered an anomaly, and if a collapsed tower is detected, an abnormality message is generated, and the corresponding results are sent back to the service interface.

(5) Insulator Loss Identification Program

1) Insulator Damage Overview

Insulators, as crucial insulation devices in power systems, play a vital role in providing mechanical support and preventing current from flowing to the ground in overhead transmission lines. As one of the components prone to faults, insulators are susceptible to damage and loss due to natural factors such as disasters, temperature, and humidity. These faults directly pose a threat to the transmission stability of the entire power system.

In recent years, with the rapid development of unmanned aerial vehicle (UAV) technology and computational image processing, the fault inspection of key electrical equipment in transmission lines based on aerial images has become a major direction to replace traditional manual line inspections.

In line with the development direction of UAV inspections, a detection method for insulator damage and loss has been proposed. This method takes advantage of the fixed number of insulators in each section of the transmission line. By preprocessing the insulator images, extracting their contours, and counting the number of insulators, a simple and efficient fault detection approach is applied to identify insulator faults. This method provides a reference for fault detection in transmission lines.

2) Algorithm ideas

First, images are captured by a UAV at fixed navigation points. The captured images are then subjected to image preprocessing to enhance their quality. Next, insulator localization is performed on the processed images to identify the target regions containing insulators. Finally, a fault analysis is conducted on the target regions to detect any damages or faults. The algorithmic flowchart is illustrated in Fig. 3.49.

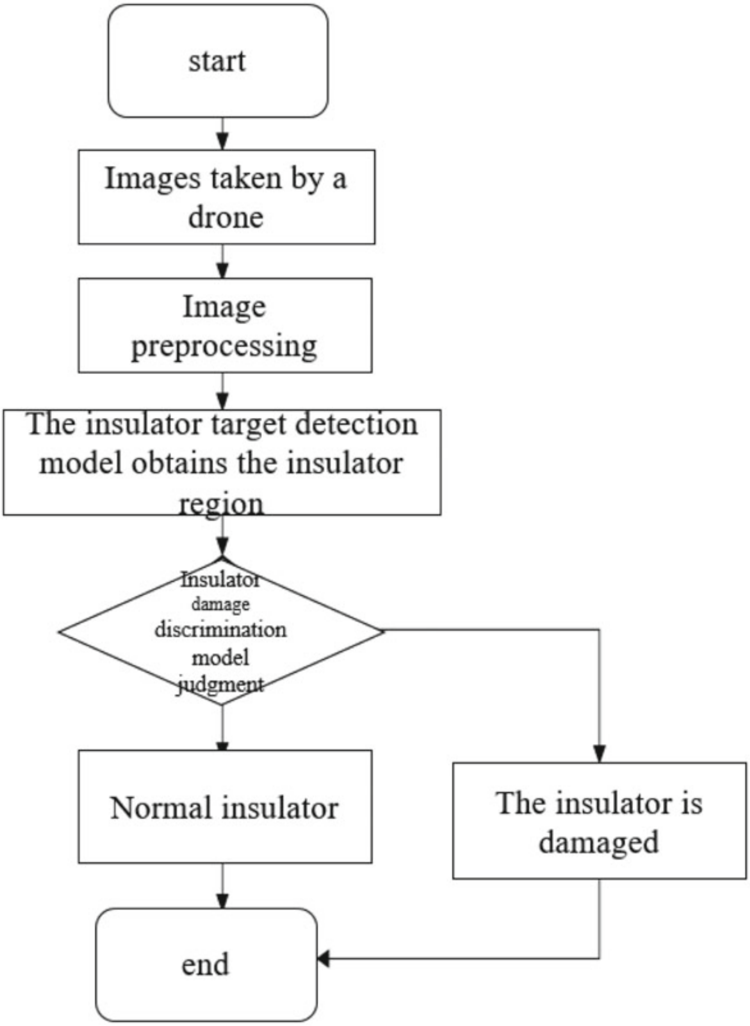


Fig. 3.49 Insulator loss identification process

3) Image target detection

a) One-stage based target detection

Yolo is a representative algorithm for one-stage object detection. This algorithm directly performs classification regression and bounding box regression using a feature extraction network. Compared to two-stage algorithms, it eliminates the need for the region proposal generation stage, resulting in faster detection speed. However, the detection accuracy may be slightly compromised. The Yolo series

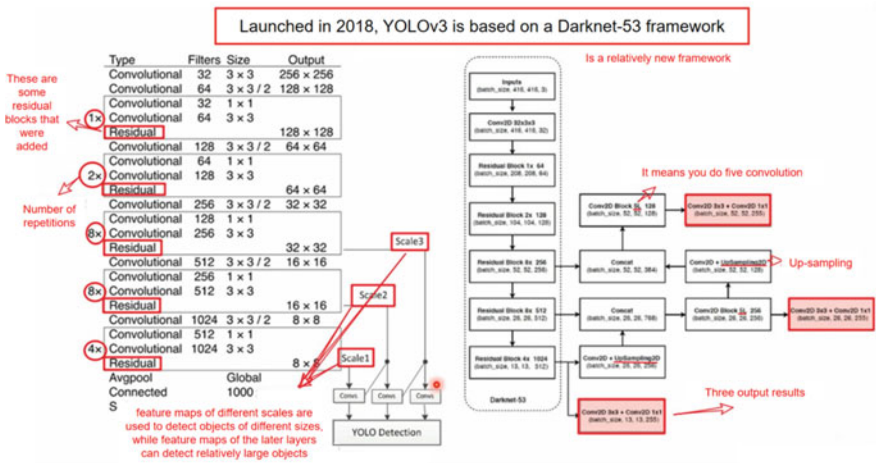


Fig. 3.50 A simple illustration of the structure of Yolov3

networks employ a feature pyramid structure that combines deep and shallow features, enriching the information extracted by the network and improving accuracy.

The simple structure of Yolov3 is illustrated in Fig. 3.50.

b) Two-stage based target detection

The second stage target detection algorithm is represented by Faster RCNN, which uses the feature extraction network Feature Map (Feature Map), uses on the Feature Map to generate ROI regions of interest, and then implements on the regions of interest Classification regression and bounding box regression. The ROI generation stage is more than that of the first-stage algorithm, so the recognition accuracy is higher than that of the first-stage algorithm. The detection accuracy is higher than that of the one-stage algorithm, but the detection speed is reduced.

The structure of the Faster RCNN model is shown in Fig. 3.51.

4) Anomaly detection algorithm

a) Image based classification model

After the object detection in the image, clear and high-resolution images are extracted based on the detection information and saved. These images are then divided into positive and negative samples, which are fed into the classification model for training.

The insulator damage classification model is constructed as shown in Fig. 3.52.

Insulator damage detection is shown in Fig. 3.53.

b) Based on image restoration model

Based on the object detection, the positional information of the detected targets is obtained. High-resolution target images are then extracted from the original image

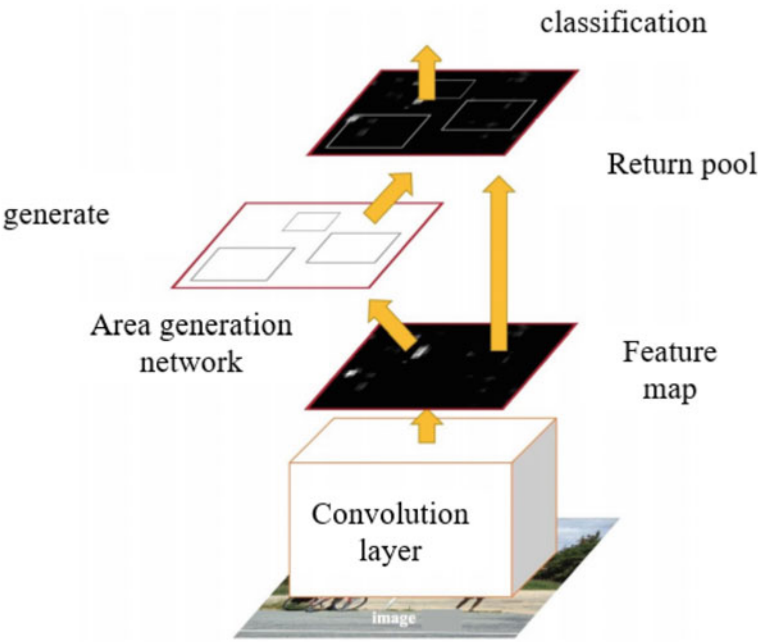


Fig. 3.51 Structure of faster RCNN model

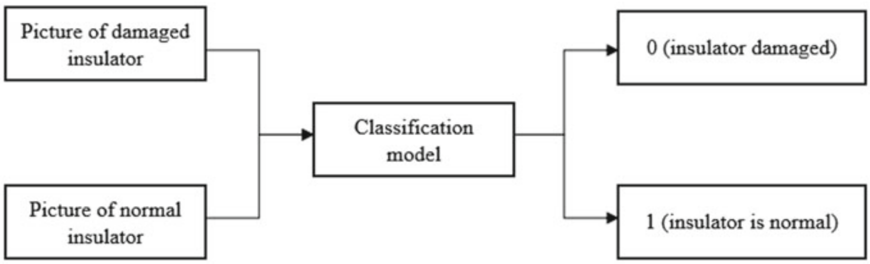


Fig. 3.52 Insulator damage classification model construction idea

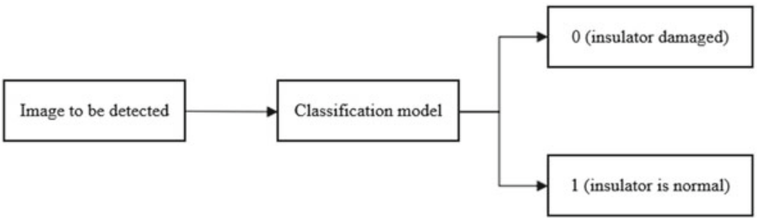


Fig. 3.53 Insulator damage classification model construction

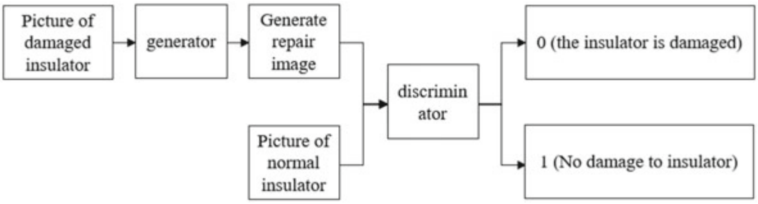


Fig. 3.54 Image restoration model construction

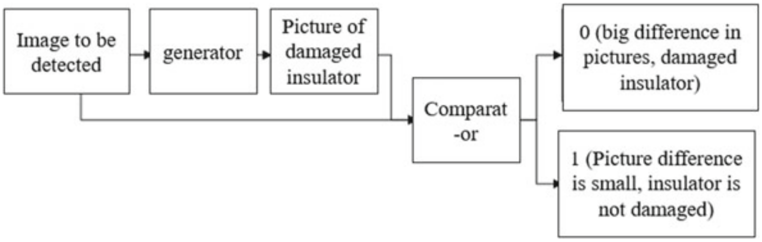


Fig. 3.55 Detecting damaged insulators

based on the position coordinates. These target images are fed into an image restoration model. When the input image represents a complete target, the model generates an image that closely resembles the original image. However, when the input image represents a damaged target, the model repairs the image and generates a completed image of the target, which may have significant differences from the original image. The degree of difference between the restored image and the original image is used to determine the presence of anomalies. The construction of the image restoration model is illustrated in Fig. 3.54.

Insulator damage detection is shown in Fig. 3.55.

(6) Tower head loss identification solution

The overall flow block diagram is shown in Fig. 3.56.

1) Image target detection

Based on the image database, supervised labeling of samples is performed to train a deep neural network model. This process enables the learning of the main target object, and as a result, the bounding box of the outermost perimeter of the object is obtained, thereby determining the position information of the target.

2) Image retrieval algorithms

During the inspection process, the tower top position information is manually determined or automatically located using a deep neural network model. This information is then stored in the corresponding database location, and the data is continuously recorded and updated. This enables easy retrieval and comparison of captured images

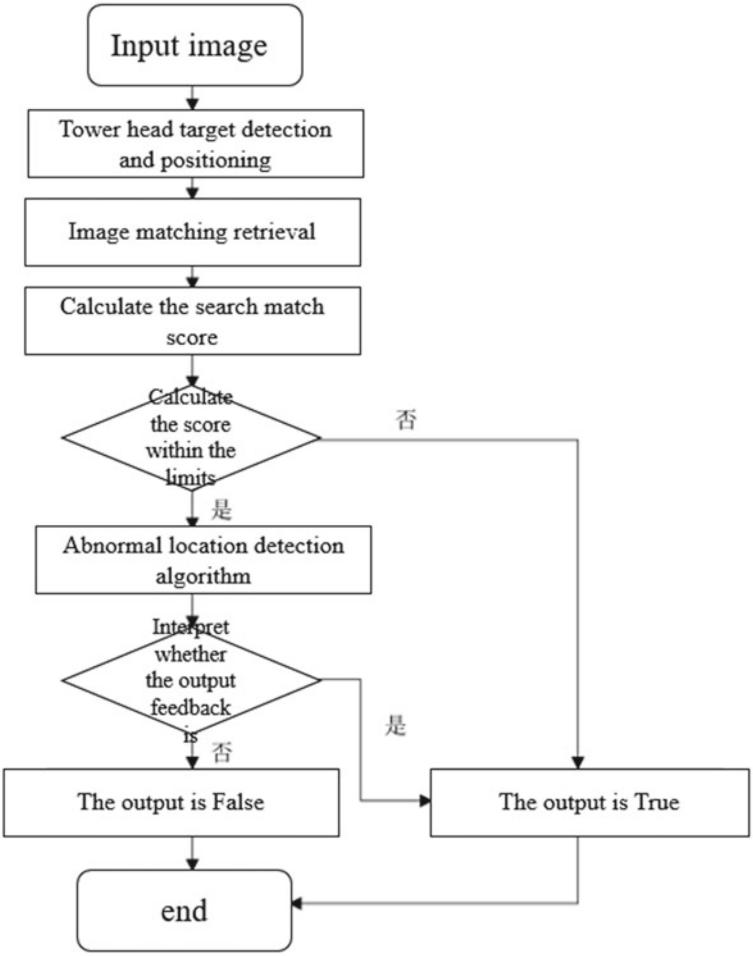


Fig. 3.56 Tower head loss identification process

in the database for subsequent analysis. If a significant difference is observed during the comparison, it is considered as a missing tower top component. If no significant difference is found, the input is analyzed using an anomaly detection algorithm for further analysis.

3) Abnormal site detection algorithm

The captured images are matched and compared with the feature and sample libraries stored in the database. Traditional computer vision techniques, such as calculating contour area and other relevant information, are used as criteria. By analyzing these criteria, it is determined whether there are any anomalies in the identified parts. The detection results are then generated based on this analysis.

(7) Foreign body suspension identification solution

1) Overview of foreign body suspension

Severe natural conditions directly contribute to incidents of insulator stringing, while human activities lead to frequent power line failures and foreign object intrusions. These incidents not only severely impact the safety of power grid operations but also pose a significant threat to the lives and property of people.

In recent years, short circuit and tripping incidents caused by foreign objects such as plastic films, kites, and bird nests on power transmission lines have become another common form of external damage. These incidents also pose a risk to the safety of pedestrians and vehicles under the power lines. Therefore, it is of great significance to promptly detect foreign objects and take appropriate measures.

The situations involving insulator stringing, foreign objects in the power grid, and accidents caused by large vehicles during construction are highly complex and widely distributed. They are characterized by their suddenness, randomness, and dispersal, posing significant challenges to preventive and control work.

Considering the drawbacks of low efficiency, poor reliability, and risks to personnel safety in manual inspections, unmanned aerial vehicle (UAV) line inspection robots are used to move along power transmission lines, inspecting and documenting potential hazards caused by foreign objects. These robots significantly improve the level of automation in inspections.

2) Testing ideas

a) Foreign object detection based on generative adversarial networks and deep residual neural networks:

The structure of the generative adversarial network based on the sample set expansion of the generative adversarial neural network is shown in Fig. 3.57.

The loss function in the training process of GAN (Generative Adversarial Network) is:

$$\min \max V(D, z = E_{x \sim \mathcal{O}_{\det(x)}}[\log D(x)] + E_{x \sim \mathcal{O}_x(x)}[1 - \log(1 - D(G(x)))] \tag{3.36}$$

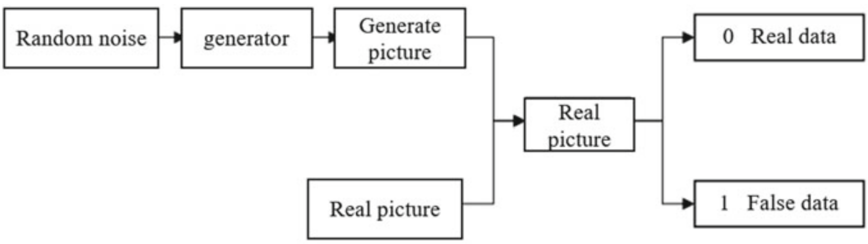


Fig. 3.57 Generating an adversarial network

Specific steps:

① m data samples are selected from noise distribution $p_{data}(x)$.
② m real data samples are also selected from the training data samples.
③ For the discriminant network D, the gradient change of its loss function $J^D(\theta^{(G)}, \theta^{(D)})$ with respect to parameter $\theta^{(D)}$ is:

$$\theta^{(2)} \leftarrow \theta^{(2)} + \nabla \frac{1}{m} \sum_{i=1}^{m} \left[\log D\left(x^{(i)}\right)\right] + \log\left[1 - \log\left(1 - D\left(G\left(z^{(i)}\right)\right)\right)\right] \quad (3.37)$$

④ For the generated network G, the gradient change of its loss function $J^G(\theta^{(D)}, \theta^{(G)})$ with respect to parameter $\theta^{(G)}$ is:

$$\theta^{(G)} \leftarrow \theta^{(G)} - \nabla \frac{1}{m} \sum\nolimits_{i=1}^{m} \left[\log\left(1 - D\left(G\left(z^{(i)}\right)\right)\right)\right] \quad (3.38)$$

⑤ Use the ReLU function as the activation function in the G network, use the tanh activation function in the last layer, and use the LeakyReLU as the activation function in the D network. The three activation function expressions are as follows:

$$ReLU(x) = \max(0, x) \quad (3.39)$$

$$\tanh(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}} \quad (3.40)$$

$$LeakyReLU(x) = \max(0.01x, x) \quad (3.41)$$

3) Residual neural network

Figure 3.58 shows the residual structure module.

The formula is as follows:

$$H(x) = \mathbb{F}(x) + x \quad (3.42)$$

$$x_k = x_0 + \sum_{i=1}^{K} F(x_i - 1) \quad (3.43)$$

$$\frac{\partial Lass}{\partial x_0} = \frac{\partial Loss}{\partial x_0}\left(1 + \frac{\partial}{\partial x_0} \sum_{i=1}^{K} F(x_{i-1})\right) \quad (3.44)$$

The overall foreign body detection process is shown in Fig. 3.59, which consists of three main parts: depth residual neural network for feature extraction of input images, regional recommendation network and region-based classifier of interest.

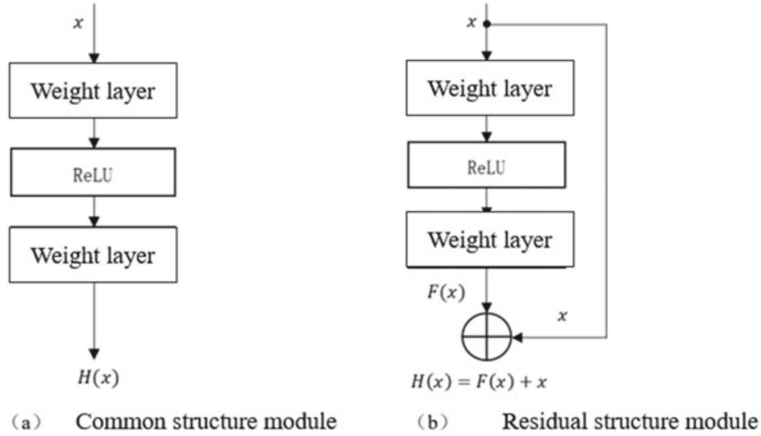


Fig. 3.58 Residual structure module

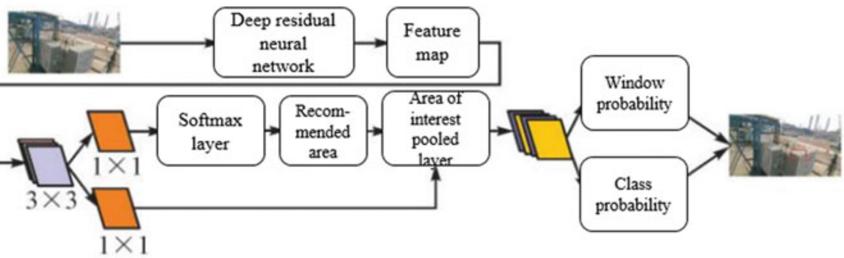


Fig. 3.59 Flowchart for detecting foreign bodies

4) Sample expansion

In addition to some sample pictures generated by generative adversarial network, some samples commonly used in digital image processing field are also added.

a) 2D rotation. Rotate the input picture at a random Angle.
b) Mirror image. It includes horizontal mirror image and vertical mirror image.
c) Dimensional transformation. Shrink the target image appropriately.
d) Image filtering. The method used is to add Gaussian filtering. Let the size of the picture be N × N, and establish the mapping of $f(i, j) \rightarrow g(x, y)$ as:

$$\begin{cases} g(x, y) = \frac{1}{|S|}\sum_{i,j\in S} w(i, j) f(i, j) \\ w(i, j) = Ae^{\frac{i^2+j^2}{2\sigma^2}} \end{cases} \quad (3.45)$$

3.4 Disaster-Related Social Information Collection Technology

3.4.1 Summarize

Research the intelligent collection, sharing and integration technology of social public emergency information related to disaster loss areas, support the integration of disaster information, and realise the integration with the government's emergency management data platform. By sharing information and resources with the emergency platforms of various regions and departments, the overall emergency plan can be linked with special plans, departmental plans, local plans and grassroots plans, vertically involving the national, provincial, municipal, county and grassroots levels, and horizontally involving natural disasters, accidents and calamities, public health and social security, truly realising a coordinated response between multiple departments and localities.

3.4.2 Disaster Damage Geographical Related Social Public Emergency Information Collection

Study the intelligent collection, sharing and integration technology of social and public emergency information related to disaster and loss regions, support the integration and integration of disaster and loss information, and realize the integration with the big data platform of government emergency management. The integrated framework of intelligent collection of public emergency information is shown in Fig. 3.60. Through information exchange and resource sharing with emergency platforms in various regions and departments, we have the ability to connect the overall emergency plan with special plans, departmental plans, local plans, and grassroots plans, vertically to the bottom, involving the country, province, city, county, and grassroots, horizontally to the edge, involving natural disasters, accident disasters, public health, and social security, truly achieving collaborative response among multiple departments and regions. The disaster loss regional information acquisition subsystem is different from the general acquisition, that is, it only pays attention to signal access and ignores the automatic processing of the signal, and should also have the preliminary information analysis and processing function. Take the image monitoring as an example: Both China and the United Kingdom have successfully developed the technology of using the image monitoring system to automatically monitor the fire conditions in large space and outdoor large places and urban areas. After a fire occurs, the system will automatically give an alarm signal and switch the scene image of the fire to the control center; Utilize the urban traffic image monitoring system to automatically analyze license plate numbers at key checkpoints in and out of the urban area, compare them with data in the database, take photos and give early warnings, and assist road management departments and public security organs in investigating cases; With the development of society, at present, more and more data sensor networks and image monitoring networks are organically integrated. When abnormal signals such as pressure, temperature, and concentration appear, the relevant images on site are immediately automatically sent to the control center for processing and confirmation by the on duty personnel; By using satellite remote sensing images, precipitation analysis, typhoon analysis, heavy fog monitoring, sand storm information, water regime monitoring, sea ice monitoring, vegetation change, dry early monitoring, forest fire information, snow information, Urban heat island, estuarine sediment, land desertification analysis, etc. can be realized. For the above analysis, some can be completed automatically, while others require more in-depth data processing and analysis. This project adopts the combination of peacetime and wartime. It intends to exchange the data distributed with the relevant departments of power emergency work through the data center, and then complete the data exchange and sharing system. The data exchange and warning data of professional government departments (such as the relevant data of government departments such as meteorology, land and forest) will access the data through the data access platform, and then, so as to provide effective technical solutions for the data integration of the system.

This project has realized the comprehensive access integration of meteorological data in disaster areas, as shown in Fig. 3.61, giving an example of intelligent collection and sharing integration of public emergency information, and the specific access data include:

(1) Real-time meteorological monitoring: visually display the real-time situation of meteorological information such as rainfall, temperature, wind speed, wind

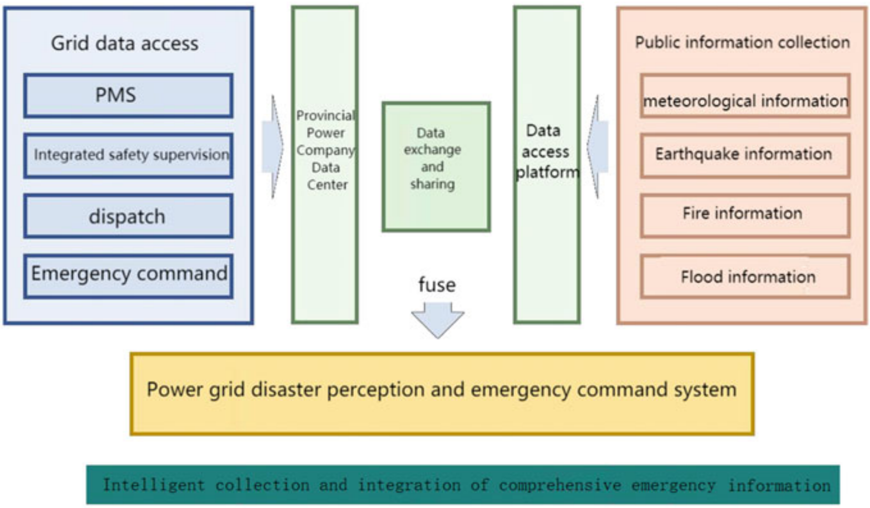


Fig. 3.60 Integrated framework diagram of intelligent collection of public emergency information

Fig. 3.61 Intelligent collection and sharing and integration technology of public emergency information

direction, air pressure and humidity in the disaster area, sort the list of meteorological elements, highlight the characteristic value (maximum value, minimum value and average value), and display the change process of meteorological elements in the way of process line. Graded display of meteorological stations, according to the day, month, year and other statistical cycle, the rainfall, style of meteorological stations bar chart statistical display;

(2) Weather forecast: obtain authoritative weather forecast information through the local meteorological station in the disaster area. Data of meteorological stations in disaster areas: typhoon forecast path, short, medium and long-term weather forecast documents, city and county weather forecast, prefecture-city numerical forecast, prefecture-city three-day forecast;

(3) Meteorological warning: based on public meteorological information, coupling the on-site situation of power grid equipment, real-time monitoring and display, and the warning notice can be automatically generated after analyzing abnormal weather. Realize the real-time early warning and early warning level forecast of disasters. The real-time warning function automatically notifies the number of abnormal meteorological data, meteorological disaster warning and other information.

3.4.3 Multi-source Social Public Emergency Information Collection

The main sources of social public emergency information include:

(1) Government departments. At present, a relatively complete system of government emergency response departments has been established in China, and the

central government and local governments undertake the tasks of emergency monitoring, early warning, decision-making and command. For example, after the occurrence of a disaster, the Ministry of Emergency Management shall collect and release disaster information; the sources of epidemic emergency information monitoring mainly include information collection of national, provincial, municipal and county epidemic prevention and control agencies.

(2) Private institutions. The emergency information stored by consulting agencies, community organizations, enterprises, schools, public welfare organizations, etc., is often targeted and each has its own characteristics, and the knowledge and experience of institutional experts is also a valuable wealth.
(3) The masses of the people. It can fill the omissions in the scope of information collection of government departments and non-governmental institutions, and play the role of collective prevention and control.
(4) The Internet. Social and public emergency information collection channels can be divided into institutional channels and non-institutional channels.

Institutional channels mainly include:

(1) Reporting channels. The national government sets up reporting channels to timely obtain emergency information through the reports of units and individuals.
(2) Reporting channel. After the occurrence of an emergency, each region and department shall report immediately, and continue to report the relevant situation in time.
(3) Document channels. Collect information through administrative channels. Non-institutional channels mainly include: (1) media channels, including newspapers, magazines, radio, television, the Internet and so on. Mass communication media has the characteristics of fast speed, wide range and great influence. (2) Oral channels. (3) Literature retrieval channel. (4) Communication and interaction channels, including regional, institutional communication, etc.

Emergency information collection methods include traditional information collection methods and modern information collection methods. Traditional information collection methods include personnel on duty, emergency investigation method, consultation method, etc., mainly manual collection. Modern information collection methods rely on advanced science and technology for collection, including docking with the collection system of special monitoring institutions for collection, public opinion information collection, etc. Other methods also include regional communication. Traditional collection methods consume a lot of human and financial resources, In addition, it cannot fully meet the requirements of various natural disasters. This project mainly focuses on modern collection methods.

The technology for collecting and utilizing social public emergency information includes (1) sensor technology. The number of information sources collected According to the processing and identification. Sensor technology can be used in emergency management to obtain the information of emergencies and affected objects. (2) 3S technology. 3S technology is invested in the method of geological disaster early warning and monitoring, first using field investigation of disaster zone, then extracting remote sensing information; using GIS to analyze disaster distribution, using GPS to monitor landslide activities; and finally using the collected information to evaluate and warn disasters. (3) Internet of Things technology. At present, the application scope of the Internet of Things in geological disaster emergency response is small, which can be collected for fixed-point information. The Internet of Things technology can be used to build a disaster monitoring platform, and realize the comprehensive monitoring of disaster information through model simulation calculation and quality management. (4) Radio-frequency identification technology. This is a kind of radio frequency information technology, the working principle is mainly to exchange data between readers and tags, identify time sequence and energy to communicate, which is widely used in libraries and archives. After the information archives encounter a flood or other crisis events, it can use the barrier-free reading function of radio frequency identification technology to quickly collect relevant information, locate the geographical location information of the archives, and save the archives in time. (5) Web-crawler technology. Web crawler is a program or script that automatically captures massive information on the Internet according to certain rules. It uses focused network crawlers or theme network crawlers to selectively crawl those pages related to the social public emergency information to meet the needs of emergency staff for information in the field of public emergency information.

With the increasing demand for public emergency information collection in the society, the information collection relying on advanced modern science and technology is becoming more and more dominant. Monitoring institutions, monitoring stations, monitoring terminals into, the collection of line information, tends to be professional, digital, intelligent. Although the traditional collection method has some disadvantages, it should not be ignored and is still an important auxiliary collection method. The emergency information collection mode gradually tends to the integration of emergency management, and the operation of emergency information collection, organization, reporting, early warning and so on are gradually integrated in one management system; establishing the special database of emergency information resources is another development trend, which is helpful to timely call relevant geographic information, disaster information, cases, etc. In terms of emergency information collection technology, 3S technology, Internet of Things, wireless communication, topic detection and tracking technology are widely used, making the multi-source social emergency information collection gradually mature.

3.4.4 Research on Technical Standards of Information Collection and Sharing Push Interface

Modern emergency management attaches great importance to the collection and management of emergency management information and resources. Only by mastering the relevant information and resources in advance, can we make the most scientific and effective decisions and actions when an emergency occurs. Power grid emergency needs panoramic state data, and the massive, heterogeneous and polymorphic data generated in the process of operation, maintenance and management of power grid have typical big data characteristics. Massive and complex data cannot effectively support the power emergency work. Electricity response needs to be formulated Emergency data collection technical specifications, standardized information collection, sharing and push interface, to provide strong data and information support for the power emergency disposal work.

By standardizing the power emergency data classification, data collection scope, data collection requirements, etc., the internal information data collection regulations and external information data collection regulations are formulated, as shown in Tables 3.9 and 3.10, to realize the information collection sharing and push.

Through the long-term in-depth cooperation between the Wisdom Research Institute and the Energy Industry Electricity Emergency Standardisation Committee, absorbing the experience of the standardisation work related to emergency business data, emergency plan data and emergency data collection in the energy industry, designing the data access interface of the emergency disaster data system and the interface standard for pushing data to the emergency data system, standardising the interface and data standard for emergency data collection from social public information in the electricity industry The development and submission for approval of a power industry standard, Technical Specification for Electricity Emergency Data Collection, through which the standard can be developed to unify the information collection and sharing interface. The standardised technical solutions for the active collection of public information by emergency systems and the interface technical solutions for the passive reception of pushed information were proposed, enabling the research results to be widely influenced in the emergency work of various units in the power industry.

Table 3.9 Internal data collection regulations table

Order number	Data name	Collection items	Update frequency
1	Power plant ledger data	Power plant name, affiliated unit, power plant type, installed capacity, responsible person, contact telephone number, address, longitude and latitude	Actual time
2	Power plant output data	Power plant name, installed capacity, unit output, adjustable output, fuel inventory	Actual time
3	Grid load data	Unit, load time, power load	1 h
4	Grid loss load data	Unit, statistical time, loss load	1 h
5	Substation ledger and other basic data	Name of substation, substation type, voltage level, subordinate unit, type of duty, number of main transformer stations, main transformer capacity, responsible person, contact number, address, longitude and latitude, operation status, and date of operation	Actual time
6	Substation shutdown (recovery) situation data	Name, voltage level, unit, outage time, recovery time and outage reason	1 h
7	Line ledger data	Line name, starting station, end station, design voltage level, line type, management unit, number of poles and towers, line length, cable length, overhead length, date of operation	Actual time
8	Line outage (recovery) situation data	Line name, voltage class, outage time, recovery time, outage cause, fault type, fault phenomenon description, reclosing situation	1 h
9	Starch ledger data	Line, tower number, tower type, tower material, elevation, tower height, gear distance, operation status, subordinate unit, loop number, tower terrain, production date	Actual time
10	Tower fault (recovery) condition data	Line, tower number, tower type, subordinate unit, fault time, recovery time, fault cause, and fault type	1 h
11	Ledger data of distribution platform area	Name of station area, subordinate line, subordinate unit, station area type, operation status, and operation time	Actual time

(continued)

Table 3.9 (continued)

Order number	Data name	Collection items	Update frequency
12	Distribution platform area stop (complex), power situation data	Name of station area, subordinate line, subordinate unit, station area type, power outage time, power recovery time, power failure reason	1 h
13	Power user ledger data	User name, user address, station area, power supply unit, voltage level, power supply type, user type, important user level, and user line	Actual time
14	Power user stop (complex), power situation data	User name, station area, power supply unit, power outage time, power recovery time, power outage reason, voltage level, user type, important user level	1 h
15	Material warehouse information and data	Warehouse name, subordinate unit, responsible person, contact person, contact information, warehouse level, creation time, warehouse address, longitude and latitude	Actual time
16	Materials (equipment), information and data	Material name, material category, material model, material quantity, measurement unit, subordinate warehouse, subordinate unit, rated inventory, minimum inventory, actual inventory, material description, factory date, effective date, storage time, and manufacturer	Actual time
17	Video surveillance information and data of key places	Site name, site category, and real-time video picture of the place	Actual time
18	Hydropower plant ledger data	Name of hydropower plant, affiliated unit, hydropower plant type, installed capacity, responsible person, contact telephone number, address, longitude and latitude	Actual time
19	Hydropower plant output data	Name of hydropower plant, installed capacity, unit output, adjustable output	Actual time

(continued)

Table 3.9 (continued)

Order number	Data name	Collection items	Update frequency
20	Reservoir ledger data	Name of reservoir, subordinate unit, responsible person, contact number, longitude and latitude, total reservoir capacity, flood limit level, maximum flow of the day, total number of holes, number of holes on the day	Actual time
21	Emergency response plan data	Name of the emergency plan, type of the emergency plan, content of the emergency plan, release unit, release time, version of the emergency plan, and report situation	In 1 year
22	Emergency organization data	Name of the emergency organization, subordinate unit, type of the emergency organization, contact information of the person in charge, responsible person, organization function, establishment time, organization members, contact information of members of the organization	Actual time
23	Emergency response team data	Team name, subordinate unit, team type, responsible person, contact information of responsible person, team location, establishment time, team expertise, team functions, and team members	Actual time
24	Emergency special vehicle data	Vehicle plate, vehicle type, subordinate unit, vehicle age, contact information of driver, vehicle status, vehicle location	Actual time
25	Warning situation information data	Event name, event type, early warning level, early warning scope, release time, release unit, early warning content, and early warning action	Actual time
26	Emergency response situation information and data	Event name, event type, response level, response unit, response time, response action content	Actual time
27	Emergency on-duty data	Event name, event type, duty classification, duty table, duty log, duty personnel, duty telephone, duty notice, duty requirements	1 Day
28	Emergency training data	Training name, training type, training lecturer, training content, training location, training time, training courseware, training object, training number, training plan, training purpose, training effect	In January

(continued)

Table 3.9 (continued)

Order number	Data name	Collection items	Update frequency
29	Emergency drill information and data	Exercise name, drill type, corresponding plan, exercise subject, exercise script, exercise personnel, exercise time, drill location, drill purpose, and drill effect	In January
30	Internal rule data	Rule data type, rule data name, rule data content, ownership unit of rule data, and effective time of rule data	In 1 year

Table 3.10 External data acquisition regulations table

Order number	Data name	Collection items	Update frequency
1	Meteorological information data	Weather forecast, real-time weather, weather phenomenon, meteorological disaster early warning information, typhoon disaster information, rain and snow freezing disaster information, radar map, satellite cloud map	1 h
2	Public opinion information and data	Public opinion event, public opinion news name, public opinion news content, news source, release date, release unit, keywords	2 h
3	Traffic information and data	Road information, road condition information, traffic video	1 h
4	Water situation information and data	Basin name, rainfall, flood disaster warning information, development of flood disaster and affected area	1 h
5	Geological disaster information and data	Rainfall, geological disaster early warning information, affected area	1 h
6	Seismic information and data	Earthquake location, magnitude, intensity, source depth, shock onset time, and affected area	Actual time
7	External rule data	Rule data type, rule data name, rule data content, ownership unit of rule data, and effective time of rule data	In 1 year

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Chapter 4
Grid Disaster Information Fusion and Integrated Prediction Technology

4.1 Current Status of Disaster Loss Modeling Research

(1) In terms of earthquake disaster loss modeling research, the main international research lies in disaster loss risk assessment, which studies the risk of damage outcomes and their impacts with an indicator system model. From the 1970s to the present, various governments have made great progress in disaster risk research and application, while many scholars have conducted in-depth research on disaster risk. A series of global and regional comprehensive disaster risk assessment programs, such as the Disaster Risk Indicator Initiative (DRI), the Multi-Period Indicator Program (HotsPot), and the American Programme (AP), have been carried out internationally for the first time, and corresponding results have been achieved. In the 1990s, the Scientific and Technical Committee of the United Nations International Decade for Disaster Reduction approved the Global Earthquake Hazards Assessment Program to reduce earthquake disaster losses, and the United States, France, and several other countries conducted risk assessment and risk management studies for different spatial scale regions and domains such as entire countries, regions, states, provinces, and societies. In 2005, the Organization for Economic Cooperation and Development (OECD), in order to reduce earthquake losses, proposed the development of a global risk assessment, using the Global Earthquake Model (GEM) as the authoritative standard for earthquake hazards and risks. In 1985, the Applied Technology Council (ATC) completed and published the ATC-13 (Vulnerability Inventory Method) report, which proposed a set of expert experience-based seismic hazard assessment (ATC-13) methods. In 1997, FEMA and NIBS developed a GIS-based seismic hazard damage assessment software that included seismic hazard, structural vulnerability, and economic and social vulnerability (HAZUS). In 1999, HAZUS99 was further improved, and in 2004, the ability to estimate losses from floods and hurricanes was added, resulting in a multi-hazard disaster loss assessment software (HAZUS-MH) that can quickly and accurately assess

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human casualties, building (structure) damage conditions, economic losses, and secondary hazards caused by earthquakes. At present, HAZUS-MH has been widely used. In 1951, Kawasumi showed that there was a linear correlation between the magnitude and intensity of earthquakes, and in 1970, Lomnitz explored the relationship between earthquake casualties and the time of the earthquake based on the data of the Chilean earthquake. In 1976, Westgate and O'Keefe, geographers at the University of Bradford, UK, were the first to explore the correlation between vulnerability and population and economy. In 1983, Ohta, et al. identified a mathematical model of the number of earthquake fatalities and the amount of building damage, and in 1983, Rachel Davidson proposed the first earthquake disaster risk index (EDRI) to quantify the level of earthquake risk among cities and to compare the relative severity of potential earthquake hazards and the contribution of different factors to earthquake risk. The first earthquake damage assessment was conducted after the 1989 Datong earthquake in Shanxi Province, and the first earthquake damage analysis of the Tangshan earthquake was conducted by Liu Chuoxian in 1986. Huang Chongfu and Shi Peijun established a mathematical model for urban seismic hazard risk evaluation using fuzzy set method, and gave a model of earthquake incubation environment, a model of earthquake intensity decay, and a formula for calculating urban hazard risk. Fu Zhengxiang and Li Ge Ping analyzed the relationship between the number of earthquake fatalities and the magnitude, seismic intensity, and damage state of houses. Yin Zhiqian et al. proposed the relationship between building vulnerability and seismic hazard loss, and at the same time gave a dynamic building damage matrix based on time change, and established the link between future building damage matrix and current existing building damage. The seismic damage matrices for single and group buildings were established by Sun, Baotao et al. Jane You et al. applied the information diffusion method to analyze the seismic hazard risk in the western region from two aspects: annual maximum magnitude and annual frequency of seismic hazard at all levels, respectively, and the overall feature is that the smaller the seismic hazard level is, the larger the occurrence probability value is. Some other scholars have carried out the work of seismic hazard damage assessment by combining the secondary development of RS and GIS with a series of software. For power grids, researchers elaborated the mechanism and analysis methods of the impact of seismic hazard on power grids from the perspective of equipment vulnerability or resilience by calculating the ground shaking intensity at the location of power grid equipment. Shouxiang Wang studied the damage probability of towers under seismic hazards and assessed the resilience of distribution networks; Tianhua Li studied the vulnerability of grid nodes under seismic effects using a variable fuzzy clustering model; Han Wang conducted a study on the seismic impact of electrical interconnection systems and assessed the resilience of electrical interconnection systems under earthquakes. Among the existing studies, the research on electrical system vulnerability or toughness helps to identify the risk of the grid system, which has a certain effect on improving the resilience of the grid system from the perspective of precautionary measures, and it is difficult to accurately predict the occurrence of earthquakes with today's technical means, while the completion of the disaster damage prediction in the first time after the earthquake is beneficial for the emergency commanders to make timely decisions and deployments, and to carry out emergency repair for the possible key loss equipment. This is of great significance for post-disaster emergency response and recovery. Many scholars at home and abroad have conducted a series of studies on earthquake damage prediction from the perspective of theoretical and mathematical models, but the overall research on earthquake damage assessment and prediction of power grid equipment is still in the initial stage, and the mechanism and assessment methods need to be further explored.

(2) In terms of typhoon disaster loss model research, although in recent years, China has attached importance to the assessment of typhoon disaster risk and organized experts, scholars and research institutions to find solutions, a unified and comprehensive assessment method has not yet been formed and is still at the stage of mapping and discussion. Early studies on typhoon disaster risk assessment, early warning and damage assessment were mainly based on historical statistics, using mathematical statistics and data mining methods. Such methods select assessment factors from disaster-causing factors, disaster-bearing bodies, and disaster-inducing environments, and use historical data to train the selected models, which are then used for disaster assessment. In terms of risk assessment, a more representative one using mathematical statistical methods is the risk assessment of typhoon disasters in Guangdong and Zhejiang by Ding Yan, Peijun Shi, and Yafei Zhou, respectively. Mathematical statistics and data mining methods require a large amount of accurate historical typhoon disaster data as support, while the early data have certain defects due to many reasons such as backward technology, and even the monitoring data in recent years have been questioned, which seriously affects the accuracy of the assessment; typhoon disaster-causing principles are complex, so the disaster assessment also requires a high level of modeling methods, as far as the modeling methods used by scholars are concerned The results of the disaster assessment are simple, but with only a set of overall data of the disaster, such as the amount of economic loss, the number of casualties, etc., which cannot reflect the spatial and temporal distribution of the disaster. With the popularization of GIS application, its powerful spatial analysis and mapping capabilities, fine grid processing and visualization results display, more and more scholars at home and abroad apply it in the study of typhoon disasters. With the help of GIS tools, these methods are combined with system tools to input hazard system data such as hazard-causing factor hazard, disaster-inducing environment sensitivity, and vulnerability of disaster-bearing bodies, and to use GIS spatial up-and-down superposition operations to map out the regional risk and disaster distribution in the form of heat maps. GIS software is also suitable for risk assessment of typhoon hazards by overlaying typhoon wind and rain intensity and frequency with environmental sensitivity and vulnerability of disaster-bearing bodies in GIS to obtain risk distribution maps. The GIS-based analysis method has also replaced the

mathematical and statistical methods as the mainstream of current research. However, the problem of such methods is that the rationality of the simple GIS spatial overlay method is doubtful, and the accuracy and stability of the research results have not been tested by cases. In terms of disaster assessment method applications, although China's Central Weather Bureau and Shanghai Typhoon Institute also have advanced typhoon information systems, these systems tend to focus on weather forecasting and the impact of weather factors, and do not assess disasters or generate countermeasure recommendations. The IMASH intelligent integrated dynamic information management tool in the United States, which can provide comprehensive data and emergency response plans for relevant hurricane hazards, can be considered as a disaster assessment system in the true sense. Scholars in China have also done a lot of research and accumulated many results. For example, with Zhejiang, Hainan, Anhui, Taizhou and other regions as research objects, they are making attempts to apply wind hazard assessment methods in practice. However, in typhoon risk planning and disaster assessment, research results in Guangdong Province are relatively scarce. The budget models studied by many scholars in the past are almost all based on a single linear regression model. Whereas the influence factors of natural disasters (typhoon intensity factors, geographic environment and socio-economic conditions) and disaster situations have highly uncertain non-linear relationships, traditional mathematical models can hardly solve such problems satisfactorily. After the accumulation of research and improvement of methods, the current disaster loss prediction methods can be broadly divided into two categories: one is to construct nonlinear prediction model methods (such as neural network, SVM, etc.) for disaster loss prediction; and the other is to make comprehensive use of geographic information system (GIS), remote sensing (RS), numerical simulation and other technologies for disaster loss prediction. In the power grid, typhoon-induced transmission tower collapse and wind deflection discharge have attracted a lot of attention from researchers. Regarding the analysis of downed towers of transmission towers, the finite element method is generally used for structural modeling Kitipornchai used the beam-column model to derive the geometric nonlinear stiffness matrix with only one unit representing one rod, used the concept of concentrated plasticity analysis and yield surface for material nonlinearity, considered the nonlinear properties of shear bolts, and analyzed the nonlinear morphology of transmission towers under static forces. The curve of displacement of the top node of the tower versus the applied load is used to determine the damage of the transmission tower. Jinwen Wang established a structural finite element model and finite element model modification for a towering transmission tower structure, proposed a dynamic analysis method for the tower-line coupled system under the action of ordinary near-ground wind loads, a fatigue life estimation method for high circumferential crack sprouting caused by long-term wind vibration, studied the mechanical model for downstrike storm loads and the method of simulation, a plastic fatigue damage model for spatial steel structure rods, and considered the fatigue damage model to simulate the transmission tower structure under strong wind.Irvine used two methods, considering transmission line stiffness and not considering transmission line stiffness, to build a continuum model of the structure and analyze the dynamic characteristics of the structural model of the cable tower structure under wind loads. Tsujimoto et al. proposed a multi-degree-of-freedom spring-mass calculation model of the conductor, and calculated the wind deflection response of a single-span conductor and compared it with the measured results of the line. The current code in China uses a single pendulum model to calculate the wind deflection of the conductor by the static method. Some researchers have established the static and dynamic models of the conductor respectively, simulated and compared the dynamic characteristics of different conductors in different wind speeds, and proposed that with the increase of the file distance, the focus of suppressing the asynchronous wind deflection protection is the horizontal interphase, and the analysis shows that the contribution of multi-order vibration type must be considered in the calculation of dynamic wind deflection of the conductor, and the current transmission line design does not consider the value of wind deflection pulsation as the main cause of wind deflection flashing under high wind. The failure to consider the wind deflection pulsation value in current transmission line design is one of the main causes of wind deflection flashover under high wind. So far, based on the development of meteorological science, typhoon paths and wind speeds have been predicted by scholars, which lays the foundation for the scientific, accurate and quantitative development of typhoon damage prediction for power grid equipment. Today's research focuses on the impact of typhoons on lines and towers, as well as the impact of secondary typhoon hazards, such as high winds and strong convection and other extreme weather, on power grid equipment, and the corresponding damage mechanisms and assessment models need to be studied in depth.

(3) In terms of flooding, developed countries started to carry out relevant flood damage calculation work at a very early stage. Developed countries such as the U.S., Japan, and France have carried out meticulous and comprehensive research and survey projects for the evaluation of flood losses. In developed countries and regions, flood insurance is widely purchased, and statistical information such as socio-economic information and information on the vulnerability of various industrial assets necessary for flood damage assessment is more complete, which provides data support for timely and efficient evaluation of flood damage. Since the 1960s, the U.S. government has carried out extensive research on floodplain management and developed a comprehensive approach to flood damage assessment. In 1978, based on the simulation model developed by his predecessors, Professor Lee in the U.S. solved a new curve for many different types of properties, which is called the average curve. This curve was widely used in the calculation of flood damage. In the 1990s, Jonge used GIS to study the evaluation and calculation methods of flood losses; in the same period, proferi used Landsat remote sensing data to carry out flood damage assessment; Srikantha Herath in Japan used geographic information technology and remote sensing technology combined with distributed hydrological models to carry out flood inundation calculation and related damage The insurance companies in

Munich, the second largest city in Germany, firstly researched a set of flood damage assessment model that can be used in the whole country according to the willingness to insure, which provides data support for insurance payouts in flood disasters and provides new ideas for the development of the insurance industry. Compared with the perfection of foreign flood evaluation system, the research of flood damage assessment tools in China started later, and along with the global scientific research on flood prevention and mitigation, the results of flood damage calculation gradually appeared in China until the 1980s. In the loss assessment of flash floods, Huang Wei, Nie Hua, Zhang Jieyun and others have carried out many mapping research works. For example, in 2005, Huang Wei et al. systematically analyzed and organized the existing flood disaster investigation and assessment methods at home and abroad, and explored the method of using the frequency method to assess the benefits of flash flood disaster control. In 2006, Nie Hua et al. used the pilot flash flood control carried out in 2002 in Washing Horse Township, Hongjiang City, Hunan Province, as an example, and elaborated from two parts: disaster loss assessment and study of prevention and control benefits. In 2000, Feng Wei et al. et al. explored the losses in urban flooding, summarized the loss laws, and established a flood disaster loss simulation and early warning model; Wang Waxchun et al. studied the typical flood disasters in Taihu Lake area by combining socio-economic information analysis, and obtained a flood disaster prediction and early warning model and a water body overflow range model for the area; in 2012, Zhang Jieyun et al. used remote sensing technology combined with information grid technology to establish a model for damage assessment of flood disasters, taking into full consideration the uneven distribution of socio-economic data. In terms of power grid, Alexis Kwasinski et al. conducted a study on the reliability of power system operation in the Garner region of the U.S. By collecting meteorological data under the local floods caused by heavy rainfall and the damage data of major power equipment such as transformers and insulators, and based on BP neural network theory, they analyzed the impact of rainfall intensity on major power equipment such as transformers and insulators. Xin Miao et al. collected meteorological, geographic and electric power data under 18 floods in Wilmington area from 1985 to 2005 for the safe operation of electric power system, and based on statistical analysis theory, they established a linear Hybrid model, which also uses the feature quantity extraction method to extract feature quantities from meteorological factors, geographic factors and electric power factors to establish a model of the impact of flooding on electric power equipment and to test the fit of the model. They also established a probability model of rainfall intensity, estimating the probability of insulator flashover and the probability of transformer failure, and calculating the probability of transmission and substation line outage failure under flooding, and based on this, they completed the power system load cutting. On this basis, the calculation of power system load shedding and economic loss evaluation of power outage are completed. For the prediction of grid damage in flooding, a comprehensive judgment should be given with the local geological and hydrological information of the equipment. In recent years, with the continuous development of fluid mechanics, seepage mechanics and CFD technology, the research results of heavy rainfall and flooding disaster loss have emerged. In addition, the 7–20 extreme rainstorm disaster in Henan Province has also sounded an alarm to emergency responders that the mechanism of damage to different power grid equipment by heavy rainfall and flooding varies, and the existing damage assessment methods are subjective and quantitative and accurate evaluation methods need to be further explored.

4.2 Typical Disaster Event Loss Model

4.2.1 Earthquake Disaster Damage Model

(1) Ground vibration parameters and their attenuation relations

PGA is the first and most widely used strength indicator in most countries, but PGA mainly reflects the amplitude characteristics of the local high frequency components of seismic waves, and the high frequency components do not play a key role in the seismic response of the structure. PGV is another important ground-vibration strength index, which is used in Japanese seismic design codes to guide the seismic design of engineering structures in correspondence with the seismic intensity:

$$PGA = \max|a(t)| \tag{4.1}$$

$$PGV = \max|v(t)| \tag{4.2}$$

$$PGD = \max|d(t)| \tag{4.3}$$

where $a(t)$ is the acceleration of ground shaking at time t; $v(t)$ is the velocity of the ground shaking at time t; $d(t)$ is the displacement of ground shaking at time t.

The ground shaking attenuation relationship is a functional relationship that characterizes the variation of ground shaking parameters with magnitude, distance, site and other factors. Common ground shaking parameters in engineering include seismic intensity, acceleration, velocity, displacement peak, as well as ground shaking response spectrum, ground shaking holding time and ground shaking envelope function, etc., while the more common name for the attenuation relationship in the international arena is the ground shaking prediction equation.

The attenuation relationship describes the different effects of earthquakes on sites under different conditions, and has a wide range of uses in seismic zoning, seismic safety evaluation of engineering sites and earthquake damage prediction, and is of great research importance in engineering. Both seismic zoning and small-area zoning require the use of attenuation relations to determine ground-motion input parameters. Strong ground shaking attenuation relations can roughly determine the impact of engineering sites during earthquakes based on the characterized earthquake source, propagation path and local site conditions, and therefore have an important role in seismic risk assessment.

The earliest documented empirical decay relationship was proposed by Esteva and Rosenblueth in 1964:

$$a = ce^{\alpha M} R^{-\beta} \tag{4.4}$$

where a is the peak acceleration of ground shaking in cm/s^2. The two used data from the western U.S. ground shaking record to determine the coefficients in the attenuation relationship: $c = 2000$, $\alpha = 0.8$, and $\beta = 2$.

Due to the historical conditions, the initial attenuation relationships were often very simple and were based on a relatively small number of observation records. With the gradual accumulation of ground-motion records and the gradual improvement of observation means, attenuation relations that take into account more complex conditions began to appear.

Campbell C selected 229 horizontal acceleration records from 27 earthquakes worldwide and regressed the peak accelerations using a weighted least squares method. The peak acceleration was regressed using the weighted least squares method to obtain the decay relationship.

$$\ln Y = -4.1414 + 0.868M - 1.09 \ln\left(D + 0.0606e^{0.7M}\right) \tag{4.5}$$

Y is the peak acceleration, M is the magnitude, and D is the epicenter distance.

The records he selected do not impose restrictions on seismic magnitude, fault type, or geological conditions at the record site, but they do provide a more detailed classification of the previous simple method of site delineation, i.e., bedrock and overlying layers, respectively. The importance and necessity of this classification idea is pointed out in the subsequent comparison in his paper.

In contrast, J.R. Huo selected 329 acceleration records from 41 earthquakes in the western United States and mixed them with single and multiple random variable regressions of peak and absolute acceleration response spectra without distinguishing between bedrock and upper layers:

$$\lg Y = -0.935 + 1.24M - 0.046M^2 - 1.9041\text{g}\left(D + 0.3268e^{0.6125M}\right) \tag{4.6}$$

In addition, they weighted the information to ensure that the sum of the weight coefficients was uniformly distributed in the M-R plane, and the magnitude and distance were graded.

In general, the attenuation relationship is the variation of peak ground acceleration with seismic intensity and epicenter distance, mostly obtained by fitting. Yu Yanxiang and Xiao Liang et al. gave the Seismic ground motion parameters zonation map of China (GB18306-2015) in the research results from the eastern strong seismic region:

When the earthquake magnitude $M < 6.5$:

$$\ln Y = A_1(T) + B_1(T)M - C(T)\ln(R + D\exp(E \times M)) + \varepsilon \tag{4.7}$$

where Y represents the peak ground acceleration, R is the epicenter distance, M is the magnitude, A_1, B_1 A_2, B_2, C, D, and E are the regression coefficients, and ε is the standard deviation.

(2) Ground shaking of power grid equipment causes disaster mechanism

The probability of different degrees of damage to the grid equipment can be described by the cumulative log-normal distribution function as:

$$p_k^{\mathrm{DMG}}(\mathrm{PGA}) = \int_0^{\mathrm{PGA}} \frac{1}{\sqrt{2\pi}\xi_k S}\exp\left(-\frac{1}{2}\cdot\frac{\ln s - \lambda_k}{\xi_k}\right)\mathrm{d}s \tag{4.8}$$

In the formula, k = 1, 2, 3, 4, respectively, indicates four damage states: minor damage, moderate damage, server damage, and complete damage. p_k^{DMG} is the probability of the equipment reaching the kth damage state, which is related to the intensity of ground shaking in its area; λ_k and ξ_k are the log mean and standard deviation of the vulnerability curve of the equipment in the kth limit damage state, respectively. This formula is a common formula for analyzing the damage degree of building facilities, transportation systems, lifeline systems, etc. under earthquakes, and is widely used worldwide for calculating the damage rate of facilities under earthquake hazards.

For some of the grid equipment, the damage curves are shown in Figs. 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, and the peak ground acceleration decay relationship in the eastern part of China is shown in Fig. 4.13.

The combined percentage of damage to grid equipment in a single earthquake can be expressed as:

$$p^{\mathrm{DMG}} = \sum_{k=1}^{4} \omega_k Z_k p_k^{\mathrm{DMG}}(\mathrm{PGA}) \tag{4.9}$$

where

$$\omega_k = \frac{p_k^{\mathrm{DMG}}(\mathrm{PGA})}{\sum_1^4 p_k^{\mathrm{DMG}}(\mathrm{PGA})} \tag{4.10}$$

where ω_k is the weight coefficient of grid equipment in the kth extreme damage state, which is dynamically set according to the size of the regional PGA in proportion to the vulnerability curve; Z_k is the percentage of damaged grid equipment corresponding to the kth extreme damage state. The proportions of light, moderate, high and complete damage of the equipment are 4%, 12%, 50% and 80% respectively, i.e. $Z_1 = 4\%$, $Z_2 = 12\%$, $Z_3 = 50\%$ and $Z_4 = 80\%$. As an example, the percentage of damaged

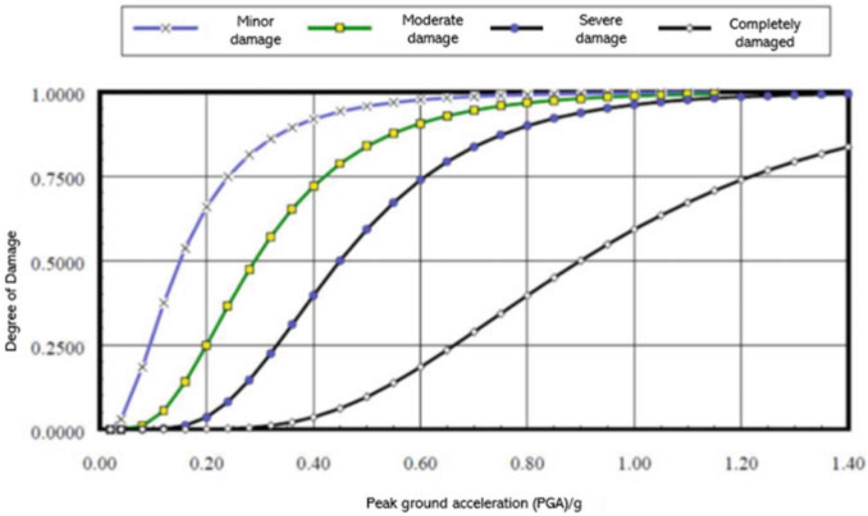


Fig. 4.1 Damage curves for low-voltage substations with seismic-resistant components

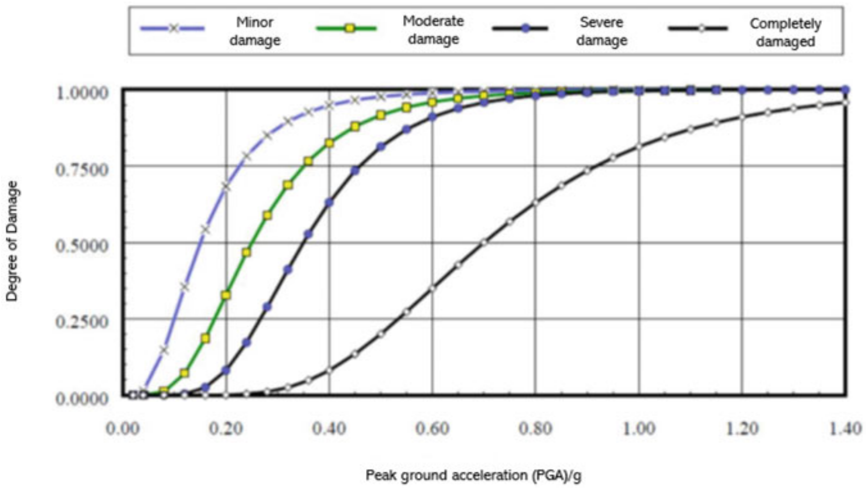


Fig. 4.2 Damage curves for medium voltage substations with seismic-resistant components

distribution lines is shown in the figure. As seen in Fig. 4.14, the proportion of faults in distribution lines increases as the magnitude increases or the epicenter distance decreases, and when the magnitude is >6.5, the proportion of damaged distribution lines increases sharply regardless of the epicenter distance.

The research in this section shows that earthquake damage analysis can be used to quantitatively describe the degree of damage to grid equipment under a certain

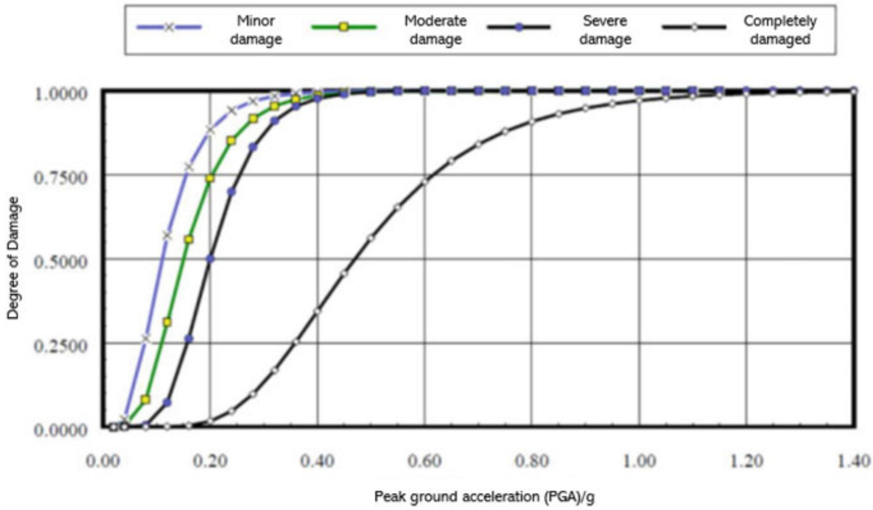


Fig. 4.3 Damage curves of high-voltage substations with seismic-resistant components

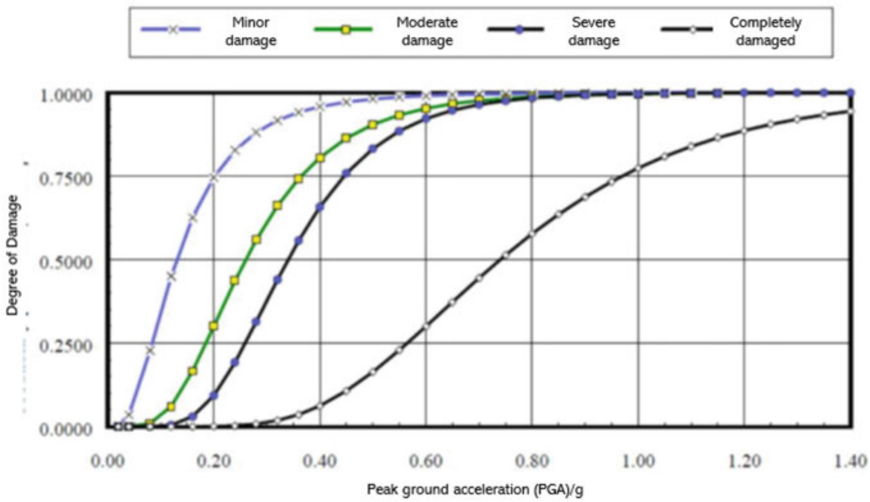


Fig. 4.4 Damage curves of low-voltage substations without seismic elements

intensity earthquake by combining the calculation of peak ground acceleration (PGA) with a loss probability function to provide assistance to emergency commanders.

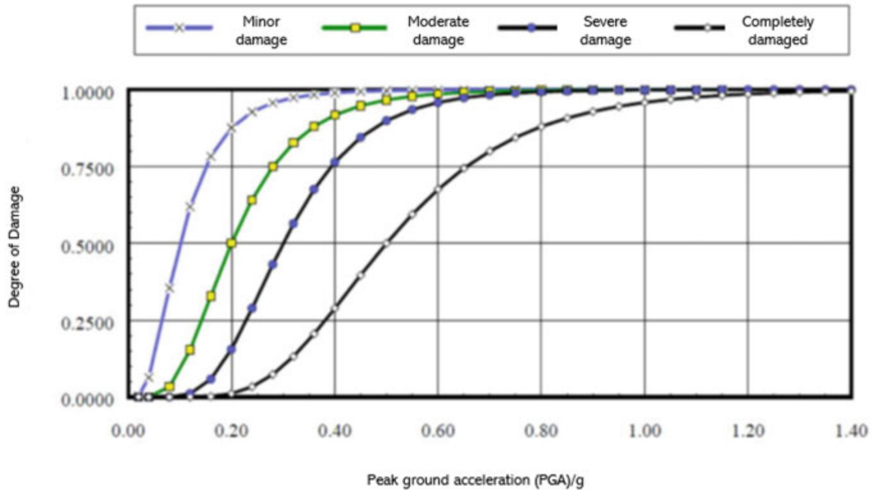


Fig. 4.5 Damage curves of medium voltage substations without seismic elements

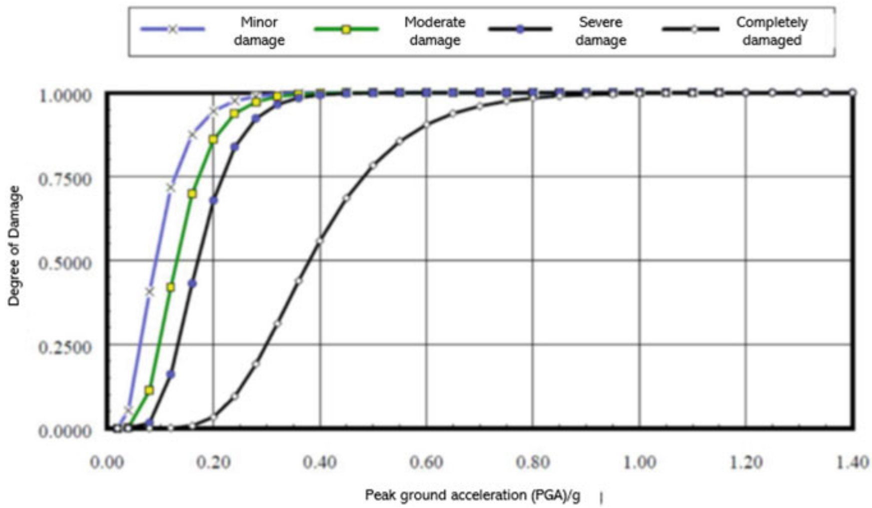


Fig. 4.6 Damage curves of high-voltage substations without seismic elements

4.2.2 Landslide Disaster Damage Model

The common theory of slope stability analysis in engineering is the limit equilibrium method based on the strength criterion of Moore and Coulomb. The limit equilibrium method has two basic characteristics. Firstly, it only considers the mechanical equilibrium condition and the Mohr–Coulomb law. The second is that by introducing some

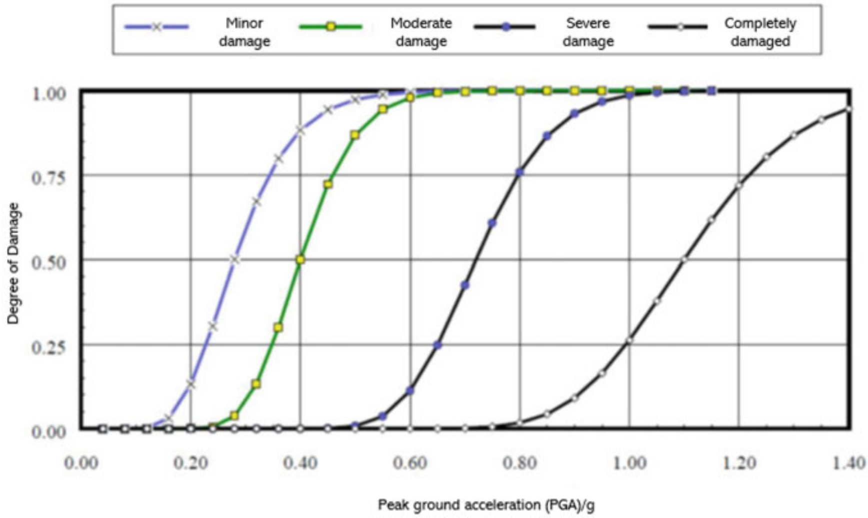


Fig. 4.7 Damage curves of distribution lines with seismic-resistant components

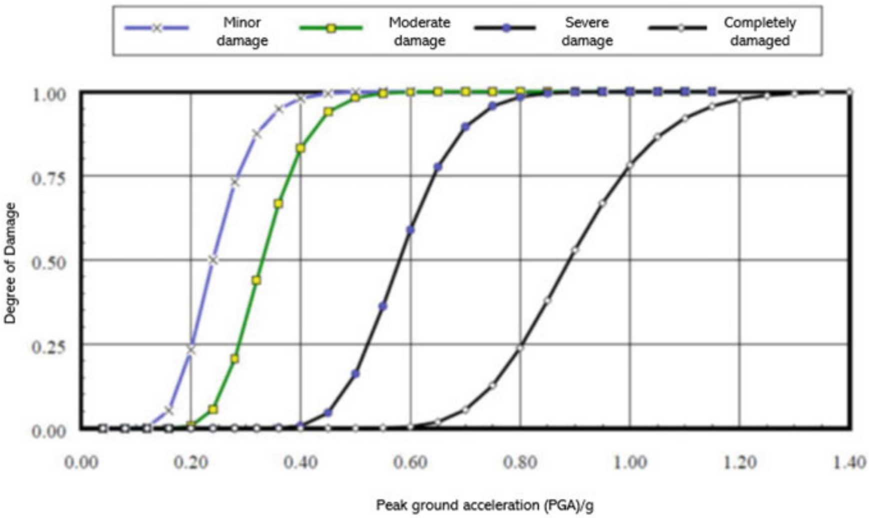


Fig. 4.8 Damage curves of distribution lines without seismic elements

simplifying assumptions, the problem becomes static and solvable. The expressions are:

$$\tau_f = c' + \sigma' \tan\phi' = c' + (\sigma - u)\tan\phi' \tag{4.11}$$

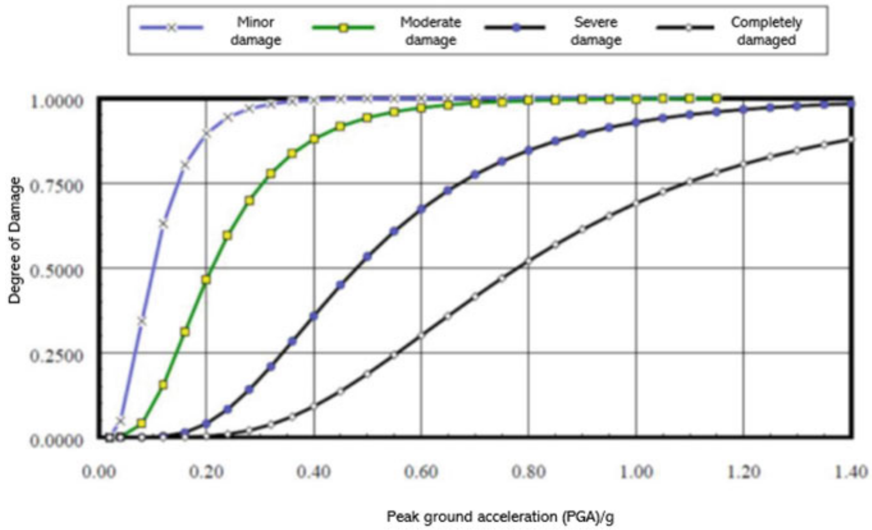


Fig. 4.9 Damage curves for small power generation facilities with fixed components

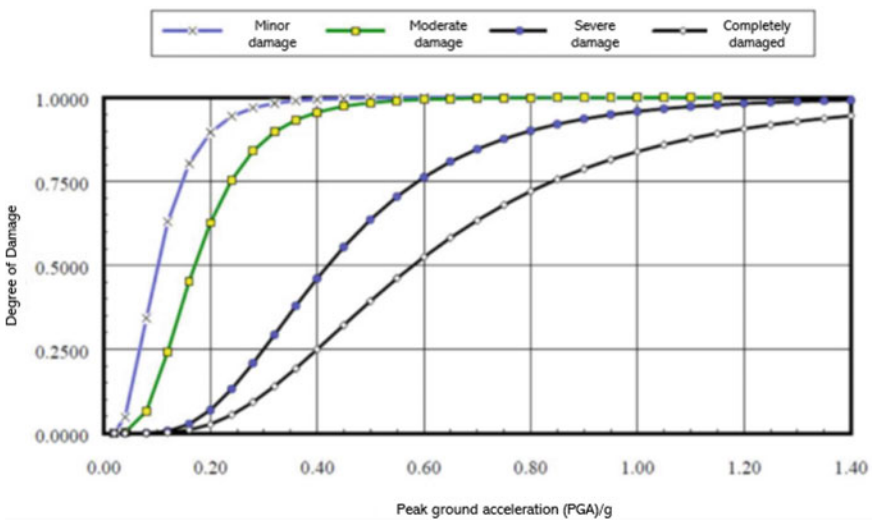


Fig. 4.10 Damage curves for small power generation facilities with unfixed components

where τ_f is the shear stress on the damage surface; $c^{'}$ is the effective cohesion of the soil; σ, σ' are the total stress on the damage surface; $\phi^{'}$ is the effective internal friction angle of the soil; u is the pore water pressure.

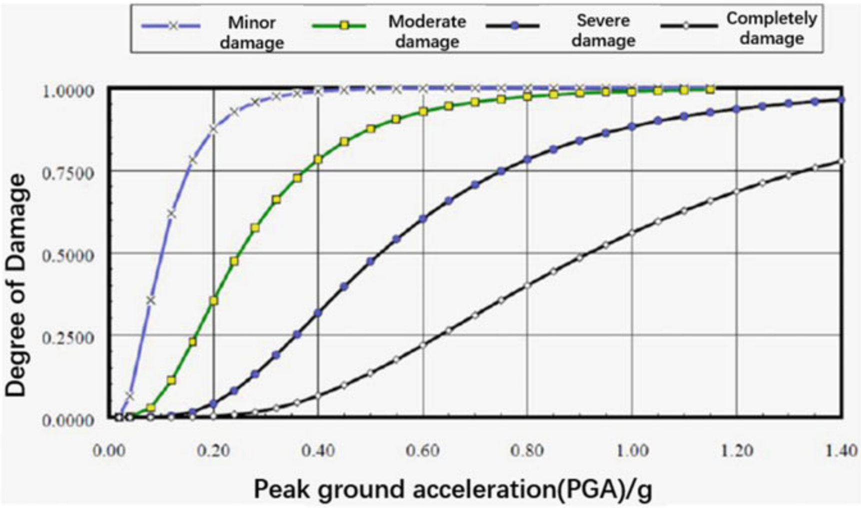


Fig. 4.11 Damage curves of medium and large power generation facilities with all fixed components

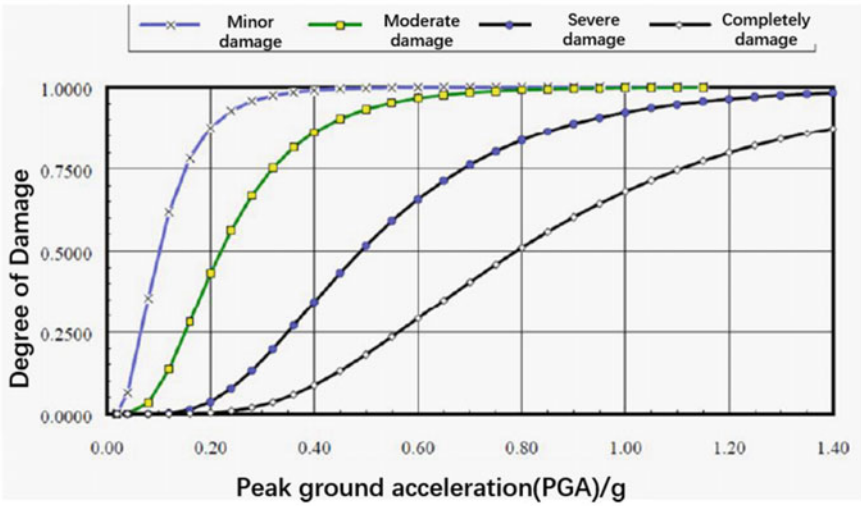


Fig. 4.12 Damage curves for medium and large power generation facilities with unfixed components

(1) Seepage slope instability

The root cause of slope instability is that the shear stress is located on a certain surface inside the soil exceeds or is at the critical value of its shear or crack strength,

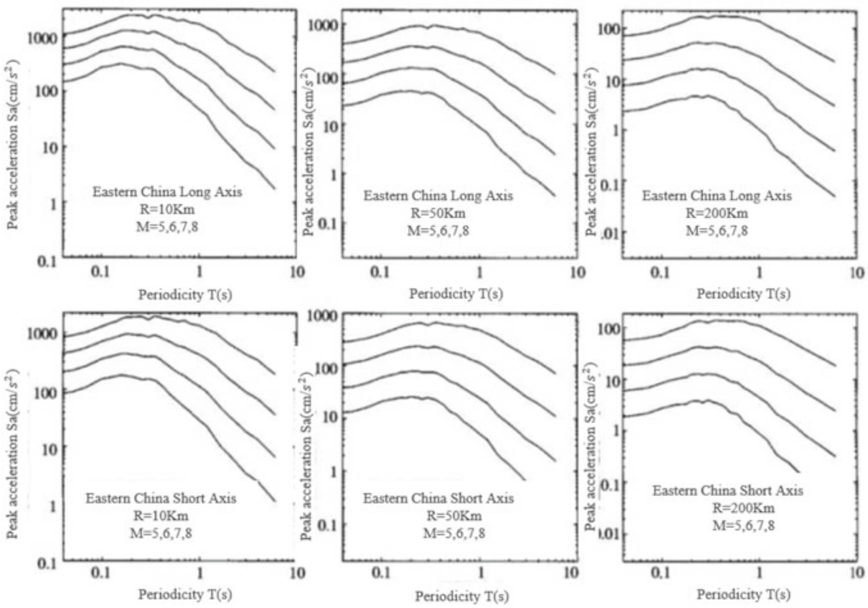
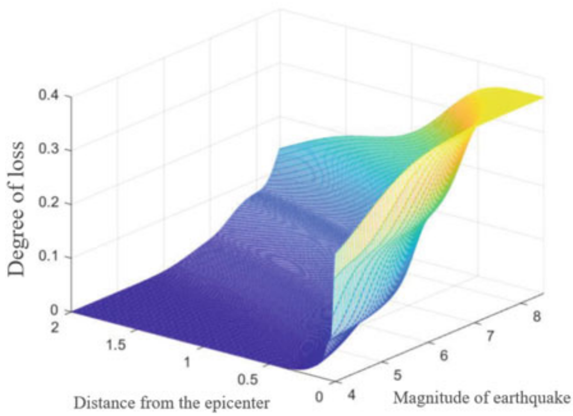


Fig. 4.13 Decay relationship of peak ground acceleration in eastern China

Fig. 4.14 Degree of damage to distribution network lines



resulting in the loss of balance inside the soil. Due to the increase of shear stress or the weakening of the shear strength of the soil itself, the shear stress reaches or even exceeds its own shear or crack strength, and this damage and sliding will be increased by the effect of rainfall infiltration. For example, the infiltrated rainwater makes the soil, which is unsaturated at the beginning, reach saturation, thus causing its capacity to increase, which makes the shear stress inside the soil increase, and along with the increasing infiltration of rainfall, the water content of the soil continues to increase, and the strength will also change. Under the infiltration of rainfall, the pore water pressure, that is, the fluid in the soil particles between the pores of the seepage water pressure, in the calculation of its stability, along the arc sliding surface of the pore water pressure, despite all through the sliding circle resulting in no sliding moment, can reduce the effective stress to a certain extent so that the shear strength is reduced, and therefore has a great impact on stability.

To analyze the influence of rainfall infiltration on slope stability, we focus on the effect of seepage water body on slope, including dynamic water load and static water load. With the dynamic water load, that is, the flow of water in the soil, for the fluid on the soil particles have a certain impact or tug force and exert adverse impact on the stability of the slope, especially when the slope has downhill outflow, while with the existence of infiltration force, the stability of the slope is greatly unfavorable. The so-called hydrostatic load, results from the situation where the water content of the soil in the unsaturated area of the slope increases continuously with the infiltration of rainfall, the capacitance increases, and the pore water pressure may also increase, which leads to an increase in shear stress or a decrease in the shear strength of the soil itself.

In general, unsaturated soils of the same nature exceed saturated soils in strength. Only when the water content of unsaturated soils increases do the suction force and the strength of the soil decrease substantially. However, the effective internal friction angle $\varnothing'$ of both saturated and unsaturated clay soils is less affected by external forces or matrix suction.

The soil in the unsaturated zone will increase in water content with the infiltration of rainfall, which makes part of the unsaturated soil transform to saturated soil and makes the shear strength decrease, while the matrix suction decreases, which further makes the shear strength of the unsaturated soil decrease. For several years, studies have shown that the loss or reduction of matrix suction in unsaturated soils caused by infiltration of rainwater has a great influence on the shear strength of unsaturated soils, and the matrix suction affects the stability of slopes by influencing the shear strength of slope soils.

The infiltration of rainwater first increases the saturation of the soil in the surface layer, then gradually moves to the lower part and accumulates in the impermeable layer at the foot of the slope first, making the infiltration line form at the foot of the slope, which is due to the short infiltration path at the foot of the slope and the fast increase of saturation at the foot of the slope. After that, as the rainfall continues, the infiltration line at the foot of the slope rises and moves continuously. The increase of soil water content, i.e., the transformation of soil from unsaturated state to saturated state, mainly occurs within the infiltration line. Of course, the rise of pore water pressure, the decrease of soil strength and the increase of soil capacity are also the direct causes of slope instability.

Through the above analysis, it can be seen that different slope gradient and soil quality are greatly affected by rainfall, and soil slopes are also affected to different degrees with different rainfall intensity and types. Different soils have different permeability, and the mechanism of influence on slope stability is also different; the larger the slope is, the smaller the stability under rainfall is; the larger the average daily rainfall intensity is, the lower the safety coefficient of soil slope is (since the surface layer of soil slope will form a transient saturation zone when encountering strong rainfall, thus making the infiltration capacity of soil body lower, and rainwater cannot infiltrate and overflow); the smaller the rainfall intensity change is, the lower the corresponding safety factor is.

(2) Seismic slope instability

The current seismic slope stability analysis is mainly based on limit equilibrium theory and stress-deformation analysis. For saturated state soil, because the water in the soil cannot provide shear strength, according to the Mohr–Coulomb law and the effective stress principle, the factors affecting the soil strength from the above equation of soil shear strength are the effective stress σ', cohesion c' and the angle of internal friction ϕ'. In general, earthquakes last from a few seconds to several tens of seconds, and the water pressure u generated by the earthquake in such a short time does not dissipate in time. The effective stress σ' in the soil is reduced because it does not dissipate in time. At the same time, there is a seismic action to cause super pore water pressure, which will make the soil content. The increase of water content will weaken the soil cohesion c' and the angle of internal friction ϕ'. These are the reasons for the decrease of soil shear strength due to earthquake.

Earthquake has always been one of the factors to be considered in slope stability analysis. The main research concerns of slope stability analysis under the effect of earthquake are: (a) how to calculate the seismic force; (b) the location and shape of slope instability; (c) the possibility and factors to judge the slope instability under the effect of earthquake; (d) the calculation of permanent deformation or permanent displacement of slope instability. The first two are the prerequisites of the study, and the last one is the key research concern. The main causes of slope instability under earthquake action are inertia force caused by seismic force and reduction of shear capacity due to cyclic degradation. Usually, the seismic slope instability includes inertial instability and attenuation instability.

Seismic dynamics is very complex, so in order to simplify the calculation, it is unified and simplified into horizontal seismic dynamics and vertical seismic dynamics, and the following are their effects on the slope soil stress respectively. For the horizontal seismic force, it is assumed that the seismic wave is simple harmonic (mainly for the quantitative expression of the earthquake), and the seismic dynamics is shown in Fig. 4.15.

For a simple slope, before the earthquake, the stress state of a soil unit within the slope soil is shown in Fig. 4.16, where $\sigma_1 = \gamma h$, $\sigma_3 = k_0 \gamma h$, which corresponds to the solid line circle in the Mohr stress circle. During the earthquake, the stress state of this soil unit at time t_2 is: $\sigma_1 = \gamma h$, $\sigma_3^{'} = k_0 \gamma h F_h$, which corresponds to the dashed circle in the Mohr stress circle, as shown in Fig. 4.17. The dashed circle is closer to the strength damage line than the solid circle, indicating that the horizontal component of the seismic dynamics can make the soil stress state close to the damage.

Near the top of the slope and the slope face, because h is smaller, when the earthquake is strong, the main stress $\sigma_3' = k_0 \gamma h F_h < 0$, that is, the slope top and

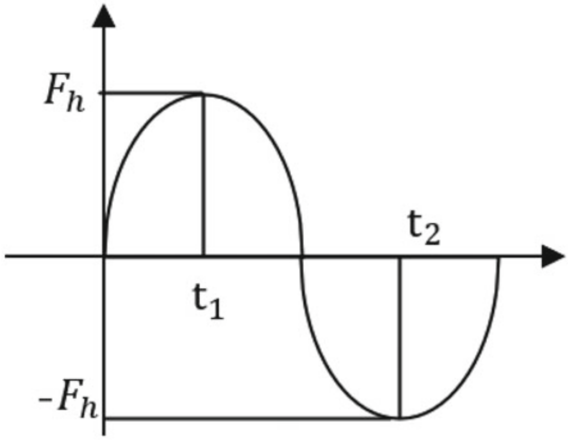


Fig. 4.15 Horizontal seismic dynamics (harmonic wave)

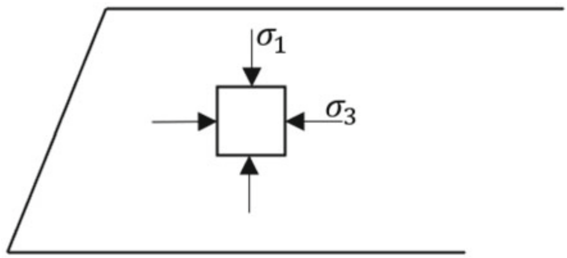


Fig. 4.16 Soil unit stress state diagram

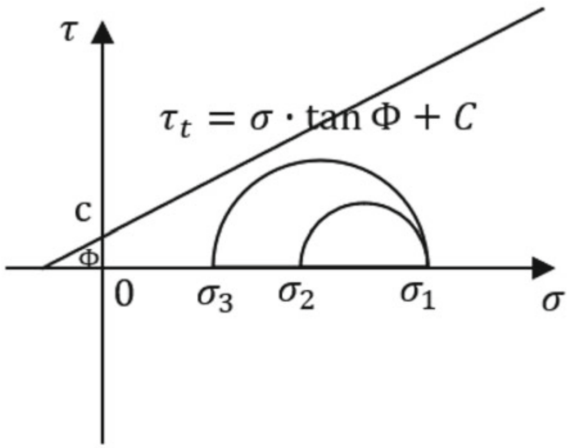


Fig. 4.17 The effect of horizontal seismic dynamics on the stress state of the soil unit

slope face parts are likely to have tension, which well explains why the slope first appears at the slope face and the top of the slope.

Vertical seismic dynamics is caused by the longitudinal waves in seismic waves, and its destructive force cannot be ignored. The vertical seismic force analysis can be carried out in the same way as the above-mentioned analysis of the effect of horizontal seismic dynamics on the force state of soil units, i.e., the vertical seismic force where the change with time is also in the form of simple harmonic waves. Before the earthquake, the stress state of a unit in the slope soil body is shown as the solid circle in Fig. 4.18, $\sigma_1 = \gamma h$, $\sigma_3 = k_0\gamma h$. During the earthquake, the stress state of the unit at t_1 time is: $\sigma_1' = \gamma h + F_h$, $\sigma_3 = k_0\gamma h_h$, as the dashed circle in the next. The dashed circle is also closer to the strength damage line (solid line) than the solid circle, indicating that the vertical component of the seismic force makes the increase of the first principal stress, which causes the stress state of the soil unit to be on the verge of damage. t_2, F_h is reversed with gravity, $\sigma_1' = \gamma h - F_h$, and the shear strength of the soil unit can be expressed as the dashed line in the figure at this time. It can be seen that the vertical seismic force at time t_2 also leads to the reduction of soil strength and causes the slope instability damage. Therefore, the influence of the vertical seismic force should be fully considered in the seismic slope stability analysis.

In summary, rainfall will reduce the strength of the slope body, while seismic forces (including seismic horizontal and vertical dynamics) likewise have an effect on the strength of the slope soil body. Under some specific conditions, such as continuous rainfall after a major earthquake, when a mega-earthquake occurs in an area with abundant rainfall, aftershocks and continuous rainfall after a major earthquake, the continuous influence effect of earthquake and rainfall may have a scourge weakening effect on the stability of the slope body, resulting in a huge landslide disaster.

The Newmark slider displacement method was first proposed based on the limit equilibrium theory for analyzing the stability of dams under the action of earthquakes,

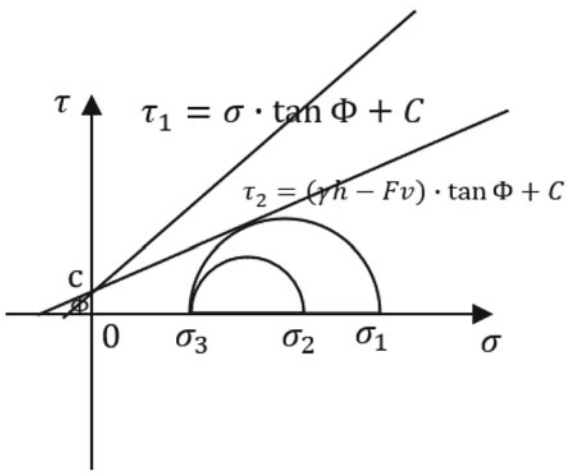
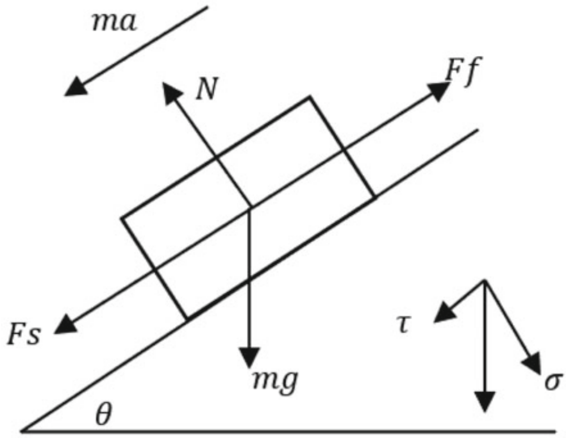


Fig. 4.18 The effect of vertical seismic dynamics on the stress state of the soil unit

Fig. 4.19 Newmark slider force analysis



and was widely used in slope stability analysis due to the clear physical meaning of the model and the simplicity of the principle in subsequent studies. In order to make the model simple and easy to operate, only horizontal ground vibration is considered and acts in the direction of the slope, and the slider is displaced only when sliding downward, and the critical acceleration is kept constant.

The displacement principle of the Newmark slider is shown in Fig. 4.19. Assume that a slider of mass m is located on a slope with a slope of $\theta°$. The slider is subjected to both the anti-slip force F_f along the upward slope and the downward sliding force F_S along the slope, where σ is the positive stress generated by gravity mg; σ is the positive stress generated by gravity mg; τ is the shear stress generated by gravity mg; γ is the weight of the slider soil, the thickness of the sliding block is h, and a is the critical acceleration.

The positive and shear stresses satisfy $\sigma = \gamma h\cos\theta$ and $\tau = \gamma h\sin\theta$, respectively. Since the anti-slip force is influenced by the shear strength of the soil, $F_f = TA$, T is the shear strength, $T = C + \sigma\tan\varphi$, C is the equivalent cohesive force of the slide drawing, φ is the equivalent the effective internal friction angle, and A is the sliding block bottom area, then the anti-slip force can be written as:

$$F_f = (C + \gamma h\cos\theta\tan\phi)A \tag{4.12}$$

The downward sliding force can be expressed as $FS = \tau A$, which can be further expressed as:

$$F_S = \gamma h\sin\theta A \tag{4.13}$$

According to the equation of motion it is known that $F_f - F_S = ma$, where $m = hA(\gamma/g)$, combined with the above equation it is known that the critical acceleration is:

$$a = g\left[\frac{C}{\gamma h} + \cos\theta\tan\varphi - \sin\theta\right] \tag{4.14}$$

Let $F_S = a/a'$, where a' is the acceleration of ground shaking at any moment, then:

$$F_s = \frac{g}{a'}\left[\frac{C}{\gamma h} + \cos\theta\tan\varphi - \sin\theta\right] \tag{4.15}$$

If the effect of pore water is considered, the safety factor equation can be rewritten as:

$$F_S = \frac{g}{a'}\left[\frac{C}{\gamma h} + \cos\theta\tan\varphi\left(1 - \frac{t_w\gamma_w}{\gamma}\right) - \sin\theta\right] \tag{4.16}$$

where t_w denotes the ratio of the thickness of saturated water in the slide to the thickness of the slide, γ_w denotes the weight of water (N/m^3), F_S is the safety factor at this time, $F_S > 1$ means the slope is in stable state, equal to 1 is the ultimate equilibrium state, when $F_S < 1$, the slope is unstable. According to the analysis of rainfall, river runoff statistics and water content of sampling points in the study area, the water content of slopes in the study area is low, and the t_w follows the normal distribution with the mean value of 0.3 and variance of 0.15. For the value of landslide thickness, the Newmark is applied to the natural shallow slope. As Newmark is applicable to the evaluation of natural shallow landslide hazard, Wang Tao et al. analyzed the landslide caused by the Hanchuan earthquake by taking the value of 4 m. When the value is 4 m, the physical properties of the strata in the study area are similar to those in the study area of the paper. Liu Jiamei evaluated the landslide hazard in Tianshui area. In the evaluation of landslide hazard in Tianshui area, the value of landslide thickness is 3 m. Considering the geographical proximity and the similarity of lithological and physical parameters of the strata with the study area, it is possible to evaluate the thickness of landslide in the study area. Taking into account the geographical proximity and the similarity of the physical parameters of the formation with the study area, the thickness of the landslide body $h = 3$ m can be taken as a reference.

When the slope is subjected to seismic action, the input ground shaking is greater than the critical acceleration, which will lead to instability of the slope and displacement along the slope surface. After stopping the input of ground shaking, the total displacement occurring in the landslide can be obtained by quadratic integration of the part of ground shaking acceleration $a'(t)$ greater than the critical acceleration a:

$$D = \iint \left(a'(t) - a\right)dt \tag{4.17}$$

Since the site type has little effect on the regression coefficients in the cumulative displacement model, the cumulative displacement is related to the ground vibration parameter PGA and the critical acceleration a is related as in Eq. (4.18):

$$\log D = 0.194 + \lg\left[\left(1 - \frac{a}{PGA}\right)^{2.262}\left(\frac{a}{PGA}\right)^{-1.754}\right] \pm 0.371 \tag{4.18}$$

where D is measured in cm, and the coefficient of determination is $R^2 = 91.4\%$, showing that the model has good correlation with the regression data. The correlation between the model and the regression data is good. The cumulative displacement of D characterizes the degree of damage to the slope caused by ground shaking. In general, 5 cm can be considered as the critical value of cumulative displacement for slope instability. Thus the probability of instability of a slope with critical acceleration a under the action of ground shaking with intensity value x can be expressed as:

$$P(slap|x) = P(D \geq 5\ \text{cm}\,|\ x, a) \tag{4.19}$$

where $P(D \geq 5\ \text{cm}|x, a)$ represents the probability that the slope produces a displacement D greater than 5 cm after a critical acceleration of a and an input ground vibration of x.

The above analysis shows that researchers have analyzed the impact and influence of earthquakes on soil slopes with the help of NewMark theory and Mohr-Column damage criterion, and the evaluation and mechanism of earthquake-induced landslides have gradually changed from being qualitative to becoming quantitative.

Considering the impact damage process of the tower due to the instability of the rock slide, we aim to establish the mathematical model of the tower deformation due to the landslide, and the deformation process of the tower due to the rock slide is shown in Fig. 4.20.

From the energy point of view, the landslide body from high potential energy position to low potential energy position sliding process will be accompanied by a huge energy release, based on the landslide body movement energy consumption mechanism that can be obtained from the landslide body acting on the transmission tower equivalent impact force $F = \sqrt{\frac{6mgh \cdot E_1(1-\mu \cdot \cot\theta)}{x^3}}$ x is the equivalent height from the base of the tower when F acts on the transmission tower; m is the total mass of the landslide body, h is the vertical height of the center of mass of the landslide from the base of the tower, E_1 is the bending stiffness of the transmission tower, μ is the coefficient of friction of the sliding surface; θ is the inclination angle of the slope body; g is the acceleration of gravity, often taken as 9.8 N/kg.

The linear displacement of the axis of an object such as a vertical tower in the direction perpendicular to the axis is defined as the deflection in structural mechanics, which is used to measure the degree of bending deformation of the object. Therefore, the deflection of the transmission tower is used as the control index and based on the cantilever beam. The top deflection of the transmission tower with flexural stiffness of E_1 is, which is based on the simplified method of cantilever beam: $\omega(x) = -\frac{Fx^2}{6E_1}(3H - x)$ where H is the overall height of the transmission tower; ω value is negative; the smaller the value is, the greater the tower deflection is. It has been pointed out that the

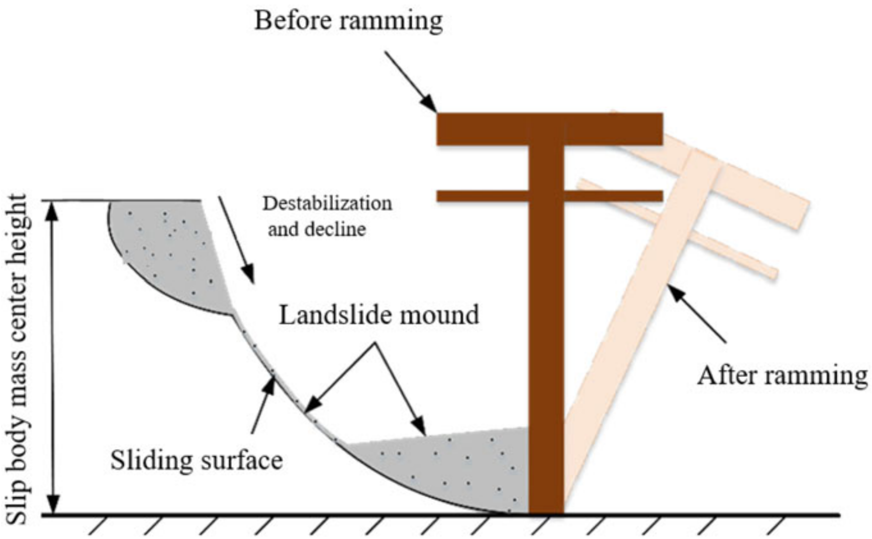


Fig. 4.20 Rock slide deformation process of the tower

normal distribution can accurately express the deformation of transmission towers caused by landslides of the probability distribution. The deflection at the midpoint of the elastic cantilever beam, ω_c and the coefficient of variation δ can be written as:$f(\omega) = \frac{1}{\sqrt{2\pi\sigma}}\exp[-\frac{(\omega-\mu)^2}{2\sigma^2}]$, where ω is the actual deflection degree; μ is the mean value, often taken asω_c; σ is the standard standard deviation, often taken as$\delta\omega_{\max}$. As the transmission towers are located in different environments and under different rainfall meteorological conditions, the coefficient of variation is 0.02~0.12.

The probability density function$f(r, \omega)$ of transmission tower damage is a conditional probability density function, and the geotechnical landslide event and the tower deformation caused by the landslide are independent of each other. The events of landslide and tower deformation due to landslide are independent of each other, therefore, the transmission tower damage density function$f(r, \omega)$ is the product of the probability density function of landslide and tower deformation,, i.e.,

$$f(r, \omega) = f(r) \cdot f(\omega) \tag{4.20}$$

Then the transmission tower damage probability $F(r, \omega)$ is:

$$F(r, \omega) = \iint f(r, \omega) dr d\omega \tag{4.21}$$

A transmission line consists of dozens or even hundreds of towers, a rainfall may cover multiple towers, the line Any tower damage in the line will result in the entire line out of service, and then the probability of loss of P_k for line k is:

$$P_k = 1 - \left\{ \prod_{m=1}^{n+1} [1 - F_m(r, \omega)] \right\} \tag{4.22}$$

where $F_m(r, \omega)$ indicates the probability of damage of the mth transmission tower; n is the number of stalls of the kth transmission line.

This section of the study allows quantitative assessment of the impact of landslide hazards on transmission towers, calculation of the probability of line damage, and assistance in the development of emergency repair decisions.

4.2.3 Typhoon Disaster Damage Model

(1) Typhoon wind field calculation model

At present, the methods for solving the circulation wind speed component of tropical cyclone wind field can be broadly divided into two categories: the first category of methods is to solve the tropical cyclone pressure distribution first, and then derive the circulation wind speed distribution of tropical cyclone according to the gradient wind speed formula. The second method is based on the empirical model of tropical cyclone circulation wind speed distribution, which is given directly by the parameters of maximum wind speed and maximum wind speed radius, without solving the barometric distribution. This method is based on an empirical model of the tropical cyclone circulation wind distribution, which is given directly by parameters such as maximum wind speed and maximum wind radius, without solving the pressure distribution. The empirical model of circulation wind speed distribution in this type of method reflects the wind speed of tropical cyclone along the radial direction from the eye area to the cloud wall area (caused by the intersection of cold and warm air peaks), and the wind speed from the cloud wall area to the outer area gradually decreases. Commonly used empirical models of circulation wind speed distribution include Rankine model, Jelesnianski (1965) model, Jelesnianski (1966) model, Miller model, Chan and Williams model, etc.

The method of solving tropical cyclone wind field based on the empirical model of tropical cyclone circulation wind velocity distribution does not need to solve the pressure distribution first, so it has the advantages of simple principle and easy calculation. However, since both the circulation wind speed model and the moving wind speed model contain the key parameter of the maximum wind speed radius, it is necessary to identify the maximum wind speed radius more accurately first.

1) Circulating wind speed calculation model

In general, typhoon transit will lead to the collapse of a large number of towers. After analysis, it is found that tower collapse is related to wind, the tower design strength, tower structure, geographic location and other factors.

Typical models for calculating the circulating wind speed are:

a) Rankine Model

$$V_r = \begin{cases} \left(\frac{r}{R_{\max}}\right) V_{\max} r \in [0, R_{\max}] \\ \left(\frac{R_{\max}}{r}\right) V_{\max} r \in [R_{\max}, \infty) \end{cases} \tag{4.23}$$

b) Jelesnianski (1965) Empirical Model

$$V_r = \begin{cases} \left(\frac{r}{R_{\max}}\right)^{1.5} V_{\max} r \in [0, R_{\max}] \\ \left(\frac{R_{\max}}{r}\right)^{1.5} V_{\max} r \in [R_{\max}, \infty) \end{cases} \tag{4.24}$$

c) Jelesnianski (1966) Empirical correction Model

$$V_{\mathrm{r}} = \frac{2\left(\frac{r}{R_{\max}}\right)}{1 + \left(\frac{r}{R_{\max}}\right)^2} V_{\max}\ r \in [0, \infty) \tag{4.25}$$

d) Chen, Kongmo (1994) Empirical Model

$$V_r = \frac{3(R_{\max} r)^{1.5}}{R_{\max}^3 + r^3 + (R_{\max} r)^{1.5}} V_{\max} r \in [0, \infty) \tag{4.26}$$

e) Miller Model

$$V_r = \begin{cases} \left(\frac{r}{R_{\max}}\right) V_{\max} r \in [0, R_{\max}] \\ \left(\frac{R_{\max}}{r}\right)^x V_{\max} r \in [R_{\max}, \infty) \end{cases} \tag{4.27}$$

f) Chan and Williams(1987) Model

$$V_{\mathrm{r}} = V_{\max}\left(\frac{r}{R_{\max}}\right) \mathbf{e}^{\frac{1}{d}\left[1-\left(r/R_{\max}\right)^d\right]} r \in [0, \infty) \tag{4.28}$$

In the above equations: V_{r} is the circulation wind speed at a point in the tropical cyclone wind field, and V_{rmax} is its maximum value; x and d are the shape parameters of the model.

If $r/R_{\max}$ is taken as the horizontal axis and $V_{\mathrm{r}}/V_{\mathrm{rmax}}$ as the vertical axis, the distribution of the circulation wind speed for each of the above models is shown in Fig. As can be seen from the figure, the general trend of the circulation wind speed distribution of each model is the same: as the observation point gradually moves away from the center of the tropical cyclone, the circulation wind speed increases first, and then gradually decreases after increasing to the maximum circulation wind speed at the radius of the maximum wind speed. The difference between the models is the speed of increase or decay of the circulation wind speed, as shown in Fig. 4.21.

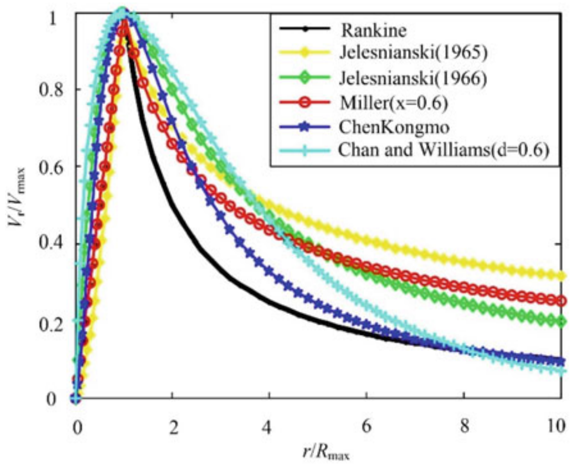


Fig. 4.21 Comparison of circulating wind speed models

2) Maximum wind speed radius calculation model

Graham and Nunn studied tropical cyclones along the U.S. East Coast and in the Gulf of Mexico, plotted the effects of central pressure, geographic latitude, and migrating winds on the radius of maximum wind speed, and proposed a parameterization scheme for the radius of maximum wind speed.

$$R = 28.52\tanh[0.0873(\varphi - 28)] + 12.22\exp\left(\frac{\varphi - 1013.2}{33.86}\right) + 0.2V + 37.22 \tag{4.29}$$

where φ is the geographic latitude; V is the speed of the migrating wind; P_c is the central pressure of the tropical cyclone.

Jiang Zhihui's study, based on the "Tropical Cyclone Yearbook" central pressure and maximum wind speed radius information, analyzed the average trend of the maximum wind speed radius, giving the maximum wind speed radius of the tropical cyclone central pressure of the power exponential empirical formula.

$$R = 1.119 \times 10^3 \times (1010 - P_c)^{-0.805} \tag{4.30}$$

Willoughby obtained an exponential relationship between the radius of maximum wind speed and the variation of maximum wind speed in the flight level and geographical latitude based on the flight sounding records of tropical cyclones in the Atlantic and Eastern Pacific Ocean from 1977 to 2000 published by the National Oceanic and Atmospheric Administration (NOAA).

$$R = 51.6\exp\left(-0.0223V_{f\max} + 0.0281\varphi\right) \tag{4.31}$$

where $V_{f\max}$ is the maximum wind speed in the flight level; φ is the geographical latitude.

Kato, in his work on the simulation and evaluation of storm surges off the coast of Japan, pointed out that the linear expression for the radius of maximum wind speed versus the central pressure of a tropical cyclone:

$$R = 80 - 0.769(950 - P_c) \tag{4.32}$$

The typhoon wind field model gives information on cyclone direction, wind speed and movement path in the local area, which can provide support and prerequisite for the establishment of typhoon disaster assessment model for power grid equipment.

(2) Wind speed and wind direction variation study

The non-uniformity of horizontal wind is an important source of danger in engineering construction, which is related to the wind-excited vibration and deformation of the structure. Wind shear can indicate the non-uniformity of horizontal wind. Both horizontal wind shear and vertical wind shear have the effect of structural damage. For engineering construction, horizontal wind shear can cause more severe damage than vertical wind shear, especially near the maximum wind speed radius and eye wall area. The main concern here is horizontal wind shear, and the equation is as in Eq. (4.33).

$$\begin{aligned} S_h &= \sqrt{\left(\frac{\partial \overrightarrow{V_h}}{\partial x}\right)^2 + \left(\frac{\partial \overrightarrow{V_h}}{\partial y}\right)^2} \\ &= \sqrt{\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2} \end{aligned} \tag{4.33}$$

V_h is the horizontal wind, u and v are the x and y components of the horizontal wind, and S_h denotes the horizontal wind speed shear module, which reflects the reflects the horizontal non-uniformity of wind field. The wind speed run diagram and the maximum 10-m horizontal wind speed shear diagram are shown in Figs. 4.22 and 4.23.

The maximum horizontal wind speed shear Qiongzhou Strait during the passage of the typhoon is shown in the figure above. The prominent difference between these two typhoons is due to their different structures. Figure 4.23 shows that the horizontal wind speed shear is most significant in the area of the eye wall and the spiral rain band, while its horizontal wind speed shear is most significant near the eye wall because of its stronger and more compact structure.

The non-uniformity of the wind field is manifested not only in space but also in time. As in a moving and rotating rotating system, changes in the wind vector of a tropical cyclone can cause temporal variations and thus anomalies. Wind speed and wind direction are used to quantify these abrupt changes. They are defined as

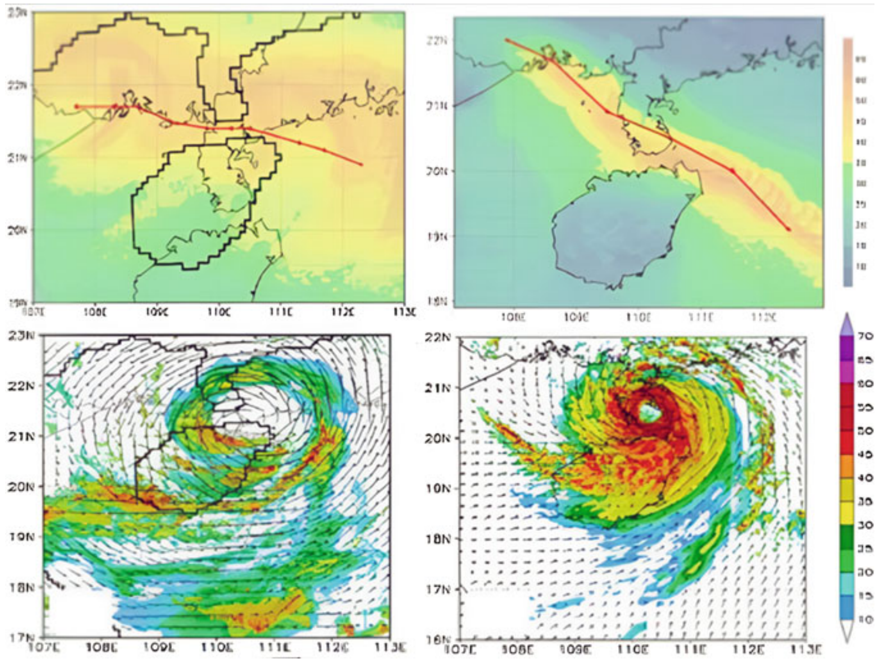


Fig. 4.22 Typhoon wind speed run chart

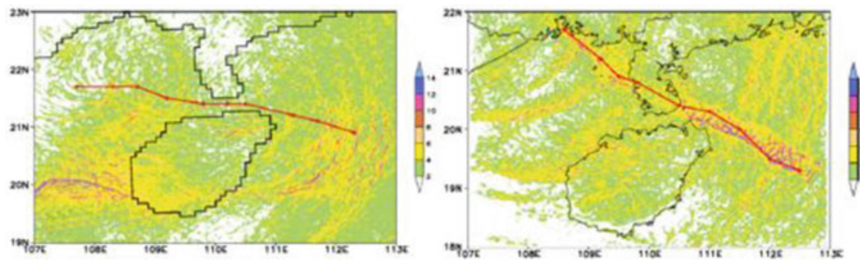


Fig. 4.23 Maximum 10 m horizontal wind speed shear

the difference between the wind speed and direction at time t and the previous time $(t - 1)$, as shown in Fig. 4.24.

It is clear from Fig. 4.24 that for tropical cyclones, the maximum values mainly vary from 15 to 35 m/s, distributed along the trajectory. In contrast, for typhoons, the greater the intensity is, the more drastic the temporal variation in wind speed is, arriving at 50 m/s before landfall. For the 30 min wind variation, the maximum values are mainly distributed in the typhoon eye area.

In summary, the temporal variation of wind speed is most significant in the spiral rainband area on the eye wall, while for wind direction the greatest temporal variation

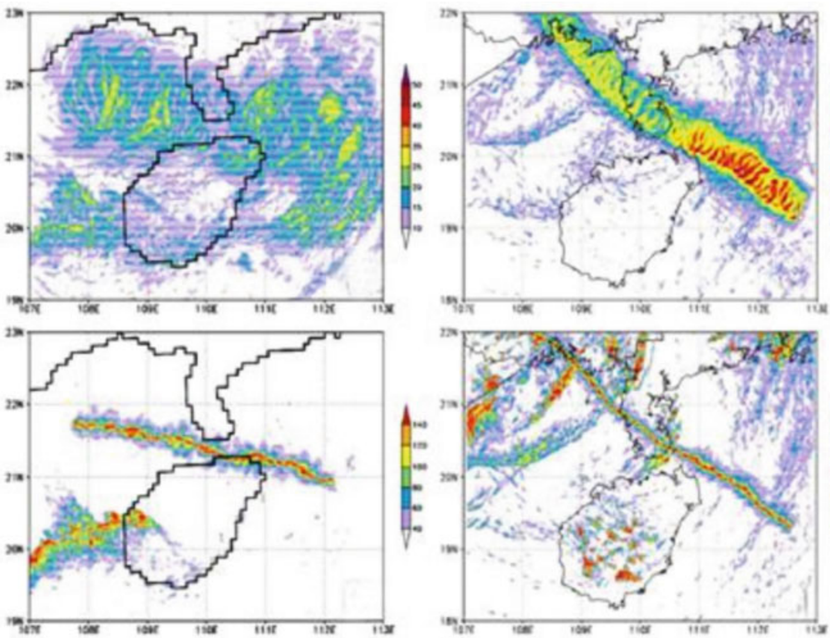


Fig. 4.24 Maximum time variation of wind speed

occurs in the eye area. The largest temporal variation in wind direction is in the eye region. Both parameters reflect the rapid changes in the core wind speed of tropical cyclones. These areas are particularly dangerous for engineering structures. In addition, the high values of the temporal variation of wind direction allow to visually track the tropical cyclone eye, where the risk is expected to be high.

(3) Construction of a disaster damage assessment model for typhoon disaster power grid equipment

In the course of typhoon, the risky towers in different geographical locations will last for a period of time from the beginning to the end of the typhoon impact. Under the cumulative effect of the growing duration, the reliability of the tower will be continuously reduced with the increase of plastic fatigue damage of the tower. At the same time, during this duration, the relative position of the typhoon center and the tower changes constantly, and the wind field strength of the typhoon itself also changes constantly, which leads to the constant changes in the wind speed of the tower.

As shown in Fig. 4.25, O' and O'' with a risk tower distance from the risk wind circle radius R_{risk} are the initial impact and end impact tower typhoon center points.

Under the short-term linear forecast path, the latitude and longitude of the two intersections of O' and O'' can be calculated jointly, where the latitude and longitude coordinates of the risk tower are (x_g, y_g), the latitude and longitude coordinates of

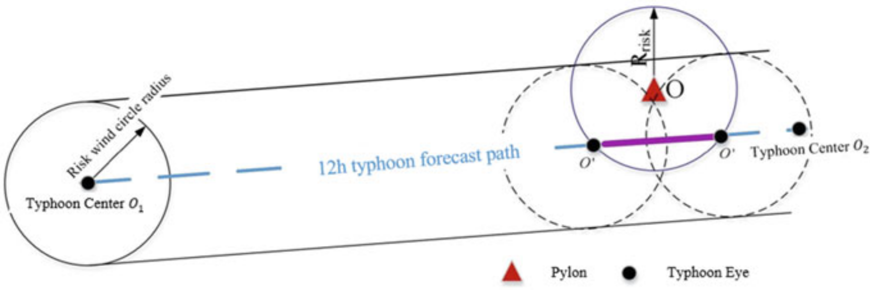


Fig. 4.25 Short-term forecast under the tower affected by the typhoon diagram

the typhoon center O_1 and O_2 are $\left(x_{O_1}, y_{O_1}\right)$, (x_{O_2}, y_{O_2}), respectively, and (x, y) are the coordinates of a point where the typhoon center is between O_1 andO_2.

$$\left[\left(x - x_g\right)\frac{\pi R}{180^0}\cos y_g\right]^2 + \left[\left(y - y_g\right)\frac{\pi R}{180^0}\right]^2 = R_{\text{risk}}^2 \tag{4.34}$$

$$\frac{y - y_{O_1}}{x - x_{O_1}} = \frac{y_{O_2} - y_{O_1}}{x_{O_2} - x_{O_1}} \tag{4.35}$$

where R is the radius of the earth, generally taken as 6371 km.

When O' and $O'\prime$ latitudes and longitudes are the same, the tower is only affected by the wind speed of the typhoon risk circle, and there is no time cumulative effect. Otherwise, the tower is affected by the typhoon for the duration of:

$$t_h = \frac{|O'O''|}{|O_1 O_2|}\Delta T \tag{4.36}$$

where $|\ O'O''\ |$ is the length of the risk area from the beginning to the end of the typhoon effect on the tower; $|\ O_1O_2\ |$ is the distance between O_1 and O_2, the short-term center points of the typhoon; ΔT is the length of short-term forecast time.

During the typhoon, the distance between the tower and the typhoon center changes continuously due to the movement of the typhoon, and the wind speed of the tower also changes. According to the historical typhoon information, the typhoon's moving wind speed is generally much smaller than its circulation wind speed, especially in the high-grade wind speed component, the proportion of the circulation wind speed is more obvious, so it can be approximated that the typhoon circulation wind speed of the tower is constant within 10 min, and the duration of the tower by the typhoon is divided into n time intervals with 10 min as the span, that is:

$$n = \text{int}\left(\frac{60 \times t_h}{10}\right) \tag{4.37}$$

Let (x_0, y_0) be the latitude and longitude coordinates of the center O' where the typhoon begins to act on the tower, and assume that the typhoon at the short-term forecast time ΔT, the longitude and latitude of the typhoon center after the i-th time interval (x_i, y_i) is:

$$\begin{cases} V_0 = \frac{|O_1 O_2|}{\Delta T} \\ \left[(x_i - x_{i-1})\frac{\pi R}{180^0}\cos y_{i-1}\right]^2 + \left[(y_i - y_{i-1})\frac{\pi R}{180^\circ}\right]^2 = \left(\frac{V_0}{6}\right)^2 \\ \frac{y_i - y_{o1}}{x_i - x_{o1}} = \frac{y_{o2} - y_{o1}}{x_{o2} - x_{o1}} \end{cases} \tag{4.38}$$

Using the Rankine model, the wind speed to which the tower is subjected is related to the distance from the tower to the eye of the typhoon, and the different time intervals can be approximated by the distance:

$$d_i^2 = \left[\left(x_i - x_g\right)\frac{\pi R}{180^o}\cos y_g\right]^2 + \left[\left(y_i - y_g\right)\frac{\pi R}{180^o}\right]^2 \tag{4.39}$$

$$d_{i+1}^2 = \left[\left(x_{i+1} - x_g\right)\frac{\pi R}{180^o}\cos y_g\right]^2 + \left[\left(y_{i+1} - y_g\right)\frac{\pi R}{180^o}\right]^2 \tag{4.40}$$

$$r_i^{i+1} = \frac{1}{2}(d_i + d_{i+1}) \tag{4.41}$$

The above equation is an expression for the distance from the typhoon center to the risk tower at the beginning of the ith time interval, and is an expression for the distance from the typhoon center to the risk tower at the end of the ith time interval. r_i^{i+1} is the approximate distance from the tower to the typhoon eye in the ith time interval. Considering the radius of maximum wind speed and maximum wind speed of the typhoon under typhoon movement as linear changes, the typhoon circulation wind speed of the tower at different time intervals under the predicted typhoon path can be obtained.

Strong typhoons generally maintain high winds for about two days after landfall, and due to their strong destructive force, low circumferential fatigue damage will be brought to the towers for a number of hours before and after landfall, and the towers are prone to enter a plastic state thus generating fatigue failure problems. According to the analysis of literature experimental results, the fatigue damage of the structure and the wind load show an exponential relationship, and the wind load is proportional to the square of the wind speed, then the fatigue damage model of the tower under strong typhoon can be given by the wind speed of the tower:

$$D_i = \begin{cases} 0 & V_i \in [0, V_0) \\ ae^{bV_i^2} & V_i \in [V_0, V_m) \\ 1 & V_i \in [V_m, \infty] \end{cases} \tag{4.42}$$

where a and b are the model coefficients, varying according to different tower material strength, since different materials have different fatigue damage values, even if the wind speed is the same, and therefore the size of the coefficient is different, for the specific material of the tower can use the tower production design fatigue experimental data to determine the a, b coefficients. V_i is the typhoon wind speed for the tower at time i; V_0 is the critical wind speed when the typhoon begins to hit the tower and causes low cycle fatigue damage; V_m is the extreme wind speed when the typhoon reaches a load failure on the tower; D_i denotes the low cycle fatigue damage of the tower per unit minute.

According to the Palmgren–Miner linear fatigue damage criterion, the total accumulated fatigue damage D of the rod can be obtained by superimposing the single fatigue damage. When D equals to 0, the rod is considered to have no damage; when D equals to 1, the rod is considered to have fatigue damage.

The failure rate of transmission towers under strong typhoon weather is related to the accumulated time of fatigue damage, and considering that Poisson model can effectively predict the failure rate of components under short time weather conditions, the probability model that a tower does not collapse in the first i time intervals can be modified as:

$$P_{toi} = e^{\left[\sum_{j=1}^{i}\left(-\frac{D_j}{1-D_j}\Delta t\right)\right]} \tag{4.43}$$

Then the probability of the inverted tower occurring in the first i time intervals is:

$$P_{towerlossi} = 1 - P_{toi} \tag{4.44}$$

where Δt is the length of each time interval. As can be seen from the equation, when $D_j = 0$, regardless of how long the typhoon acts on the tower, the tower collapse is an impossible event; when $D_j = 1$, the tower collapse is an inevitable event.

This section suggests the calculation and evaluation methods of typhoon disaster impact on transmission towers. Based on the conclusion of typhoon wind field analysis and comprehensive consideration of wind speed and wind direction changes, a transmission tower damage assessment model is constructed, which can give the probability of transmission tower damage after typhoon disasters and provide assistance for emergency relief decisions.

4.2.4 Heavy Rainfall and Flooding Disaster Damage Model

(1) Rainfall prediction model

1) Based on historical rainfall extrapolation model

Considering that heavy rainfall will affect the safety of the power grid directly or through secondary disasters, urban flooding is mainly caused by short-term heavy precipitation, landslides, mudslides, etc., which is related to the 24 h daily rainfall and the accumulated rainfall in the previous 10 d. In the real-time assessment of the risk of disaster-causing factors, the previous day's 1 h P_{1h}, 3 h rainfall maximum P_{3h}, the previous day's daily rainfall P_{1d}, the current day's rainfall (forecast value) P_{1df}, and the previous 10 days' effective rainfall P_{10d} are extracted for calculation, and the calculation expressions are as follows:

$$H = 0.253X_{1h} + 0.1342X_{3h} + 0.33500X_{1d} + 0.0958X_{1\mathrm{df}} + 0.1870X_{10\mathrm{d}} \quad (4.45)$$

where X_{1h}, X_{3h}, X_{1d}, $X_{1\mathrm{df}}$, $X_{10\mathrm{d}}$ are the normalized indices of 1 h, 3 h, 1d actual, 1d forecast, and the first 10 days, respectively. The normalized index of effective rainfall.

The effective rainfall $P_{10\mathrm{d}}$ for the first 10 days is calculated as follows:

$$P_{10d} = \sum_{t=0}^{10} f(t) \times P_t \quad (4.46)$$

$$f(t) = \frac{60.96 \exp(-1.93 \times t)}{100} \quad (4.47)$$

where t is the number of days before the current moment of the assessment calculation: i.e., $t = 0$ is the day; P_t is the rainfall amount t days ago, and $f(t)$ is the weight of rainfall t days ago.

Factors that play an important role in the process of rainfall and flood redistribution are considered: the height and undulation of the terrain, the density of the river network, and the vegetation coverage. The damage caused by rainstorm disaster is eventually reflected in the disaster-bearing body, and the disaster-bearing body of the grid rainstorm disaster is the grid facilities. The more concentrated the grid facilities are, the lower the height from the ground is, and the greater the damage caused by the storm is.

2) POT model based on statistical theory

The meteorological conditions that lead to insulator flashover and transformer water ingress and moisture failure are usually severe weather such as heavy rainfall or rainstorm. Therefore, heavy precipitation is the direct cause of insulator flashover and transformer water ingress. Considering that the probability of failure prediction of power equipment under flooding can be equated to the probability of rainfall intensity exceeding a certain threshold value (above which the equipment will fail), the extreme value theory model POT (Peaks over threshold) is available for its analysis. The model takes all the individual exceedance samples of rainfall intensity observations that reach or exceed a certain threshold value as the analysis sample and fits Generalized Pareto Distribution (GPD). The theory proves that the tail distribution of all distributions approximates GPD as the selected threshold increases. The POT model is a model based on GPD, in which the number of samples of the rainfall intensity V sequence $\{vt\}$ is assumed to be N, and $F(v)$ is its distribution function.

Define $F(w)$ as the Conditional Excess Distribution Function (CEDF) of the rainfall intensity, which is the conditional distribution function of the rainfall intensity exceeding the threshold value u, and can be expressed as:

$$F_u(w) = P(v - u \leq wv > u) == \frac{F(u + v) - F(u)}{1 - F(u)} \tag{4.48}$$

When u is large enough, there exists a GPD such that:

$$F_u(w\xi, \sigma) = \begin{cases} 1 - [1 + \xi \frac{w}{\sigma}]^{-\frac{1}{\xi}} \xi \neq 0 \\ 1 - \exp\left(-\frac{W}{\sigma}\right) \xi = 0 \end{cases} \tag{4.49}$$

where ξ is the shape parameter; $\frac{1}{\xi}$ is the tail index; σ is the scale parameter. When $\xi = 0$, F_u is the Gumbel distribution; When $\xi < 0$, F_u is weibull distribution; When $\xi > 0$, F_u is Frechet distribution.

And the density function of rainfall intensity greater than u:

$$f(v) = \begin{cases} \frac{N_u}{N\sigma} [1 + \xi \frac{v-u}{\sigma}]^{\frac{1}{\xi}1} \ \xi \neq 0 \\ \frac{N_u}{N\sigma} \exp\left(-\frac{v-u}{\sigma}\right) \ \xi = 0 \end{cases} \tag{4.50}$$

The real-time risk assessment index system of the power grid is constructed by considering four factors, namely, the risk of disaster-causing factors, the sensitivity of disaster-inducing environment, the exposure of disaster-bearing body and the disaster prevention and mitigation capability. The real-time assessment model of grid rainstorm disaster is based on the four elements of risk assessment; the classification of the impact of rainstorm on grid security is carried out; the index method is used to calculate.

$$FDRI = \left(H^{W_h}\right)\left(S^{W_s}\right)\left(E^{W_e}\right)(1 - R)^{W_r} \tag{4.51}$$

Among them, FDRI is the storm disaster risk assessment index of the grid. The larger its value is, the higher the risk to the grid is, and failure is more likely to occur. H, S, E, and R denote hazard factors, disaster-pregnant environment sensitivity, exposure of disaster-bearing bodies, and disaster prevention and mitigation capability, respectively, and W_h, W_s, W_e, and W_r are the weights of the corresponding indicators, as shown in Table 4.1. All indicators are classified into 5 levels: very low, low, medium, high, and very high; disaster-causing factors are graded according to rain, heavy rain, rainstorm, heavy rainstorm, and megastorm; except for disaster-causing factors, all other indicators are graded by the natural breakpoint method. The grading criteria are shown in Table 4.2.

Precipitation is a key parameter of heavy rainfall and flooding, and the precipitation prediction model can support the subsequent disaster damage assessment in this section.

Table 4.1 Indicator weights

Target layer	Guideline layer	Weight
Power grid storm disaster risk assessment system	Hazard factors	0.43
	Disaster-pregnant environment sensitivity	0.21
	Exposure of disaster-bearing bodies	0.24
	Disaster prevention and mitigation capabilities	0.12

Table 4.2 Grid risk assessment index grading criteria

Indicator level	Extremely low	Low	Medium	High	Extremely high
Hazard factors	0	(0,0.08)	[0.08, 0.29)	[0.29, 0.51)	≥0.51
Disaster-pregnant environment sensitivity	<0.41	[0.41, 0.54)	[0.54, 0.72)	[0.72, 0.89)	≥0.89
Exposure of disaster-bearing bodies	<0.05	[0.05, 0.15)	[0.15, 0.28)	[0.28, 0.47)	≥0.47
Disaster prevention and mitigation capabilities	<0.05	[0.05,0.11)	[0.11, 0.30)	[0.30, 0.64)	≥0.64
Grid risk assessment	<0.08	[0.08,0.20)	[0.20, 0.30)	[0.30, 0.43)	≥0.43

(2) Construction of disaster damage assessment model for power grid equipment in heavy rainfall disaster

1) Insulator flashover

The insulator is a special insulating control that supports the wire and prevents the current from returning to the ground in overhead transmission lines. Once an insulator flashover occurs in a high-voltage grid, it will cause a short-circuit fault in the transmission line, resulting in a transmission line outage. Insulator flashover is one of the main causes of transmission line outages under flooding caused by heavy rainfall and other adverse weather conditions.

The influence of altitude on the flashover characteristics of insulators lies mainly in the influence of atmospheric pressure on the flashover characteristics of insulators. As the atmospheric pressure decreases, the DC and AC flashover voltages of insulators decrease, and the flashover voltage U_f is non-linearly related to the air pressure P linear relationship, i.e.,

$$U_f = U_0\left(\frac{P}{P_0}\right)^n \tag{4.52}$$

where P_0 is the standard atmospheric pressure layer; U_0 is the flashover voltage of insulator under standard atmospheric pressure; n is the drop index reflecting the influence of atmospheric pressure on the flashover voltage.

The atmospheric pressure intensity is mainly related to the altitude of the location, and the function can be expressed as

$$P = P_0\left(1 - \frac{H}{44330}\right)^{5.25} \tag{4.53}$$

where H is the elevation of the insulator.

When the rain falls on a clean, dry insulator surface for an extended period of time, the conductivity fluctuates more strongly. The conductance of insulators subjected to rain fluctuates greatly. When the rainwater on the insulator surface reaches stability, the conductance will also reach stability. The surface resistance of the insulator when the rainfall surface reaches stability can be expressed as:

$$R_w = c\rho(A + 0.02)^{-0.44} \tag{4.54}$$

where c is a constant; ρ is the rain resistivity; A is the rainfall intensity. The above formula shows that the insulator reaches a stable wetting after the insulator reaches the stable wet state, its surface resistance is more influenced by the rain resistivity than by the rain intensity. For the insulator flashing mechanism and characteristics, the surface resistance of the insulator is influenced by the rain resistance. For the mechanism and characteristics of insulator flashover, the exponential function of insulator flashover voltage and rain surface resistance under standard atmospheric pressure is linear. The insulator flashover voltage at standard atmospheric pressure is linearly related, i.e., the insulator flashover voltage at standard atmospheric pressure is

$$U_0 = a\exp(R_w) + b \tag{4.55}$$

where a and b are constants.

Combining the above equations, the flashover voltage of the insulator can be expressed as

$$U_f = \left[a\exp(c\rho((A + 0.02)) + b)\right]\left(\left(\frac{p}{p_0}\right)^a\right) \tag{4.56}$$

In addition, under flooding, when the combined force of water and wind exceeds the resistance capacity of the transmission line or pole hitch, it will cause damage such as broken lines and fallen poles. Some cross-river transmission lines with poles built on the river are easily submerged or even washed away. Under the action of heavy rain and wind, tree branches are easy to be broken. Some of the broken branches pressed on the overhead transmission lines, causing transmission line disconnection. In addition, heavy rainfall has different degrees of impact on overhead equipment such as reactors, lightning arresters, capacitors, transformers and fuses on transmission and substation lines.

2) Transformer failure

Power transformer is one of the core equipment of the power grid; transformer is the node of the transmission and transformation network; its safe and reliable operation is a prerequisite for the power system to provide reliable power to the load. Transformer failure has been the main factor that endangers the safety of the power grid. Transformer failure rate of the largest part is the transformer's internal insulation, the main failure characteristics of the transformer insulation material moisture. Under the flood disaster, there are two main reasons for causing the transformer to enter water and moisture: a) Under the flood disaster, the air humidity is extremely high, due to poor sealing of the top connection cap of the casing. Moisture in the air enters the winding insulation along the lead wire, causing a breakdown accident; b) in the transformer operation, if the desiccant filled in the breathing apparatus fails, the explosion-proof tube is not tightly sealed, or the suction side of the submersible pump is leaking, external rainfall or humid air will enter the transformer through these ways, resulting in the insulation material moisture and thereby insulation accidents.

For the transformer operating characteristics, the insulating oil moisture content W_1 and oil-impregnated paper moisture content W_2 in the transformer under heavy rainfall disaster can be expressed as follows:

$$W_1 = a_1 \frac{N}{\pi} \sqrt{A^{0.949} + b_1} \left(\frac{P}{P_0} \right)^{n_1} \tag{4.57}$$

$$W_2 = a_2 \frac{N}{\pi} \sqrt{e^{x^{x^{123}}} + b_2} \left(\frac{P}{P_0} \right)^{n_2} \tag{4.58}$$

where N is the duration of rainfall, A is the intensity of rainfall; P is the atmospheric pressure at the location of the transformer; P_0 is the standard atmospheric pressure; $a_1, a_2, b_1, b_2, n_1, n_2$ are constants.

Both transmission line faults and transformer faults can lead to outage faults on transmission and substation lines. Therefore, it is possible to calculate the probability of the outage fault probability of transmission and transformation line under rainstorm disasters by studying insulator flashover probability and transformer fault probability of transmission line. If the insulator flashover critical value U_ζ is calculated, the critical value of rainfall intensity A_ζ can be expressed as:

$$A_\zeta = \left\{ \frac{\ln\left[\frac{U_\zeta}{a\left(\frac{p}{p_0}\right)^n} - \frac{b}{a} \right]}{cP} \right\}^{-\frac{1}{0.055}} - 0.02 \tag{4.59}$$

If the rainfall intensity density function is $f(x)$, the individual insulator flashover probability can be obtained as

$$P_{\text{insulator}} = 1 - \int_0^{A_r} f(x)dx \tag{4.59}$$

Assuming that the rainfall time is a constant, the critical rainfall intensity $A_{1\zeta}$ of insulating oil spark discharge and the critical rainfall intensity of oil-impregnated paper being broken through can be expressed as:

$$A_{1\zeta} = \left\{ \left[\frac{W_1 \pi}{a_1 N} \left(\frac{p_0}{p} \right)^{n_1} \right]^2 - b_1 \right\}^{\frac{1}{0.949}} \tag{4.61}$$

$$A_{2\zeta} = \left\{ \ln\left[\frac{W_2 \pi}{a_2 N} \left(\frac{p_0}{p} \right)^{n_2} - b_1 \right] \right\}^{\frac{1}{1.323}} \tag{4.62}$$

Based on the transformer operating characteristics, the transformer failure probability can be expressed as:

$$P_{\text{txasforner}} = P_{\text{transformer1}} + P_{\text{transform2}} - P_{\text{transform1}} \times P_{\text{transform2}} \tag{4.63}$$

where the probability of spark discharge of insulating oil and the probability of oil-impregnated paper being struck can be obtained as:

$$P_{transformer1} = 1 - \int_0^{A_{1\zeta}} f(x)dx \tag{4.64}$$

$$P_{transformer2} = 1 - \int_0^{A_{2\zeta}} f(x)dx \tag{4.65}$$

Assume that the number of insulators of the transmission line in the affected area is n. When the value is more than n, $s\%$ of the insulators develops a flashover, the transmission line will experience a shutdown fault. Let

$$m = [n \times s\%] \tag{4.66}$$

where [] denotes rounding to positive infinity.

If the impact of other equipment on the transmission line is not considered, there will be at least s insulators flashing before the transmission line is out of service. From the Bernolli probability model, the probability that at least m of the n insulators will flash is

$$P_{line.insulator} = \sum_{i=m}^{n} C_n^i (P_{inculator})^i (1 - P_{insulator})^{n-i} \tag{4.67}$$

where Pinsulator is the individual insulator flashover probability.

The occurrence of either of these events, insulator flashover and transformer failure, will result in the shutdown of the transmission and substation line. Assume that insulator flashover and transformer failure are mutually independent events, the transmission line outage probability is:

$$P_{\text{1ine}} = P_{\text{i1insulator}} + P_{\text{transformer}} - P_{\text{iiline inalator}} \times P_{\text{transformer}} \tag{4.68}$$

The storm disaster seriously affects the normal operation of transmission lines and transformers, and the damage probability of transmission lines and transformers can be calculated by Eqs. (4.52) to (4.68), and then we can quantitatively analyze and assess the impact on the power grid system to provide support for emergency decision-making.

(3) Construction of disaster damage assessment model for flooded power grid equipment

The analysis of the impact of flooding on power systems is the key to assess the damage of power system equipment under flooding. With the advancement of technology, the technology of collecting meteorological data, geographic data and power data under floods has also developed greatly. The statistical modeling is the most effective means to deal with this problem.

When modeling the impact of flooding on power systems, usually as many impact factors as possible are selected to reduce model bias due to the lack of important factors. However, in the actual modeling process, it is necessary to find the subset of influence factors that are most explanatory to the equipment influence variables, i.e., feature quantity extraction (or model selection, variable selection), in order to improve the explanatory and prediction accuracy of the model. Under the flood disaster, selecting the feature quantity among the many influencing factors that lead to the failure of power equipment is the key to reasonably analyze the failure of power equipment. Considering to the complexity and randomness of flooding itself, this project establishes a model of the impact of flooding on power system equipment based on the analysis of the impact of flooding on the power system, and uses the least squares method to obtain the parameters.

Floods have a significant impact on the power generation, transmission and distribution equipment of the power system. Power equipment is widely distributed and diverse, and the impact of flooding on it is highly complex. The degree of damage to the power system by flooding is mainly determined by the severity of flooding and the characteristics of the power system itself. On the one hand, the generation and development of flood disasters are mainly influenced and constrained by meteorological and geographical factors. Therefore, meteorological and geographic factors are indispensable in analyzing the impact of flooding on the power system, including the meteorological factors such as rainfall amount and rainfall intensity under flooding. On the other hand, the power equipment's own conditions (including operation status, operation age, etc.) are also the main factors affecting the disaster loss of electric power equipment.

The specific definitions and descriptions of the variables of flooding impact and its influencing factors are shown in Table 4.3.

Let $y = \ln\frac{P}{1-P}$, the relationship between y and the influencing variables in the above table can be written as:

$$y = \beta_0 + \beta_1 x_1 + \cdots + \beta_{16} x_{16} + \varepsilon \tag{4.69}$$

$\beta_0, \ldots, \beta_{16}$ are statistical parameters and ε is the model error without bias, variance and correlation.

For power equipment in different areas, select suitable and representative influence factors from $x_1, \ldots, x_{16}$ as the set of influence factors according to the characteristics of the environment in which they are located $\{a_1, \ldots, a_n\}$, describe the impact of flooding on electrical equipment impact. The observations of the set of power equipment disaster impact variables y and impact factors under N floods were collected as the sample set$\{(A_t, Y_t), t = 1, 2, \ldots, n\}$. Each set of sample values satisfies the

Table 4.3 Flooding impact and its influencing factors

Influence factors	Description
Equipment failure rate P	Failure rate of electrical equipment within the specified range after a disaster, [0,100%]
Average daily temperature × 1	°C
Daily average wind speed × 2	m/s
Daily maximum wind speed × 3	m/s
Daily rainfall × 4	mm
Maximum rainfall intensity × 5	Precipitation in unit time mm/min
Air humidity × 6	Water content in unit volume of air g/mm^3
River network density × 7	Length of river in unit basin km/km^2
River runoff threshold × 8	Flow volume per unit time m^3/s
Pre-disaster river runoff × 9	Flow volume per unit time m^3/s
Maximum elevation within the specified range × 10	m
Lowest elevation within the specified range × 11	m
Average altitude × 12	m
Vegetation coverage × 13	$x13 \in [0, 1]$
Average soil depth × 14	m
Soil moisture × 15	Water content of soil per unit volume %
Average daily load × 16	MW

following relationship:

$$y_t = \beta_0 + \beta_1 a_{t,1} + \cdots + \beta_n a_{t,n} + \varepsilon_t (t = 1, 2, \ldots, n) \tag{4.70}$$

where y_t is the influence variable of power equipment under the t th flood; $a_{t,n}$ is the value of the n th influence factor under the tth flood.

If the above equation is written in matrix form, we have

$$Y = A\beta + \varepsilon \tag{4.71}$$

where

$$Y = (y_1, y_2, \ldots, y_n)^T \tag{4.72}$$

$$\beta = (\beta_0, \beta_1, \beta_2, \ldots \beta_n)^T \tag{4.73}$$

$$\varepsilon = (\varepsilon_0, \varepsilon_1, \varepsilon_2, \ldots, \varepsilon_n)^{\mathrm{T}} \tag{4.74}$$

$$A = \begin{pmatrix} 1, & a_{1,1} & \cdots & a_{,n} \\ & \vdots & & \vdots \\ 1, & a_{n,1} & \cdots & a_{n,n} \end{pmatrix} \tag{4.75}$$

Let Q be the error sum of squares of the model, and then we have:

$$Q = \varepsilon^T \varepsilon = \sum_{t=1}^{n} \left(y_t - \beta_0 - \sum_{i=1}^{n} \beta_t a_{i,i} \right)^2 \tag{4.76}$$

The smaller Q is, the more accurate the model is. Therefore, let Q reaches the minimum value of $\beta_0, \beta_1, \beta_2, \ldots, \beta_n$, which is the best estimate of the model parameters and use the least squares method to estimate the model parameters. Consequently, the following optimization problem is solved:

$$\left(\hat{\beta}_0, \hat{\beta}_1, \ldots, \hat{\beta}_n\right)^T = \underset{\beta_0, \beta_1, \beta_2, \ldots, \beta_n}{\operatorname{argmin}} \left\{ \sum_{i=1}^{\pi} \left(y_i - \beta_0 - \sum_{j=1}^{\pi} \beta_i a_{i_j} \right)^2 \right\} \tag{4.77}$$

Taking the partial derivative of the above equation β_i and making the partial derivative equal to 0, we obtain:

$$\sum_{i=1}^{n} y_i a_{t,i} = \sum_{j=1}^{n} \beta_j \left[\sum_{j=1}^{n} a_{t,j} \cdot a_{t,i} \right] (i = 1.2, \ldots, n) \tag{4.78}$$

Solution:

$$\hat{\beta} = L^{-1}A^T Y \tag{4.79}$$

where $L^{-1} = A^T A$. The solution is brought into (4.70), which yields the influence factor $a_1, \ldots, a_n$ impact on electrical equipment.

Equations (4.69) to (4.79) give the impact of flooding on the power grid. The method of flooding power grid equipment damage assessment involves various factors such as terrain conditions, precipitation intensity, geohydrology, as well as equipment and facilities resilience, emergency response capability, etc. Overall, the analysis of flooding power grid equipment damage requires comprehensive consideration of the impact of multiple types of parameters.

4.2.5 Freezing Rain and Snow Disaster Damage Model

(1) Meteorological causes of ice cover

The cold air in the north of China and the warm air with high temperature and humidity in the south often intersect each other to form "stationary peaks" and their extensions "quasi-stationary peaks" from the severe winter to the early spring each year. Usually the warm and humid airflow rise through the cold airflow, often at high altitude due to the drop in temperature; they contain water molecules that break down in large numbers and continue to freeze and condense, producing fog; at the same time, when the cold air flow is relatively strong, it will lead to cold front meteorological conditions, and then the rising warm and moist air will dilute a large number of water molecules; when they are located above the 0 °C temperature line or just above the frozen altitude layer, they will change to produce snowflakes, ice crystals and supercooled water droplets (also known as supercooled clouds).

Previous studies have shown that although the occurrence of water and ice clouds is temperature dependent, the "dust" that can be used as ice cores is the central link between them. At temperatures above −18 to 20 °C, most clouds are composed of subcooled water droplets below, and below −25 °C, most are ice clouds. Supercooled water droplets in the sub-steady state (relatively unstable), in contact with the surface of the object, will freeze in the body and form ice. The existence of many dangerous weather phenomena is caused by an excessive number of supercooled water droplets (clouds), such as rain-song and ice accumulation in aircraft clouds. In southwestern and central China, "stationary fronts" and "quasi-stationary fronts, 'often can maintain a very long time; generally, the area covered by the front will appear continuous rain "freezing rain" weather. This is because the cold air mass in the north is like a wedge to the south and inserted under the warm and humid air mass and the temperature inversion phenomenon begins to appear in the atmosphere, first from the ground up; the temperature below 0 °C rises with the temperature reaching above 0 °C; if it continues to rise, the temperature will fall below 0 °C, and then it begins to contact the condensation height. Usually ice crystals or snowflakes both appear on top of the condensation height. At this time, ice crystals, snowflakes and the height of the supercooled water droplets are in the atmosphere above 0 °C; once the temperature of the supercooled water droplets have increased, ice crystals, snowflakes or all melted, or partially melted (if the temperature is not high enough in the atmosphere above 0 °C). If it continues to fall until the atmosphere is below 0 °C, the over-cooled water droplets with a large contact surface will encounter the dust that can be used as ice nuclei (such as volcanic dust, meteorite ash) on the way down and thus form ice grains, falling to the ground, called "snow". However, snow on transmission lines cannot be firmly attached to them, so they do not pose a major hazard to overhead transmission lines. If the supercooled water droplets are relatively small, their radius and surface area are small, and "dust" is difficult to be completely contained in it; in addition, their curvature and surface tension are relatively large; consequently their structure is difficult to be changed, so even in the temperature below 0 °C, they still fall to the ground in the form of supercooled water droplets, called "freezing rain". These supercooled water droplets are in a sub-stable state, if the colder objects on the ground meet them, the water molecules will gain energy due to collision vibration, resulting in the "activation" of some water molecules to form an ice nucleus, and solid ice will be transformed by the supercooled liquid water. Also, water droplets will be deformed due to collision, the surface bending degree becomes smaller, causing the surface tension to become smaller at the same time, and the surface of the transmission line wire has the function of capturing water droplets, so the supercooled water droplets will freeze into ice on the surface of the wire. Generally, the smaller the supercooled water droplets are, the easier it is to freeze into rime. Fog and drift can often be seen in plateau areas at an altitude of over 1000 m, such as the Yunnan-Guizhou plateau in China. When the altitude reaches or exceeds 2000 m or more, this situation is very common. In contrast, glaze usually appears in the area at a lower altitude, because the supercooled water droplets at this altitude are usually larger and easy to freeze. Glaze is often seen in the mountainous areas of Hunan, Hubei, Henan and Guizhou in China. In the north of China, because it is not within the influence of stationary fronts, the overhead conductor ice is presented as the phenomenon of snow or rime, such as in northeastern, northern and northwestern China. The stationary front is not the only means to produce freezing rain supporting ice, as there is another important form of icing, cloud supercooling and condensation on wires, which is also common in the southwest plateau of our country. In some mountainous areas of Sichuan, Guizhou, Yunnan and other places, if there is no wind at night in the severe winter and spring season, the sublimation ice will appear because of radiation cooling, resulting in the formation of crystalline rime, but the crystalline rime growth is slow, and generally does not pose a great harm to the overhead line. The process and conditions for the formation of ice cover are as follows:

1) Formation process

When winter is cold and spring comes, in the −10 to −0 °C temperature, the wind reaches 1–10 m/s, the transmission line operating environment encounters fog or light rain, the wire will produce rime or glaze; if the climate becomes clear, the temperature rises; the ice begins to melt, the climate has been clear, and the ice on the wire will completely melt. However, in the process of ice melting, the climate suddenly becomes colder and the temperature drops, and the water film that has just melted on the rime will freeze on the wire and become a dense rime layer. Then the temperature continues to decrease, the ice will keep changing, and the surface of the wire will be covered with a layer of fog. Continuously alternating, it leads to the production of mixed silt on the surface of the wire, and it is a mixed frozen substance caused by repeated cascading of fog silt and rain silt. When icing occurs on the wire, it often appears on the windward side at first. At this time, if the wind direction does not change arbitrarily, the ice frozen on the windward side of the wire surface will increase in thickness with the change of wind speed and temperature. When they reach a significant thickness, the eccentric weight of the ice itself will cause a change in torque, which in turn makes the wire twist. After the wire is twisted, the originally leeward side of the wire slowly turns into the windward side, and this process occurs so that the side of the wire with less ice can capture the cooling water droplets, eventually leading to an increase in ice cover and the eventual formation of round or oval ice on the wire surface. Under most conditions, the resistance of small-section wires to torsion is weak, so the ice covering on their surface is generally round, while the resistance of large-section wires is strong, so their surface ice cover type is mainly oval or crescent-shaped.

2) Basic conditions of formation

The basic conditions for ice cover include (Table 4.4):

Usually, the water droplets with larger diameter have a relatively low transition process of overcooling, and the water droplet collision rate is also relatively high, and when encountering a higher surrounding temperature, it is found that the potential heat of the water droplets evaporates very slowly at this time, and the probability of forming a rime in this case is great. If the diameter of water droplets is relatively

Table 4.4 Basic conditions for the formation of ice cover

Number	Forming conditions
1	Having enough temperature and wire surface temperature to freeze water droplets, below 0 °C, generally −200~−2 °C, which can make the droplet release latent heat immediately when freezing
2	Air with supercooled water droplets or clouds
3	Having a high humidity, because the content of supercooled liquid water in the air is a source of various ice-covered water, and the relative humidity of the air is generally above 85%
4	Having the corresponding wind speed that can make the supercooled water droplets or supercooled cloud particles in the air move, so that the water droplets collide with the wire and are captured by the wire; the general wind speed is 1-10m/s; when the relative humidity of the air is very small or there is no wind and the wind speed is very low, even if the temperature is very low, the wire is basically not covered with ice

small, the transition process of over-cooling is relatively high, and the collision rate of water droplets is relatively small, and when the surrounding temperature is low, the latent heat of water droplets evaporates quite rapidly at this time, and the probability of forming rime in this case is great. Of course, in the actual environment, the above two transformations are mutually controlled and influenced by each other, so often we can see that the surface of transmission line conductor also produces a frozen mixture, which is called mixed rime.

There are many factors that affect the ice on the wire, including meteorological conditions, topography and geography, altitude and conductors themselves, etc.

a) Meteorological factors

The meteorological factors affecting the wire icing mainly include temperature, air humidity, wind speed, wind direction, diameter of supercooled water droplets in the cloud and condensation height and other parameters, as shown in Table 4.5.

When glaze is covered with ice, the diameter of supercooled droplets is large, at about 10–40 μm, and the median volume droplet diameter is about 25 μm, a light rain; when rime is covered with ice, the droplet diameter is between 1 and 20 μm, and the median volume droplet diameter is about 10 μm; while for mixed rime, its droplet diameter is between 5 and 35 μm, and the median volume diameter is 15–18 μm.

b) Terrain type, geographical conditions

The prominent terrain with good wind conditions, such as mountain tops, narrow mountain passes, wind channels and windward slopes, and air water more adequate rivers, lakes, reservoirs and cloud-encircled mountainsides, mountain tops, etc. are all locations where night ice is extremely easy, and the degree of ice cover is also more serious.

c) Altitude and wire suspension height

Under normal circumstances, the icing of the wire is closely related to the altitude of the environment; the higher the altitude is, the thicker the ice is, and most of the frozen material is rime; if the altitude of the line is relatively low, then the ice thickness of the wire is also small, and most of the frozen material is glaze or mixed rime. At the same time, with the increase of the suspended point height of the wire, the ice thickness will increase, because the wind speed and fog density in the near ground will increase with the increase of the height of the ground. The law of ice thickness with height can be expressed by multiplying the power law: $\frac{b_z}{b_0} = (\frac{Z}{Z_0})^{\alpha}$, where b is the thickness of ice cover; Z is the height.

d) Wire

The conditions of the wire itself include the diameter of the wire, stiffness, the size of the current through the wire and other factors. For the diameter of the wire, its

Table 4.5 A summary of meteorological factors affecting wire icing

Number	Meteorological factor	Meteorological characteristics
1	Air temperature	The influence of temperature on ice cover is extremely significant. Generally, the most easily iced temperature is 0–6 °C. If the temperature is too low, the supercooled water droplets have become snowflakes and cannot form wire icing; because of this, the ice accidents in the cold northern region are lighter than Yunnan, Guizhou, Hunan, and Hubei in the southern region
2	Air humidity	The degree of air humidity has a great influence on wire icing. When the humidity is high, generally above 85%, it is not only easier to cause ice covering of the wire, but also easy to form rime. In Hunan Province, during every winter and early spring season, due to continuous rainfall, air humidity is high (more than 90%), so the wire is easy to be covered with ice, glaze in most cases
3	Wind speed and direction	Since the wind plays a role in the transport of clouds and water droplets, it has an important influence on the wire ice cover. When there is no wind and breeze, it is favorable to the formation of crystalline fog; when the wind speed is higher, it is favorable to the formation of granular fog. Almost all the models for calculating the ice on the wire include the wind speed as a factor; in general, the greater the wind speed is (0–6 m/s range), the faster the ice forms on the wire. The wind direction will mainly have an impact on the shape of the ice cover; when the wind direction is perpendicular to the wire, ice will be on the windward side, where the top is formed first, creating an eccentric icing and when the wind direction is parallel to the wire, it is easy to produce uniform ice

(continued)

Table 4.5 (continued)

Number	Meteorological factor	Meteorological characteristics
4	Supercooled water droplet size	The size of the diameter of the supercooled water droplets is related to the air temperature, which mainly affects the wire type of ice cover. Peck found that the relationship between the logarithm of the water droplet volume (V) and the droplet subcooling is linearly related
5	Condensation height	The "condensation height" refers to the altitude of the cloud when all the supercooled water droplets become ice crystals or snowflakes, which varies with different ground and dew point temperatures, and is often calculated by the Herring formula: H = 124 (T-Td), where H is the condensation height (m); T is the ground air temperature (°C); Td is the dew point temperature (°C)

influence on the ice coating of the wire is mainly manifested in the effectiveness of the wire to capture supercooled water droplets in the air, that is, the effect of the collection coefficient. According to the theory of fluid dynamics, the Stokes number of supercooled water droplets in the air stream can be expressed as: $St = \frac{2\rho_d r^2 v}{9\mu R}$, where ρd is the density of air and water droplets; r is the radius of water droplets; v is the wind speed; R is the radius of the wire; μ is the dynamic viscosity constant of air.

As can be seen from the above equation, the number of Stokes into the cooling water droplet and R is inversely proportional, that is, the larger the radius of the wire is, the smaller the Stokes number of the cooling water droplet is. And the impact rate of overcooling droplets hitting the wire is related to the Stokes of overcooling droplets: the smaller the Stokes number of overcooling droplets is, the smaller the average rate of the impact wire is. Therefore, the larger the radius of the wire is, the smaller the impact rate is. The impact rate is an important factor affecting the growth of the wire ice:

$$\frac{\mathrm{d}m}{\mathrm{d}t} = 100\alpha_1\alpha_2\alpha_3 R v \omega.$$

where $\alpha_1, \alpha_2, \alpha_3$ are the collision rate, capture rate and freezing coefficient, respectively; ω is the liquid water content in the air. From the above formula, it can be seen that the smaller the collision rate is, the slower the growth of the wire ice is. Previous studies have obtained the relationship between ice thickness and wire radius as shown in Fig. 4.26.

Wire resistance to torsion depends on its own rigid strength, and it is the main factor affecting the shape of the wire section ice. The one with less rigidity strength is generally thin wire, easy to twist, while the cross section of the ice covered wire is generally circular. Transmission lines around the electric field will exist on the

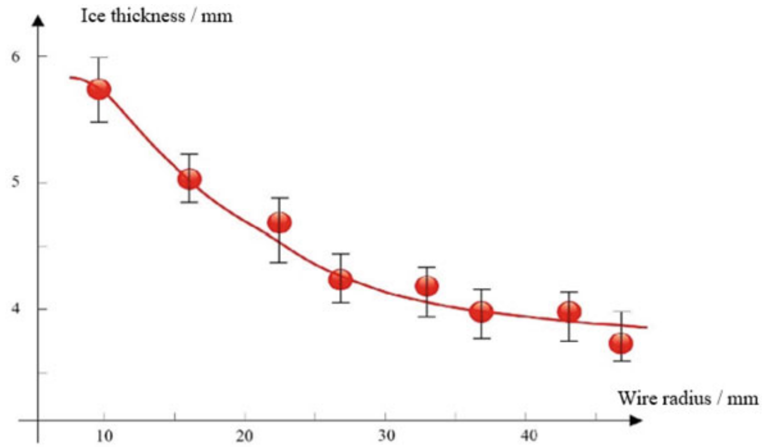


Fig. 4.26 Relationship between conductor ice thickness and conductor radius

surrounding air droplet particles of attraction and polarization, regardless of the changes in the internal charge of the droplet particles with the changes in the electric field their force is always an attractive force of the reference wire. Therefore, when the surrounding is a thick fog or light rain, due to the existence of this attraction, there are more water droplet particles towards the surface of the wire. The thickness of the ice on the wire surface increases. At the same time the wire ice is also related to the passing load current; when the load current is not large enough, the current generated by the Joule heat is not able to maintain the wire surface temperature above 0 °C, and this situation will exacerbate the growth of the wire ice thickness. If the passing load current is large enough, the Joule heat generated by the current can maintain the wire surface temperature to be above 0 °C; under this condition, the thickness of the wire surface ice will be reduced, and the reduction in the amount of ice can be enlightened to the effect of natural anti-icing transmission lines.

In summary, the icing of the wire is affected by many factors, such as wind speed, temperature and humidity, and precipitation type, and the type of ice formation also varies according to different environmental conditions. It is necessary to consider the influence of many types of factors when constructing the ice growth model.

(2) Transmission line ice cover model
1) Chaine and Skeates models

For a horizontal surface, assuming that the temperature is near or below zero, L_H represents the amount of precipitation observed during the entire freezing rainfall process and assuming that it is completely frozen as ice, then: $L_H = P \times t$, where P is the precipitation rate; t is the precipitation time. However, when the surface is at a certain angle to the wind direction, the amount of glaze ice cover on the surface will exceed the precipitation rate. In order to calculate the vertical ice cover thickness L_v, it is assumed that the mass growth rate of the glaze layer formed on a 1 m^2 flat surface perpendicular to the wind direction is related to the precipitation rate as follows:

$$L_v = 0.195EvP^{0.88}t \tag{4.80}$$

where v is the average wind speed; E is the collection factor, which is assumed to be 1 for a vertical flat plate. When the ice is generated on the wire, the concept of equivalent radial thickness is borrowed, i.e., the ice is assumed to be uniformly distributed on the wire. Then the equivalent radial thickness ΔR of the wire glaze ice is:

$$\Delta R = \left[\frac{3.23kR_0}{\sqrt{\left(L_H^2 + L_v^2\right)}} + R_0^2 \right]^{\frac{-1}{2}} - R_0 \tag{4.81}$$

where K depends on the wire diameter ice shape correction factor, as shown in Table 4.6; R_0 is the wire radius.

2) Lenhard Model

Lenhard proposed a simple model based on empirical data where the ice weight M per meter of wire can be written as:

$$M = C_3 + C_4 Hg \tag{4.82}$$

where Hg is the total precipitation during ice cover; C_3 and C_4 are constants. This model ignores all effects of parameters such as wind velocity, air temperature, and other parameters are neglected in this model.

3) Goodwin Models

Goodwin et al. assumed that all the supercooled water droplets collected or captured by the wire freeze to ice on the wire surface. In other words, the ice cover is a dry growth model. Therefore, the ice cover rate per meter of conductor is

$$\frac{\mathrm{d}M}{\mathrm{d}t} = 2Rwv_i \tag{4.83}$$

Table 4.6 Correction factor for ice cover shape

Type of ice cover	Ice adherence	Ice cover shape factor
Glaze, rime or a mixture of both	Power lines, communication lines	0.8–0.9
Glaze, rime or a mixture of both	Branches, poles	0.4–0.7
Wet Snow	Power lines, communication lines, tree branches, poles	0.8–0.95

where w is the liquid water content in the air; v_i is the impact velocity of the supercooled water droplets. At the moment t, the amount of ice covering the length of a single long conductor is:

$$M = \pi \rho_i (R_2 - R_0)^2 \tag{4.84}$$

where ρ_i is the density of ice, generally $0.8 \sim 0.9 g/cm^3$.

Combining the above equations, there are:

$$\frac{\mathrm{d}R}{\mathrm{d}t} = \frac{w v_i}{\pi \rho_i} \tag{4.85}$$

Integrating the above equation, the radial ice thickness $\Delta R = R - R_0$ of the ice over the conductor in time period t is obtained as

$$\Delta R = \frac{w V_i}{\pi \rho_i} t \tag{4.86}$$

The raindrop impact velocity is:

$$v_i = \sqrt{v_d^2 + v^2} \tag{4.87}$$

where v_d is the falling speed of raindrops, generally 6–13 m/s. Here the wind direction is assumed to be perpendicular to the wire frame direction. The liquid water content w in the air can be related to the thickness of precipitation measured during the ice cover time t:

$$\rho_{\mathrm{w}} H g = v w_d t \tag{4.88}$$

Combining the above equations, we have:

$$\Delta R = \frac{\rho_w H g}{\pi \rho_i} \sqrt{1 + \left(\frac{v}{v_d}\right)^2} \tag{4.89}$$

4) McComber and Govoni model of fog and drift ice cover

McComber and Govoni conducted a fog experiment on Mount Washington, New Hampshire, from 1978 to 1980. The experimental conductor was a 64-mm diameter steel wire set at 2.5 m above ground level and oriented perpendicular to the prevailing wind direction. Temperature, wind speed, liquid water content, droplet diameter, ice weight, and maximum ice cover diameter were measured. In all five sets of ice cover data selected for analysis, it was found that the ice cover rate increased with time. Therefore, McComber and Govoni suggested the use of an exponential growth model, namely,

$$M = M_0 e^{kt} \tag{4.90}$$

where M is the ice weight per meter of conductor; M_0 is the average initial ice weight per meter of conductor; k is a constant; t is the ice-covering time, which can be written as

$$k = 4 \times 10^{-2} \frac{Ewv_m}{\rho_i D_0} \tag{4.91}$$

The factor 4×10^{-2} in the above equation includes the conversion relationship from seconds to hours and the correction of the average typical ice diameter, the correction of v_m is the average wind speed; D_0 is the wire diameter.

McComber and Govoni found that the data they measured in their experiments fit well with the exponential growth model.

Overall, line ice cover involves a phase change process, which is influenced by a variety of factors, and the ice cover growth mechanism is complex. When faced with practical problems, it is necessary to consider the type of ice cover, meteorological conditions and line type to select a suitable ice cover growth model.

5) Modification of a disaster damage assessment model for power grid equipment in rain and snow freezing disasters considering the ice melting process

Ice melting process on the wire can be divided into 2 stages, as shown in Fig. 4.29, a) ice cylinder and wire close contact, when the highest rate of ice melting, and then, b) a thin liquid film on the surface of the wire, and ice and wire in the upper part of the liquid film is isolated. The lower part is separated by water and air space, and the melting rate decreases. The left side of Fig. 4.29 is the first stage of ice melting diagram; because the upper part of the wire has been in full contact with the ice, the melting rate is high; the right side of Fig. 4.27 is the second stage of ice melting diagram; only a small amount of ice surface contact with the wire, and as time passes its contact area is getting smaller, so the melting rate is low. As long as the current wire melts the ice cylinder, with the continuous reduction of the contact area between the ice and the wire, after a period of time, the residual ice hanging on the wire will be separated under the action of wind and gravity.

During ice melting, the heat balance expression can be written as:

$$q_J \Delta t - q_c \Delta t = Q_{Melt} = \rho \left[l + c_p (t_0 - t_s) \right] V_{Melt} \tag{4.92}$$

where $q_J = I^2 R$, being the Joule heat generated per unit length of wire; I is the ice melting current; R is the resistance per unit length of wire; Δt is the ice melting time; q_c is the convective heat exchange between the outer surface of the ice and the surrounding air; Q_{Melt} is the heat required to melt the ice; ρ is the average density of the ice; l is the latent heat of melting of the ice; c_p is the specific constant pressure heat capacity of the ice; t_0 is the ice melting temperature; t_s is the average surface temperature of the ice; and V_{Melt} is the volume of ice melting. Also, according to

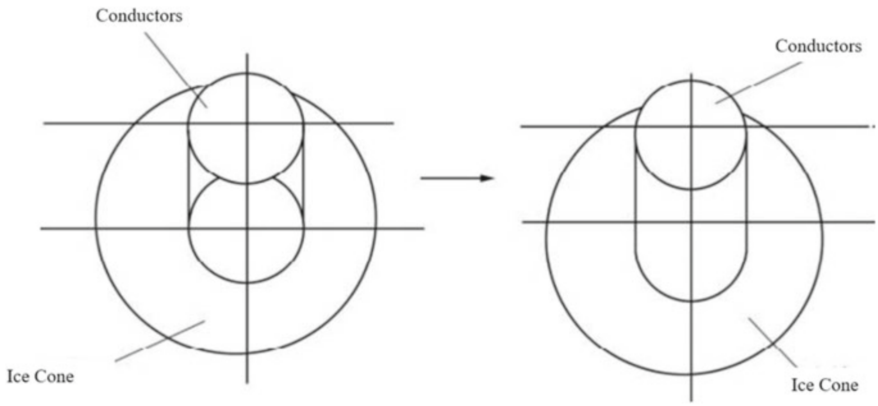


Fig. 4.27 Schematic diagram of the ice melting stage of conductors

the cylindrical thermal conductivity model in heat transfer, the q_c can be written as follows:

$$q_c = \frac{t'_0 - t_a}{\frac{\ln\left(\frac{r_i}{r_c}\right)}{2k_i\pi} + \frac{1}{2r_i\pi h}} \tag{4.93}$$

where t'_0 is the atmospheric temperature; r_i is the radius of the ice-covered column of the wire; r_c is the radius of the wire; h is the convective heat transfer coefficient of air flow across the frozen wire, and its value is related to the diameter of the ice cylinder, surface roughness and wind speed; k_i is the thermal conductivity of the ice cover.

Combining (4.92) and Eq. (4.93), it is known that the volume of ice melt can be written as:

$$V_{Melt} = \frac{\left[I^2R - \frac{t'_0 - t_a}{\frac{\ln\left(\frac{r_i}{r_c}\right)}{2k_i\pi} + \frac{1}{2r_i\pi h}}\right]\Delta t}{\rho\left[l + c_p(t_0 - t_s)\right]} \tag{4.94}$$

In this section, a variety of ice growth models are presented to calculate the ice growth over time. If ice melting measures have been taken during the actual disaster damage analysis process, the relevant research conclusions of Eqs. (4.92), (4.93), and (4.94) can be used as a supplement to the ice cover growth model, and the ice melting process can be considered in the calculation of ice cover growth. Construction of disaster damage assessment model for power grid equipment in rain, snow and ice disaster.

1) Hazardous forms of grid ice damage

The operational impact of ice and snow events on the power system is a gradual process with time scales ranging from a few hours to several days. When there is a severe ice and snow disaster weather, the surface ice thickness of the main equipment that is exposed to the environment such as lines, towers, and insulators increases, the corresponding mechanical components subject to external forces increase, including the gravity of the ice and increased wind due to the increase in the wind area of the line, and the insulation level of the insulator reduces; these factors will jointly lead to a reduction in the level of safety of the main equipment of the system.

The ice on the insulator will lead to a reduction in insulator strength, as it will cover the insulator surface with a water film, making the insulator susceptible to surface flashover which will cause tripping and lead to a further reduction in strength, thus forming a vicious cycle. For lines and towers, the continuous increase of ice cover will eventually make the corresponding power components unable to withstand the weight of ice cover and breakage or collapse of the tower and other accidents. Whether it is insulator flashover tripping, line breakage or tower collapse, it will cause changes in the system tide, the impact on power transmission. Also a long time and wide range of ice damage will affect transportation and may lead to insufficient fuel supply and limited power generation in thermal power plants, posing a great threat to the power system in terms of power supply.

2) Calculation model of transmission line load under ice-cover disaster
a) Line failure rate calculation

According to the principle of strength and stress interference model, when the ice-covered line is subjected to a load greater than its own strength; the line will fail. First define the limit state equation as:

$$Z(t) = \mathrm{R}(t) - \mathrm{S}(t) \tag{4.95}$$

where $R(t)$ represents the line strength at time t and $\mathrm{S}(t)$ is the total load on the ice-covered line at time t. Then, according to Stress and interference theory, $Z(t)$ is greater than 0 when the line is reliable; $Z(t)$ is less than 0 when the line out of operation.

According to the stress and strength interference model, the dynamic reliability index $\beta(t)$ of the line at time t can be calculated:

$$\beta(t) = \frac{\overline{R}(t) - \overline{S}(t)}{\sqrt{\sigma_{R(t)}^2 + \sigma_{S(t)}^2}} \tag{4.96}$$

where $\overline{R}(t)$ is the standard deviation of the predicted strength of the line at time t; $\overline{S}(t)$ is the predicted t moment of the total load carried by the line; $\sigma_{R(t)}$ is the standard deviation of the predicted strength; $\sigma_{S(t)}$ is the standard deviation of the predicted total load.

The span rate indicates the probability that the component is operating normally at time t and is withdrawn from operation due to a fault after time Δt, and can be written as:

$$\begin{aligned} h(t) &= \lim_{\Delta t \to 0, \Delta t < 0} \frac{P\left[Z(t) < 0 \bigcap Z(t+\Delta t) \leq 0\right]}{\Delta t} \\ &= \frac{\Phi[\beta(t), -\beta(t+\Delta t); \rho_z(t, t+\Delta t)]}{\Delta t} \end{aligned} \tag{4.97}$$

The span rate calculated by this formula is actually the aforementioned transmission line failure rate, characterized by the transmission line. The average failure rate in $[t, t+\Delta t]$ where Φ is a 2D standard normal distribution function; $\beta(t)$ denotes the dynamic reliability index at time t and $\beta(t+\Delta t)$ denotes the dynamic reliability index at time $t+\Delta t$; $\rho_z(t, t+\Delta t)$ is the correlation coefficient of the limit state equation at the corresponding two times.

b) Load calculation for ice-covered lines

The total load borne by the transmission line in the ice disaster climate includes ice load caused by snow and ice, wind load caused by wind speed and wind direction, and gravity load caused by its own weight. Among them, the calculation formula for wind load is:

$$q_m = 0.735\alpha(d + 2\Delta r)v^2 \tag{4.98}$$

where $(d + 2\Delta r)$ is the ice thickness; α is the wind speed unevenness coefficient, as in Table 4.7; v is the wind speed; d is the wire diameter.

The ice load on the transmission line is:

$$\mathrm{F}_i = 9.82 \times 10^{-9} \rho_i \pi d(d + \Delta r)L_h \tag{4.99}$$

where F_i denotes the ice load in kN; ρ_i is the ice density; d is the diameter of the conductor; L_h denotes the tower's vertical stall distance.

When the wind direction is the same as the ice load direction, the total load is maximum with:

$$S(t) = G + F_i(t) + F_w(t) = G + Q(t) \tag{4.100}$$

Table 4.7 Wind speed unevenness coefficient values

Wind speed v (m/s)	<20	20–30	30–35	>35
Wind speed unevenness coefficient α	1.0	0.85	0.75	0.70

where G is the gravity load and $Q(t)$ is the ice and wind load at time t. Theoretically, the ice and wind load $Q(t)$ obeys a normal distribution, and its predicted value at time t is expressed as $\overline{Q}_t$; the load uncertainty due to the prediction error is characterized by $\sigma^2 R$. In general, it can be considered that $\sigma_{Q(t)} = 0.15\overline{Q}_t$. In addition, since the load values of the line other than the ice and wind load are more stable, the total line load obeys a normal distribution and satisfies $\sigma_{S(t)} = 0.15Q(t)$.

c) Iced line strength treatment

Line strength R also follows a normal distribution with a standard value of $\overline{R}$. The line inevitably deviates from the standard due to errors in the production and installation process. There are errors causing the strength to deviate from the standard, and the uncertainty of the line strength is expressed as σ_R. The snow on the transmission line during the ice storm of snow and strong winds in the natural environment can affect the strength of the line, causing the line strength to decrease, and this change is time-dependent, so the line strength calculation formula is written:

$$R = R(0) - (R(0) - S_i)\left(\frac{t_i}{T}\right)^c \tag{4.101}$$

where $R(0)$ stands for the line design strength, S_i indicates the total load on the line; t_i is the line to withstand the load duration; T is the line design input life, in years; c takes a constant greater than i. Compared to the long design life of the transmission line, the duration of the line's ice cover appears insignificant; the ratio of t_i to T is the minimal value, so the strength loss of the line during ice cover can be ignored, i.e., when calculating the reliability of ice-covered lines, the strength of the lines is considered to be a time-invariant parameter:

$$R = R(0) \tag{4.102}$$

The line strength is calculated by the formula:

$$R = 1.0917Td \tag{4.103}$$

$$Td = \frac{0.6Tm}{k} \tag{4.104}$$

where R is the line strength; Td is the line maximum use tension; Tm is the pull-off tension; k is the safety factor, with a general value of 2.5.

When the total load S > R, the line is destroyed.

In summary, in this section, the ice growth rate model is constructed according to the ice type and meteorological conditions, the wind and ice load of the line is calculated, the damage discrimination conditions of the line are given in combination with the design carrying capacity of the line, and the damage assessment model of the line under the rain and snow freezing disaster is constructed.

4.3 Disaster Loss Model Validation and Optimization

4.3.1 Earthquake Disaster Cases

The model is constructed based on statistical principles based on existing data, and the model can be modified according to the actual disaster damage data of the grid equipment. In this project, the model was modified and optimized based on the actual damage data from the Ya'an earthquake in Sichuan, the Aba earthquake in Aba, and the rainstorm in Fujian and Jiangxi.

1) Earthquake of magnitude 6.1 in Lushan, Sichuan Province on June 1, 2022 and the damage caused

At 17:00 on June 1, a 6.1 magnitude earthquake was recorded in Lushan County, Ya'an City, Sichuan Province (30.40° N latitude, 102.99° E longitude), with a depth of 20 km. At 17:03; a 4.5 magnitude earthquake occurred in Baoxing County, Ya'an (30.37° N, 102.94° E). The earthquake was of magnitude 4.5 in Baoxing County, Ya'an (latitude 30.37° N, longitude 102.94° E). After the earthquake, State Grid Sichuan Power started the earthquake disaster level II emergency response at 17:20. After the earthquake, State Grid Sichuan Power started the earthquake disaster level II emergency response at 17:20, and carried out emergency disposal work according to the earthquake emergency plan, whose seismic intensity distribution map is shown in Fig. 4.28.

The impact of this earthquake on equipment above 35 kV is shown in Table 4.8.

2) Sichuan Markang 6.0 magnitude cluster earthquake on June 10, 2022

On June 10, 2022, at 00:03, a 5.8 magnitude earthquake occurred in Markang, Aba Prefecture, Sichuan Province (32.27° N latitude, 101.82° E longitude), with a depth of 10 km. An earthquake with a magnitude of 5.8 occurred at a depth of 10 km in Markang, Aba Prefecture, Sichuan Province, at 01:28 on June 10. A magnitude 6.0 earthquake occurred at a depth of 13 km in Malkang, Aba Prefecture, Sichuan Province (32.25° N, 101.82° E) at 1:28 a.m. on June 10, 2022. An earthquake with a magnitude of 5.2 occurred at 3:27 p.m. on June 10, 2022 in Markang, Aba Prefecture, Sichuan Province (32.24° N latitude, 101.85° E longitude), with a depth of 15 km. State Grid Sichuan Power upgraded its earthquake disaster level III emergency response to earthquake disaster level II at 02:40 on the 10th. The seismic intensity distribution map of the earthquake cluster is shown in Fig. 4.29.

The impact of the earthquake on equipment above 35 kV is shown in Table 4.9.

3) Model Comparison and Optimization

The model prediction results were compared with the damage of the power grid in the June 1, 2022, 6.1 earthquake in Ya'an, Sichuan, and the June 10, 2022, series of earthquakes in Markang, Aba, Sichuan, and the results showed that the information of equipment damage locations was generally consistent, and the damaged equipment

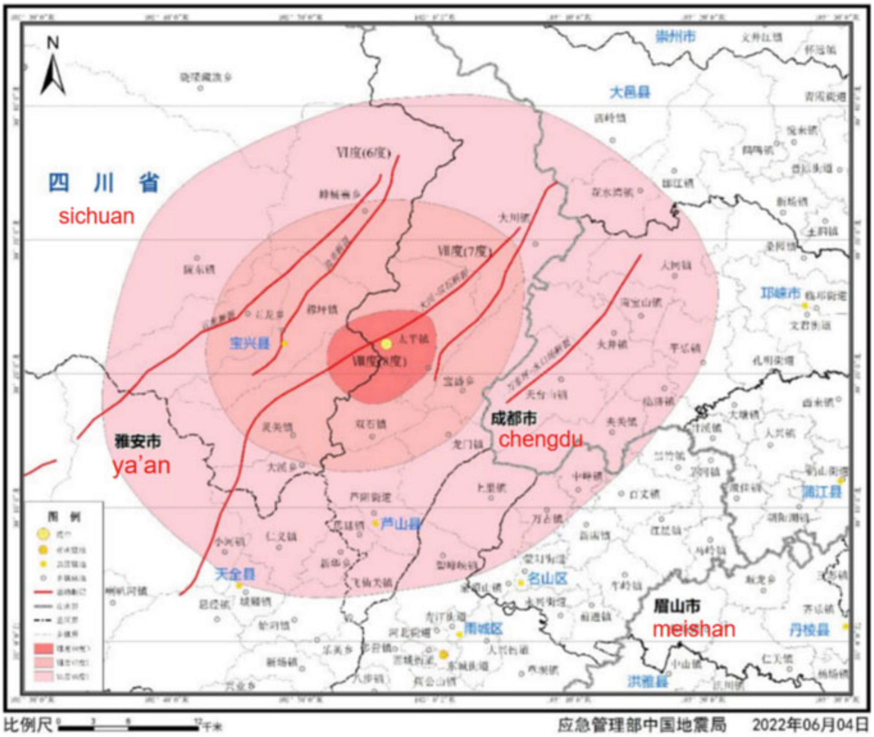


Fig. 4.28 Intensity distribution of the Lushan 6.1 magnitude earthquake in Sichuan Province on June 1, 2022

Table 4.8 Earthquake damage to power grid equipment above 35 kV in the Lushan 6.1 magnitude earthquake in Sichuan Province on June 1, 2022

Type	Voltage level/kV	Quantity	Name
Substation	110	1	Tagong Station
	35	11	Palmshuping Station, Panchao Station, Kongping Station, Baiyugou Station, Ringshutan Station, Xindu Station, Bridge Station, Kaganba Station, Shade Station, Pusarong Station, Gonggar Mountain Station, Bami Station
Line	110	1	New Tower Line
	35	11	Fengpan Line, Fenghuang Line, Xiangjin Line, Longkong Line, Taxin First Line, Taxin Second Line, Xinjia Line, Jiasha Line, Shagong Line, Shapu Line, Taqian Line

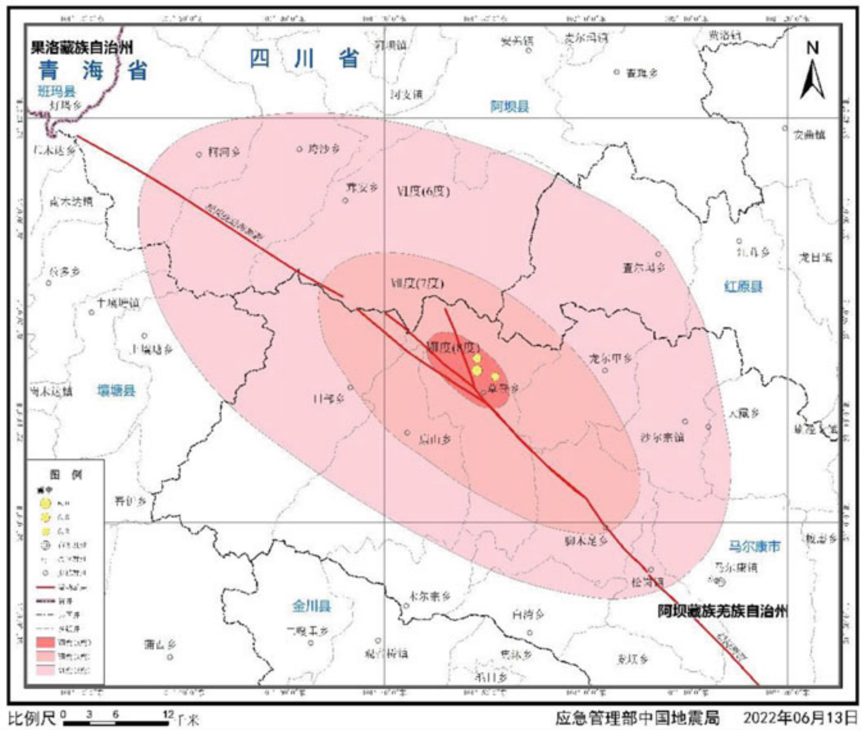


Fig. 4.29 Intensity distribution of the earthquake swarm of magnitude 6.0 in Markang, Sichuan, on June 10, 2022

Table 4.9 Earthquake damage to power grid equipment above 35 kV in the Markang 6.0 magnitude earthquake in Sichuan on June 10, 2022

Type	Voltage level/kV	Quantity	Name
Substation	35	4	CaoGe Station, Ercha Simple Substation, MengYan Simple Substation, ShaerZong Station
Line	35	2	Zhisha Line, Zhicao Line

predicted by the model also included the actual earthquake damaged equipment. In the next step, it is necessary to optimize the earthquake damage models of power grid equipment at different voltage levels to improve the accuracy of the models (Fig. 4.30).

In general, the probability of earthquake damage to power grid equipment can be described by the cumulative log-normal distribution function, as shown in Eq. (4.9). This project studied the effects of the 2008 Wenchuan earthquake, the 2013 Lushan earthquake and the current earthquake disaster, improved the prediction model for substation and line damage, and optimized the model parameters, as follows.

Fig. 4.30 Comparison analysis of earthquake damage model and actual damage data

According to Tables 4.10 and 4.11, combined with Eqs. (4.9)~(4.11), the seismic damage of the grid equipment can be evaluated based on the optimized parameters calculation.

Table 4.10 Optimization of line seismic damage assessment model parameters

Destruction status	K	110 kV		35 kV	
		λ	ξ	μ	σ
Minor damage	1	0.30	0.20	0.25	0.15
Moderate damage	2	0.40	0.20	0.35	0.20
Severe damage	3	0.55	0.40	0.45	0.40
Completely damaged	4	0.80	0.40	0.55	0.40

Table 4.11 Optimization of parameters of substation earthquake damage assessment model

Destruction status	K	110 kV		35 kV	
		λ	ξ	μ	σ
Minor damage	1	0.13	0.10	0.12	0.10
Moderate damage	2	0.26	0.15	0.22	0.15
Severe damage	3	0.34	0.20	0.32	0.20
Completely damaged	4	0.59	0.40	0.35	0.20

4.3.2 Storm Disaster Cases

In this section, the corresponding disaster damage models are modified and optimized based on the actual disaster damage data from the Ya'an earthquake in Sichuan, the Aba earthquake, and the rainstorm disasters in Fujian and Jiangxi.

At 18:00 on May 26, 2022, the Ministry of Natural Resources and the China Meteorological Administration (CMA) jointly issued a Geological Hazard Meteorological Risk Warning; the Ministry of Water Resources and the CMA jointly issued a Blue Flash Flood Meteorological Warning. At 18:00 on May 28, 2022, the Ministry of Natural Resources and the China Meteorological Administration jointly issued a meteorological risk warning for geological disasters; the Ministry of Water Resources and the China Meteorological Administration jointly issued an orange meteorological warning for flash floods; from 18:00 on May 28 to 6:00 on May 29, 2022, the Central Weather Station continuously issued a yellow warning for fog, a blue warning for rainstorm, a blue warning for strong convection, and a yellow warning for high temperature.

The model prediction results were verified by comparing the model prediction results with the damage to the power grid caused by the heavy rainfall in Fujian and Jiangxi on May 27–29, 2022, and the results showed that the model prediction location information was generally consistent, as in Fig. 4.31. However, some of the damage in the actual disaster was caused by secondary hazards (such as landslides and geological hazards), so it is necessary to construct a chain hazard model for the process of landslides induced by rainstorm. Therefore, it is necessary to construct a chain hazard model for the process of storm-induced landslides.

Precipitation is a key factor leading to the occurrence of landslides. Statistics show that the frequency of rainfall meteorology occurs during the flood season is significantly greater than other periods, and a large amount of rainfall plays a driving role in the breeding of geological hazards. Landslide hazards often occur during or after rainfall, and the degree of landslide development is enhanced with the increase of rainfall. Generally, the landslide probability density after precipitation can be written as:

$$f(Rr) = \frac{1}{\sigma_{\text{rain}}\sqrt{2\pi}} \exp\left(-\frac{(Rr - \mu_{\text{rain}})^2}{2\sigma_{\text{rain}}^2}\right) \tag{4.105}$$

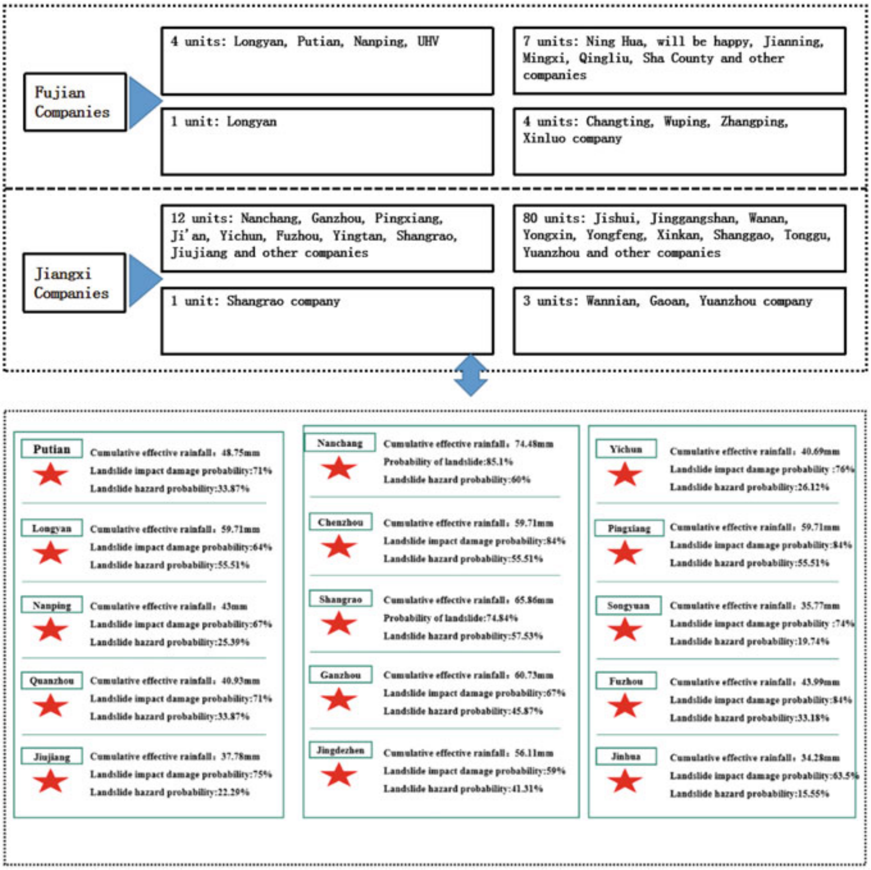


Fig. 4.31 A comparison analysis of landslide disaster damage model and actual disaster damage data

where σ is the standard deviation; μ is the expectation, and Rr is the effective precipitation, calculated from the daily average precipitation over a period of time, which can be written as

$$Rr = R_0 + \sum_{i=1}^{10} \omega_i R_i \tag{4.106}$$

R_0 is the precipitation of the day; R_i is the precipitation of the previous i days; ω is the weight; if for the first 10 days of precipitation $i = 1, 2, 3, \ldots, 10$ and $\omega_1 \sim \omega_{10}$ can be written as 0.84, 0.71, 0.59, 0.50, 0.42, 0.35, 0.30, 0.25, 0.21, 0.18.

Combining Eqs. (4.105) and (4.106), we can calculate the probability of rainstorm-induced landslide, and combined with the contents of Sect. 3.2, we can deduce and predict the disaster damage of power grid equipment in the "rainstorm-landslide" disaster chain.

4.4 Grid Loss Forecasting Technology

4.4.1 Overview

Based on the type of information, the fusion method is selected, the information integration and fusion method of disaster loss multiple information collection-disaster loss model library-emergency command comprehensive database is proposed, the information fusion technology of power grid emergency command comprehensive database and disaster loss model, fuzzy dynamic power grid loss prediction technology are studied, and the following conclusions are obtained:

(1) According to the data types, the multiple data fusion technology is studied, the information integration and fusion method of disaster damage multiple information collection-disaster damage model library-emergency command comprehensive database is proposed, the information integration and fusion technology scheme of multiple information collection-disaster damage model library-emergency command comprehensive emergency command comprehensive database is proposed, and the function and positioning of emergency command comprehensive data analysis module in emergency command system is designed.
(2) The proposed prediction model of disaster damage assessment under the combined effect of multi-hazard concurrency and disaster chains improves the accuracy of damage assessment of grid equipment by disasters and enables rapid damage assessment of grid equipment under multi-hazard concurrency, which provides a basis for emergency decision-making.

4.4.2 Grid Emergency Database Fusion Technology and Methods

(1) Data fusion techniques and methods
1) Artificial neural network (ANN)

The human brain is an extremely complex signal processing system composed of a very large number of neurons, which are interconnected in a very complex way and use a highly complex, nonlinear and parallel processing method to process signals. The artificial neural network (ANN) is a dynamic system that interconnects the nodes in a mathematical way to form a nonlinear, parallel processing system, drawing on the way and characteristics of signal processing by neurons in the human brain. Although artificial neural network is said to be a computing model that imitates the brain, it is not comparable to the neural operation of the brain, which is extremely complex to the extent that it is not yet clear to humans. The artificial neural network is an abstraction and simplification of the information processing of the neuronal network of the human brain, and the corresponding mathematical model is formulated and then simulated by computer technology. After the abstraction and simplification of the brain nerves, they become the nodes (also called elements) of the model; neurons are the basic processing unit of artificial networks, a large number of simple connections to form parallel distribution; this connection between neurons is the core idea of signaling and the key is the variable weights between neurons. BP neural network (Back Propagation neural network) means that the error is back propagated in the system according to the input layer of the network side, which is equivalent to the outside world. In fact, it means that the input layer of the error according to the network is equivalent to the external stimulus in the system, and the hidden layer in the middle region is the hidden layer of the signal transmission in the neural network to represent the outside world, and the result of the signal transmission in the neural network to represent the external element after multiple propagation. BP neural network architecture diagram is shown in Fig. 4.32.

The variables in Fig. 4.32 are defined as follows.

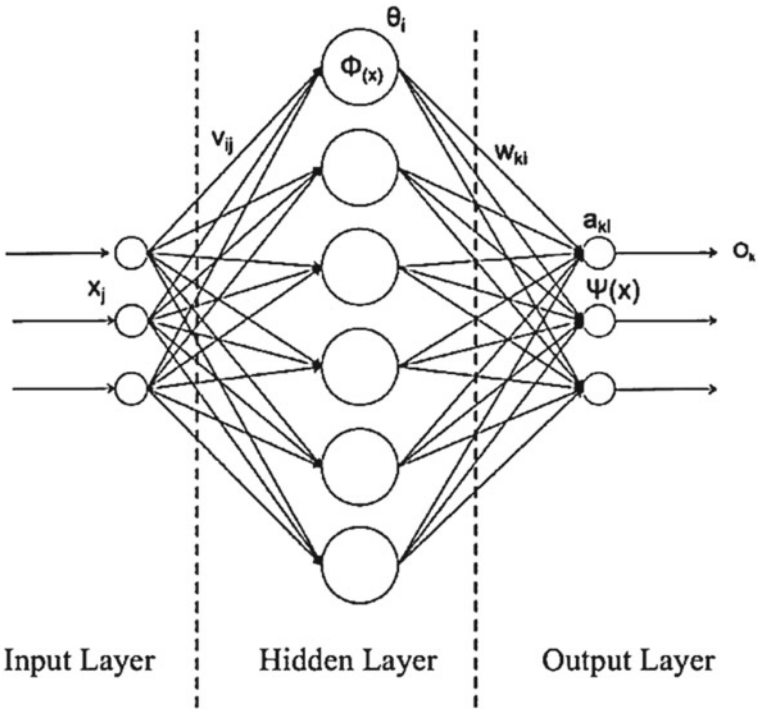


Fig. 4.32 Back Propagation neural network

x_j represents the input of the jth node in the input layer.
v_{ij} represents the weight from the ith node in the hidden layer to the jth node in the input layer.
θ_i represents the threshold value of the ith node in the hidden layer.
Φ(x) represents the activation function of the hidden layer in the neural network.
w_{ki} represents the weight value from the kth node in the output layer to the ith node in the hidden layer.
a_k represents the threshold of the kth node in the output layer.
Ψ(x) represents the activation function of the output layer.
o_k represents the output of the kth node in the output layer.

2) Particle Swarm Optimization (PSO)

PSO model: Particle Swarm Optimization (PSO) was introduced by Eberhart and Kennedy in 1995, and its basic idea is inspired by the foraging behavior of birds. Imagine a scene where a group of birds are randomly searching for food, assuming that there is only one food (optimal point) in the foraging area. Initially, all the birds do not know the location of the food, but they know the distance from their current position to the food. So what is the optimal method for searching for this food? The direct method is to focus on the bird that is currently closest to the food, and move to the surrounding area of that bird to search. In the PSO algorithm, particles represent individual birds in a flock and can be a number or vector, among other possibilities. Each particle is evaluated for its fitness through a fitness function. Each particle in PSO has a position and a flight velocity value. $X_i = (x_{i1}, x_{i2}, \ldots, x_{in})$ represents the current position of particle i, $V_i = (v_{i1}, v_{i2}, \ldots, v_{in})$ represents the current flight velocity of particle i, and $P_i = (p_{i1}, p_{i2}, \ldots, p_{in})$ represents the best position where particle i has experienced the highest fitness value. During the search process, the particle updates its velocity and position according to the following formulas:

$$\mathrm{vid} = \mathrm{w_{vid}} + \mathrm{c_1 randid(pid - xid)} + \mathrm{c_2 randpd(pgd - xid)} \tag{4.107}$$

$$\mathrm{xid} = \mathrm{xid} + \mathrm{vid} \tag{4.108}$$

The position of a particle is represented by a position vector xid, and its velocity by a velocity vector vid. The particle's personal best position is represented by pid, and the global best position by pgd. The acceleration factors c1 and c2, as well as the random numbers randid and randpd, are also involved in the update formula for each particle. Based on its personal best and global best positions, each particle dynamically adjusts its position and velocity until the optimal solution is found.

3) Data Cleaning Techniques

The huge scale, rapid growth, variety of types and differences in structure of big data of power disasters have become a practical problem that has to be faced. It is especially important to convert potentially valuable data into effective data that can be used, and data cleansing is essential to solve this problem. "Dirty data" can affect the quality of data, so data cleaning is an essential step. Only through cleaning technology to obtain clean and meaningful data and improve the quality of data, is it possible to obtain reassuring and specific intelligence through subsequent analysis and mining technology.

a) An overview of Data Cleaning Techniques

Statistical data on electric power disasters needs to be extracted from multiple business systems, which may bring erroneous or conflicting data that is clearly not usable, known as "dirty data". There may be intuitive and transparent "dirty data" in the database, which usually manifests as follows: incorrect values, duplicate records, spelling issues, values that do not meet requirements, null values, inconsistent values, destruction of data entity integrity, referential integrity, and user-defined integrity, etc. In addition, when data are extracted from multiple database sources, there may be inconsistent or redundant information due to the different design of the logical and physical structures of the databases. If not cleaned, this "dirty data" will contaminate the stored information, reduce the database's performance, disrupt the consistency between data, and affect the practical value of the data warehouse.

People have different research focuses on data cleaning techniques, so their understanding of it cannot be completely unified. In different fields, data cleaning has different status: in short, the process of improving data quality through detecting and processing "dirty data", synthesizing and resolving some data can be considered as data cleaning techniques.

b) The Basic Process of Data Cleaning

The core idea of data cleaning is to backtrack. Generally speaking, the basic process of data cleaning mainly includes four parts. The flowchart is shown in Fig. 4.33.

① Data Analysis

Data analysis refers to the analysis of the causes, types, and definition rules of "dirty data" in a database. It involves identifying constraint relationships among data attributes. In short, data analysis techniques can correct erroneous values, fill in missing values, and identify duplicate records caused by multiple data sources.

② Defining and Validating Cleaning Transformation Rules

Data cleaning rules are defined according to the number of data sources, the number of "dirty data" in the data sources and the appropriate algorithm. Of course, it is also necessary to validate and evaluate the correctness and efficiency of the defined rules. Cleaning experiments can be performed on small-scale data samples, and the rules can be continuously adjusted and improved based on the feedback results of the cleaning.

③ Cleaning dirty data

To prevent excessive cleaning and errors, it is necessary to back up the source data before cleaning. Then, based on the characteristics and properties of the "dirty data", different steps of cleaning work should be carried out.

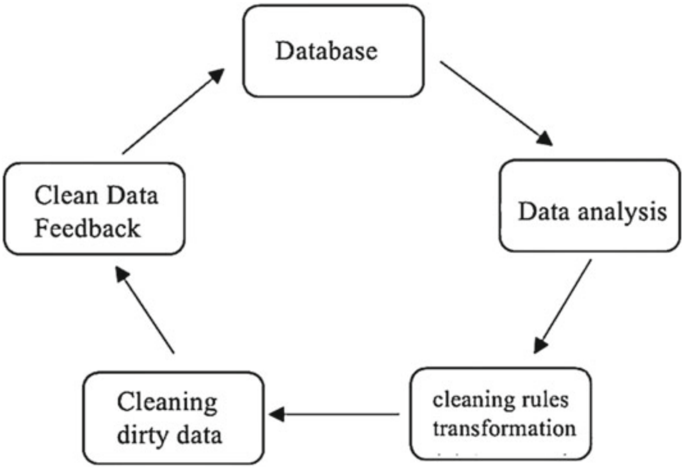


Fig. 4.33 Data cleaning process

④ The return flow of clean data

Once data is cleaned, the "clean" data can represent the entire dataset. This can improve data quality, reduce duplicated efforts, and save material and labor costs.

⑤ Objects for data cleaning

The main objects of data cleaning can be categorized into two types distinguished by pattern concept: one related to pattern-level data and the other related to instance-level data. The techniques used for data cleansing may differ depending on which of the two types is being targeted.

⑥ Data cleaning methods for pattern layer

Pattern-level data mainly include naming conflicts, attribute conflicts, and structural conflicts.

Naming conflicts can be divided into two parts: homonymy and synonymy. Homonymy refers to the situation where different data objects with different meanings adopt the same name in different applications, while synonymy refers to the situation where data objects with the same meaning have different names in different applications. Naming conflicts may occur in entities, relationships, or attributes. Naming conflicts may occur in entities, relationships, or attributes.

Attribute conflicts can be divided into two categories: conflicts related to attribute domain and conflicts related to attribute value units. Conflicts related to attribute domain may include conflicts related to the type of attribute values as well as conflicts related to the range of attribute values.

Structural conflicts refer to the situation where the same data object is represented differently in multiple data sources, which can result from inconsistencies such as differences in data types, keywords, violations of unique value constraints, violations of referential integrity constraints, or violations of user-defined integrity constraints.

⑦ Data cleaning methods for instance layer

There are mainly two types of methods for cleaning “dirty data” at the instance level, which are dealing with incorrect attribute values and handling duplicate records.

Attribute value errors mainly include empty values and erroneous values. Empty values can be divided into two categories: one is that the data exist but have not been stored in the database, and the other is that the data do not exist at all. Erroneous values refer to errors generated during the recording of original data or due to other reasons that cause the data to be incorrect.

Duplicate records are one of the most common problems in data cleaning, often caused by multiple data sources. Redundant data can affect the efficiency of querying and updating data warehouses, significantly reducing the value of database usage. Similarly, according to the number of data sources, the objects of data cleaning can be divided into two aspects: single data source data and multi-data source data. After simple combination with the pattern layer and instance layer data mentioned above, data quality problems can be classified into four categories: single data source pattern layer problems, single data source instance layer problems, multi-data source pattern layer problems, and multi-data source instance layer problems.

c) Attribute value cleaning

Data cleaning mainly includes methods for detecting and cleaning attribute value errors, as well as algorithms for detecting and cleaning duplicate records. The specific division of data cleaning work is shown in Fig. 4.34.

To clean up attribute value errors, it is necessary to first detect the existing errors, convert erroneous values to null values, and then handle null values. When the dataset

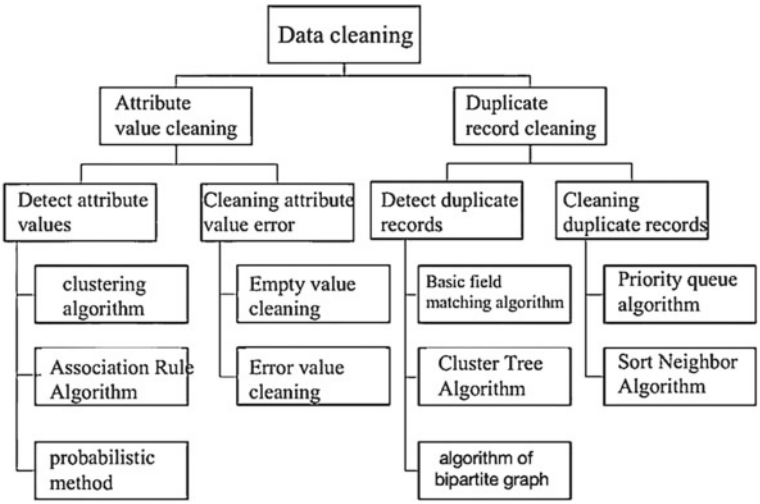


Fig. 4.34 Data cleaning work division

is large in scale, this can greatly reduce the workload and improve the efficiency of cleaning attribute value errors.

① Attribute value cleaning

There are roughly three methods for detecting attribute value errors: clustering algorithms, association rule algorithms, and probability-based statistical methods.

The clustering algorithm, also known as cluster analysis, is a method for categorizing multiple factors. Its core idea is to use mathematical methods based on various similarity and difference indicators to determine the closeness of samples based on their attributes, and to use different algorithms to cluster samples based on their closeness.

The association rule algorithm consists of two steps: the first step is to modify the rules using known knowledge, and an iterative algorithm is used to find all frequent, precise, and possible rule sets; the second step is to construct a classification using a heuristic method.

The most common method based on probability statistics is Chebyshev's theorem. The essence of Chebyshev's theorem is that for any data set, after calculating its mean and standard deviation, the proportion of data points that fall within n standard deviations from the mean is always at least $1-1/n^2$ (n is any positive number greater than 1), or equivalently, the proportion of data points outside of n standard deviations from the mean is no more than $1/n^2$. To illustrate, for a given dataset, if $n = 2$, it means at least 75% of the data fall within 2 standard deviations from the mean of the dataset; if $n = 3$, at least 88.9% of the data fall within 3 standard deviations from the mean. The formula for Chebyshev's theorem is usually represented as $P(\mu - n\alpha < X < \mu + n\alpha) \geq 1 - 1/n^2$, where X represents the dataset, n is the number of standard deviations,μ represents the mean of the dataset, and α represents the standard deviation of the dataset.

② Comparison of Algorithms for Detecting Attribute Value Errors

Cluster algorithms group a dataset into multiple clusters based on certain criteria, with highly similar data usually grouped into the same cluster and significant differences between clusters. Cluster algorithms are often used to detect isolated points that deviate significantly from normal data. Association rule algorithms are not easily affected by data distribution; although they can detect more "dirty data," it is difficult to detect exceptional isolated points. To balance the ability of cluster algorithms to detect isolated points and the characteristics of association rule algorithms to detect large amounts of data, a probability statistical method can be used, which can quickly and efficiently detect these "dirty data."

d) Duplicate record cleaning

Strictly speaking, in the real world, each entity can have a record that matches it. However, when there are multiple data sources, input errors and variations in data format and spelling may occur during the integration process, causing the database management system to fail to recognize multiple duplicate records of an entity. This can greatly reduce the value of the database's data utilization.

The harm caused by duplicate records mainly includes two aspects. Firstly, it destroys consistency. The use of different keywords to identify the same record in the database may complement each other to some extent, but it will cause data redundancy and even lead to data inconsistency. When the state of the entity changes, database administrators or database management systems may only update part of the duplicate records in some cases, leaving the remaining records unchanged. This may cause multiple records of the same entity to have inconsistent meanings, destroy information consistency, and make it inconvenient and inefficient to use data in the future. Secondly, it wastes resources. Duplicate records not only bring data redundancy but also waste valuable storage space of the database, increase management costs, reduce the cost-effectiveness of the database, and even cause dissatisfaction among data users.

In essence, cleaning duplicate records means deleting data, which has extremely important theoretical and practical significance for improving and optimizing the storage efficiency, operational performance, utilization value, and efficiency of storage systems. Firstly, duplicate records are detected, and after the screened dataset is obtained, only the first record of each batch of duplicate records is retained, and the rest of the duplicate records are directly deleted. The simplest and most primitive detection method is to directly compare each record in the data warehouse with every other record, but this algorithm is too cumbersome and resource-intensive, with a time complexity of $O(N^2)$, for example, if the total number of records is N, detecting duplicate records alone requires $N \times (N-1)/2$ comparisons. Therefore, the "sort and merge" method is used, which is also simple and clear. Its core idea is to first sort the dataset to be detected, and then compare adjacent records for equality. If they are equal, the records are merged or deleted.

The Sorted-Neighborhood Method (SNM) consists of three steps: selecting keywords from the data warehouse for sorting, sorting the records, and finally conducting the detection process by sequentially moving a sliding window over the sorted record set and comparing only the records within the window to determine if they are duplicates.

The first step of sorting is to select keywords from the data warehouse, in this case, five evaluation indicators are chosen as keywords. Secondly, radix sort is used to sort the keywords. Because the electric power disaster data being analyzed is roughly within the same range and the five indicators are used as keywords for sorting, and because the electricity consumption data have temporal characteristics, the statistical data roughly increases over time and is already roughly ordered, so radix sort is chosen for its convenience and efficiency.

The radix sort uses two basic operations, "distribution" and "collection", to perform the sorting. Here, we only introduce the least significant digit first sorting method: assuming that the record table to be sorted is composed of nodes a0, a2, …, an–1, each node has a d-tuple (kjd–1, kjd–2, …, kj1, kj0) as its key, where 0 ≤ kji ≤ r–1 (0 ≤ j < n, 0 ≤ i ≤ d–1). During the sorting process, r queues Q_0, Q_1, ..., Q_{r-1} are used.

① The sorting process involves "distribution" and "collection" steps for each$i = 0, 1, ..., d - 1$.
② distribution: At the beginning, the queue $Q_0, Q_1, ..., Q_{r-1}$ is cleared, and then each node $aj(j = 0, 1, ..., n - 1)$ in the linear table is examined in turn. If the key of node aj is equal to k, then the node aj is put into the queue Qk.
③ collection: After allocating each node to corresponding queues, we concatenate the nodes in each queue in order, forming a new linear list. The auxiliary space required for each sorting pass is r (the number of queues), so the space complexity of radix sort is O(r). Next, considering the time complexity, radix sort requires d passes of allocation and collection, each allocation pass takes O(n) time, and each collection pass takes O(r) time, and therefore the total time complexity of radix sort is O(d(n + r)).

A judgment window is set in a pre-sorted dataset, with a size smaller than the dataset size, for the purpose of searching and identifying duplicate records. Each time, only the records inside the sliding window are compared one by one to determine if they are duplicates. If the window size is w records, when the window moves, the first record in the original window is removed, and the new incoming record is compared with the original w-1 records to determine if it is a duplicate. After the use of the SNM algorithm to identify duplicate records, the first duplicate record is retained, and the remaining records are merged and deleted directly. The SNM duplicate record identification algorithm is shown in Fig. 4.35.

4) Research on Integrated Fusion Technology for Multi-Source Data
a) Basic Principles of Data Fusion

The fusion of multi-source information is a fundamental function that is commonly found in human or other biological systems. Humans utilize this ability to combine information from various sensors (eyes, ears, nose, limbs) in the body and use prior knowledge to statistically understand the surrounding environment and events occurring. The basic principles of multi-sensor information fusion technology are similar to the way the human brain integrates and processes information, making full use of resources from multiple sensors. By reasonably managing and using the observations

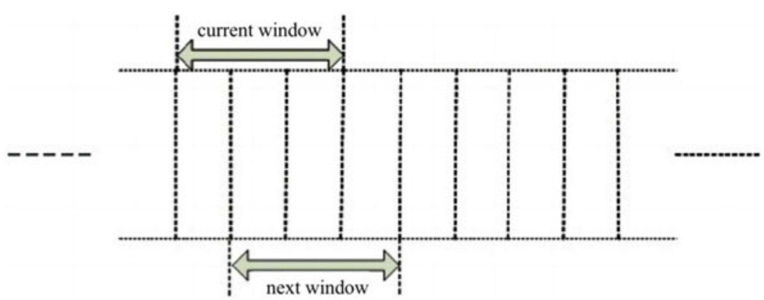


Fig. 4.35 SNM algorithm for determining duplicate records

and information from these sensors, we combine the redundant or complementary information in time and space from multiple sensors according to certain criteria to obtain a consistent interpretation or description of the observed object.

A data fusion system refers to the reasonable allocation and use of various types of real-time, non-real-time, accurate, fuzzy, fast-changing, slowly-changing, similar, or conflicting data from various data sources. Based on specific rules, redundant or complementary information is comprehensively analyzed and processed to obtain a comprehensive description of the measured object.

Specifically, the principles of multi-source data fusion are as follows:

① Collecting multiple types of data on the target.
② Extracting features from the collected data, where the feature extraction represents the characteristic vector of the target measurement data.
③ Utilizing artificial intelligence or other methods that can transform the target's characteristic vector into attribute decision mode recognition to effectively recognize and process the characteristic vector, in order to provide an explanation of the measured target based on the data collected from each sensor.
④ Based on the results of the previous step, the description data of the target is grouped together based on their associations.
⑤ By using appropriate fusion algorithms, the grouped data for each target can be synthesized to obtain a more accurate and consistent interpretation and description of the measured target.

b) Data Fusion Hierarchy

Based on the identification and alarm results data obtained by various warning and monitoring methods, the comprehensive data library and disaster-damage model library for power grid emergency command are constructed. The data are classified into unstructured, semi-structured, and structured data according to its characteristics, and information fusion technology is used to complete the fusion of the two. Structured data consists of clearly defined data types, and its pattern makes it easy to search. For computers, reading and processing structured data is relatively easy. Unstructured data has internal structure, but it is not structured through predefined data models or patterns. Semi-structured data, although it does not conform to the form of the relational database or other data table's structured data model structure, it includes relevant marks used to separate semantic elements and layer records and fields. For the data of the power grid emergency command comprehensive database and disaster-damage model library, various types of data information are automatically analyzed, synthesized, dominated, and used according to certain criteria, with full utilization of multi-source information resources at different times and spaces to obtain consistent descriptions and explanations with the tested object, in order to complete the required decision-making and estimation tasks, and to enable the system to perform data processing processes with better performance than its various components. According to the level of data abstraction, data fusion is classified into three levels: data-level fusion, feature-level fusion, and decision-level fusion.

Taking multi-sensor data fusion as an example, the data-level fusion process is shown in Fig. 4.36. Firstly, all sensor observation data are fused, and then feature vectors are extracted from the fused data and used for recognition and identification. Data-level fusion is the fusion and analysis of data directly on the collected raw data layer, before various sensor measurements are processed. This is the lowest level of fusion.

The advantage of data-level fusion is that it can maintain as much on-site data as possible and provide fine-grained information that other fusion levels cannot provide. However, it involves a large amount of basic data processing, which incurs high processing cost, long processing time, and poor real-time performance. This type of fusion is carried out at the lowest level of information, which requires high error-correcting ability in the fusion process due to the uncertainty, incompleteness, and instability of the sensor's raw information. Data-level fusion is carried out after a small degree of processing on the raw data, thus preserving as much raw information as possible. The fusion result has the best accuracy and can provide more intuitive and comprehensive understanding. However, this fusion method involves a large amount of data processing and has poor real-time performance.

The process of feature-level fusion is shown in Fig. 4.37. Representative features are extracted from the raw data provided by various sensors, and these features are fused into a single feature vector, which is then processed using pattern recognition methods. Therefore, some information compression is carried out before fusion, which is beneficial for real-time processing. At the same time, this fusion can preserve important features of the target, and the fused features provided are directly related to decision reasoning, based on which the properties of the target can be estimated. Its fusion accuracy is lower than that of pixel-level fusion.

The process of decision-level fusion is shown in Fig. 4.38. Decision-level fusion refers to the transformation of each sensor data source and obtaining independent identity estimates before fusion. Information is fused based on certain criteria and the

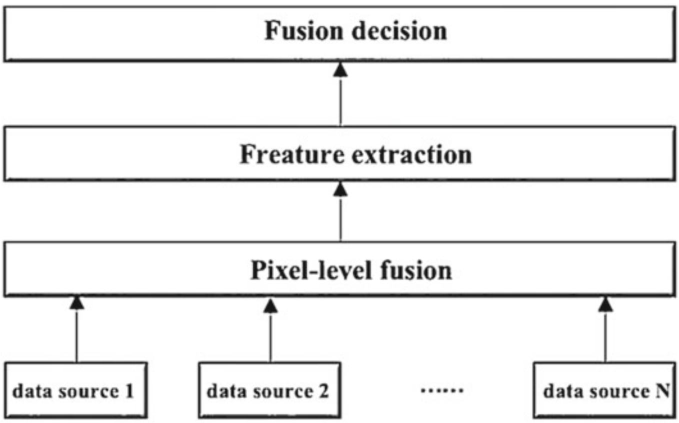


Fig. 4.36 Data-level fusion

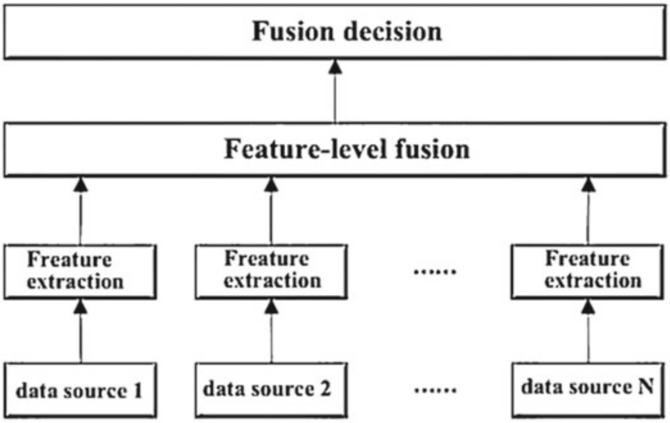


Fig. 4.37 Feature-level fusion

reliability of the decision to integrate the attribute decision results of each sensor, and ultimately obtain a consistent overall decision. The fusion data used at this level is relatively the highest level of attributes. This fusion method has good fault tolerance and real-time performance, and can be applied to heterogeneous sensors, and can also work normally when one or more sensors fail. However, its disadvantage is the high cost of pre-processing.

c) Multi-source information fusion

Multi-source information fusion, also known as multi-sensor information fusion, refers to the process of fully utilizing information resources from different sensors

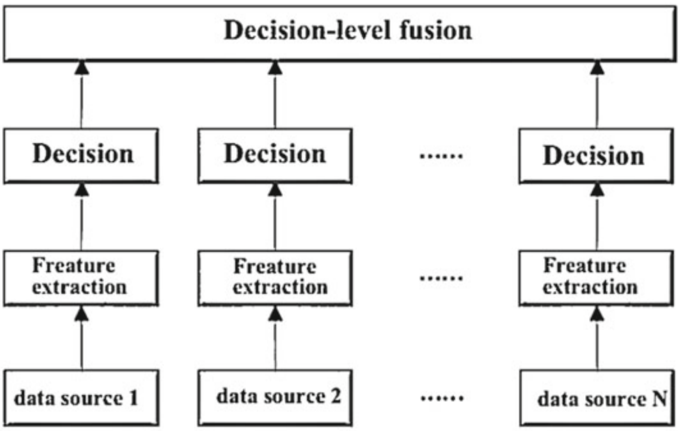


Fig. 4.38 Decision-level fusion

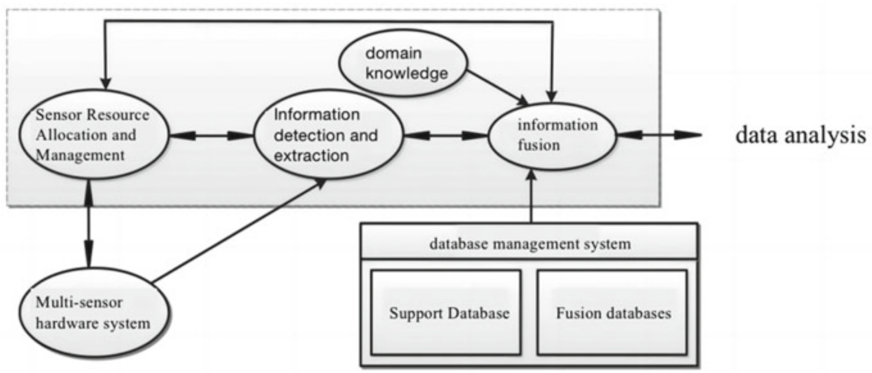


Fig. 4.39 multi-source information fusion system

at different times and spaces, using computer technology to automatically analyze, synthesize, and control multi-sensor observation information obtained according to a certain criteria, in order to complete the required decision-making and estimation tasks. Figure 4.39 shows the multi-source information fusion system, with the fusion subject represented by the dotted box.

Multi-source information fusion system fully utilizes and reasonably allocates multi-sensor resources, detects and extracts observation data, and then guides and manages sensors to achieve the best energy efficiency ratio for fusion based on relevant criteria and domain knowledge. Compared with individual sensors and subsets of system components, the entire system not only has more precise and clear reasoning and superior performance, but also has the characteristics of reducing the dimension of state space, improving measurement accuracy, reducing uncertainty, enhancing decision robustness, solving conflict problems, and saving costs. Therefore, it can be seen that the multi-sensor system is the hardware basis of multi-source information fusion, multi-source information is the processing object, and coordinated optimization and integrated processing are the core. Multi-source information fusion emphasizes the full spatiality, comprehensiveness, and complementarity of information.

Multi-source information fusion can be achieved through data-level fusion, feature-level fusion, and decision-level fusion. Data-level fusion directly processes the observation data from multiple sensors and performs feature extraction and decision-making are based on the fused results. Feature-level fusion involves each sensor abstracting its own feature vectors, which are then fused by the fusion center. Decision-level fusion involves each sensor making local decisions based on its own data, which are then combined by the fusion center. The hierarchical model diagram of the data fusion level, as well as its advantages and disadvantages are shown in Fig. 4.40 as below.

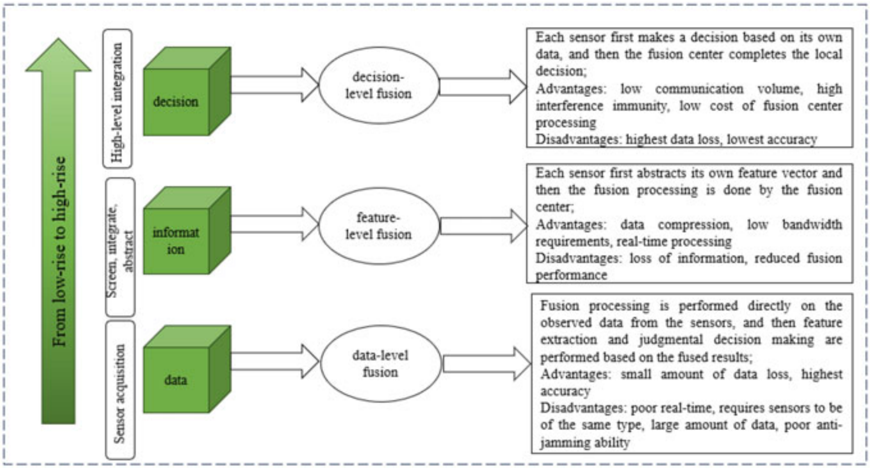


Fig. 4.40 Data fusion hierarchy model diagram

2) Multi-source Information Collection—Disaster Damage Model Library—Integrated Information Integration and Fusion Technology Scheme for Emergency Command Comprehensive Database
1) Research on Multidimensional Information Collection
a) On-site information collection

Field information includes equipment status, disaster damage, and environmental parameters. In this research project, field data will mainly be collected through sensors and image recognition.

The common information collection methods for power sensors and power transmission and transformation equipment include monitoring the operation and operating environment of the transmission equipment, which can effectively improve the perception and early warning capabilities when the transmission lines are covered with ice, tower inclination, and wire wind deflection arc. It plays an important role in realizing dynamic and full-time monitoring of the operating status of transmission equipment. For substation equipment, it mainly includes the core current of transformers, oil chromatography, GIS partial discharge, and insulation of lightning arresters. Online monitoring based on power IoT sensor technology not only can realize high-sensitivity collection of equipment operation information, but also realize the online management of pre-commissioning projects of substation equipment, so as to diagnose and evaluate the online operating status of equipment.

Image recognition technology is mainly used for identifying the overall damage of power equipment. The research on recognition algorithms is mainly based on emergency needs, and the results of the algorithm will be used to estimate the required resources for repairing power equipment and provide direct reference information for emergency decision-making. The process of using image information to identify electrical equipment is presented as follows, including image preprocessing, image registration, and image feature extraction. The image analysis process is affected by noise and other factors that are not conducive to image analysis during the image acquisition and transmission process. Therefore, the first step in image analysis is preprocessing to improve the quality of the image. The main method is to use a low-pass filter to remove image noise and improve the quality of the image. Image registration is not only necessary for the recognition of electrical equipment from infrared images to visible light images, but also for the comparison of images obtained during inspections with images in historical databases. Due to differences in angles and local regions during image capture, it is necessary to perform image registration for subsequent feature extraction. Feature matching based on the SIFT algorithm can be used to extract stable feature points and handle matching problems between two images that have undergone translation, rotation, affine transformation, and perspective transformation. The SIFT algorithm is robust to changes in illumination and can achieve high probability matching. Image features refer to the original characteristics or attributes of an image field. Some of them are natural features directly perceived by the image, while others are artificial features that need to be obtained through transformation or measurement. In inspection, the color, shape, and texture of the image can all be used as natural features, while grayscale, histograms, and infrared temperature differences can be used as artificial features for identification. Feature extraction should focus on the benefits of the extracted features for the accuracy and speed of the subsequent recognition process.

b) Public information collection

In this research project, it is proposed to collect data distributed in departments related to emergency power work, exchange data through the data center, and then integrate the data through a data exchange and sharing system. Governmental departments' warning and alert data (such as meteorology, land, forestry, and other related data from government functional departments) will be accessed through a data access platform. Afterwards, data exchange and review will be conducted through a data exchange and sharing system to provide effective technical solutions for data integration of the system.

2) Construction of Disaster Damage Model Library

Based on the disaster damage assessment models for earthquake, landslide, typhoon, heavy rain and flood, snow and ice disasters of power grid equipment developed in Chap. 3, mathematical model code implementation was carried out using Python language. Disaster-related multidimensional information is used as input parameters to the disaster damage assessment model to analyze the impact of disasters on power grid equipment. The input of multidimensional information and disaster damage assessment model library are shown in Fig. 4.41. The collected on-site and public emergency information are used as input parameters. According to the type

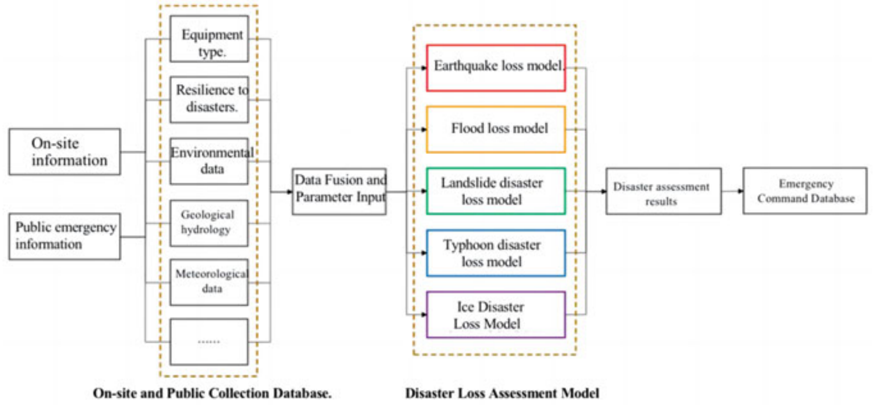


Fig. 4.41 Schematic diagram of disaster loss assessment model library

of disaster, corresponding disaster damage assessment models are inputted to obtain the assessment results, providing data support for emergency command.

3) Research on Integrated Database and Command System for Emergency Response

Based on the basic information of emergency command and disaster loss assessment, an emergency command comprehensive database is established as shown in Fig. 4.42. It comprehensively analyzes disaster site information, public emergency information, disaster loss information, power grid information, user information, emergency team and resource allocation, as well as public opinion and sentiment. The study focuses on the integration and fusion method of multi-dimensional information collection, disaster loss model library, and emergency command comprehensive database. A disaster loss prediction and analysis function module is designed and developed, which can be integrated into the power grid disaster situation intelligent perception and emergency command system.

The system provides modules for viewing warning and monitoring information, typhoon monitoring information, heavy rain and flood information, rain and snow and freezing information, earthquake information, landslide information, emergency response, work communication, public information, etc.

Typhoon monitoring includes typhoon path, satellite cloud image, radar image, nationwide power grid information, disaster information updates, and disaster damage perception. The typhoon path module allows users to view real-time and predicted paths, as well as information such as wind speed, air pressure, and movement speed. The satellite cloud image module displays current satellite cloud image information, overlaid with typhoon path information to assist in determining the current typhoon's development trend. The radar image module displays current radar image information, also overlaid with typhoon path information. The nationwide power grid information module shows the power grid GIS station line information.

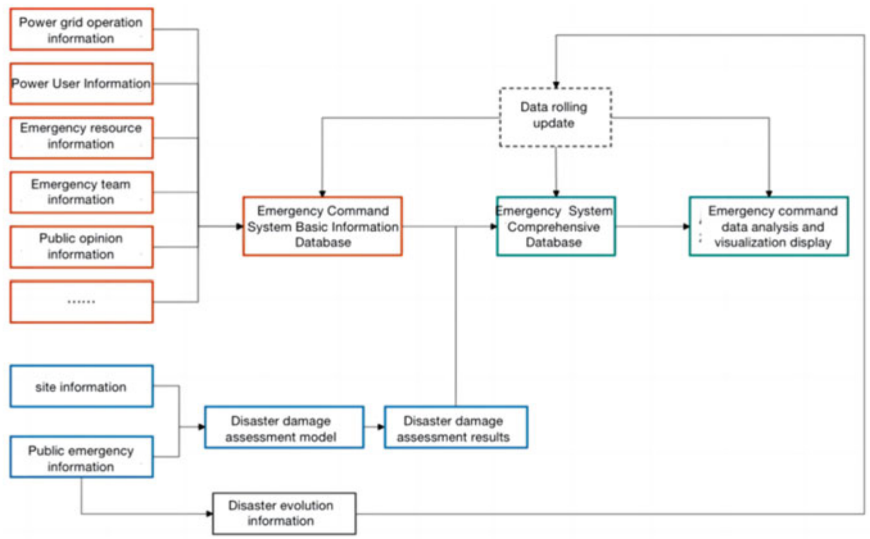


Fig. 4.42 Schematic diagram of emergency command data analysis

By analyzing the typhoon's path and predicted path, it is possible to assess the impact on substations, transmission lines, and power users, and predict the disaster damage. The disaster information updates include information bulletins and emergency situation alerts. Information bulletins report current disaster damage information using fixed templates, while emergency situation alerts allow for rapid reporting of on-site emergency situations via mobile devices. The disaster damage perception module includes both statistics and detailed information on disaster damage perception. Through unmanned aerial vehicle (UAV) images, the current status of equipment damage can be intelligently determined.

The monitoring of heavy rain and flood includes prediction of rainstorm damage, satellite cloud images, radar images, power grid GIS site information, disaster situation updates, and disaster damage perception. The rainstorm damage prediction provides information on current precipitation areas, effective precipitation amounts, and the probability of precipitation-related disasters. Satellite cloud images can be used to view current satellite cloud image information and assist in determining the current development trend of precipitation. Radar images can be used to view current radar image information and assist in determining the current development trend of precipitation. Power grid GIS site information can be displayed through the power grid GIS website, and the impact on substations, power lines, and distribution network customers can be analyzed based on the precipitation range and predicted precipitation amount. Disaster situation updates include information bulletins and risk situation updates. Information bulletins mainly report current disaster information through fixed information templates, while risk situation updates are mainly implemented through mobile devices to quickly report on-site risk situations. Disaster damage perception is divided into disaster damage perception statistics and disaster damage perception details. By using drone images, the current equipment damage can be intelligently determined.

The freezing rain and snow monitoring system includes snow disaster prediction, satellite cloud imagery, radar maps, power grid monitoring, disaster information updates, and damage assessment. Among them, the snow disaster prediction provides information on current snowfall areas, ice thickness, and total load rates per unit length. The satellite cloud imagery displays current satellite cloud information, overlaid to assist in determining the current snowfall trend. The radar maps provide current radar information, overlaid to assist in determining the current snowfall trend. The power grid monitoring system displays the GIS station and line information, and by analyzing the range and predicted snowfall, it can assess the impact on substations, power lines, and users in the area. The disaster information updates include both information bulletins and hazardous situation reports. Information bulletins report current disaster information using a fixed information template, while hazardous situation reports are submitted quickly through mobile devices to report on-site hazardous situations. The damage assessment includes both disaster assessment statistics and detailed disaster assessment. By using drone footage, the system can intelligently assess the damage to current equipment.

The earthquake information can be viewed based on different time periods of 3, 7, or 15 days, as well as based on different earthquake magnitudes, such as below 4.0, between 4.0 and 6.0, and above 6.0. The earthquake disaster situation report provides information on the affected area, including longitude and latitude, and predicts potential damage to equipment, such as substations and poles. The satellite cloud map displays current satellite cloud information, which can assist in determining the current weather conditions. The radar map shows current radar information and can assist in determining the current weather trends. The power grid GIS information system displays the power grid GIS station line information. By using the earthquake information, it is possible to analyze the impact on substations, power lines, and customers in the affected area. The disaster damage report is divided into information bulletins and risk reports. The information bulletin reports the current disaster damage information based on a fixed information template. The risk report provides a quick report of on-site disaster risks through a mobile device. The disaster damage perception system includes both statistics and detailed information. Through the use of unmanned aerial vehicles (UAVs), the system can intelligently determine the current equipment damage situation.

Landslide disasters include landslide damage prediction, satellite cloud maps, radar maps, power grid GIS site information, disaster situation updates, and disaster damage perception. Among them, landslide damage prediction can check current rainfall in landslide-prone areas, landslide disaster probability, and other information. Satellite cloud maps can display current satellite cloud map information and assist in judging the development trend of current rainfall and analyzing the possibility of landslide triggering. Radar maps can show current radar map information, assist in judging the development trend of current rainfall, and analyze landslide situations. Power grid GIS site information can display the site information of the power grid GIS, and through rainfall-induced landslides, analyze the affected situation of substations, lines, and user areas. Disaster situation updates include information bulletins and hazard situation alerts. Information bulletins mainly report current disaster damage information through fixed information templates, while hazard situation alerts mainly achieve rapid reporting of on-site hazard situations through mobile devices. Disaster damage perception includes disaster damage perception statistics and disaster damage perception details. Through pictures taken by drones, the current equipment damage can be intelligently judged.

In summary, this section has studied data fusion technology and methods, and proposed a technology scheme for integrating and fusing multi-source information from data collection, disaster damage model library, and comprehensive emergency command database. The functional design and positioning of the emergency command comprehensive data analysis module in the emergency command system have also been presented. This can provide data support and auxiliary reference for emergency command and decision-making.

4.4.3 Fuzzy Dynamic Grid Multi-Hazard Loss Prediction Technology

In recent years, meteorological and geological disasters such as typhoons, heavy rains, snow and ice, earthquakes, and landslides have occurred frequently, with strong destructive power and significant chain reactions, posing a great threat to power grid equipment such as towers, lines, and substations. Meteorological and geological disasters often do not occur alone, but are accompanied by secondary disasters or occur simultaneously with other disasters. For single meteorological and geological disasters, current power equipment damage prediction technologies, such as grey correlation degree, Petri networks, fuzzy evaluation, and artificial neural networks, can obtain relatively accurate prediction results. However, for power equipment damage prediction under multiple disasters or comprehensive disaster chains, such models are rare. After a disaster occurs, it is necessary to study multi-disaster fusion damage prediction models to quickly assess the extent of damage to power grid equipment under the combined effects of multiple disasters and disaster chains, predict the load loss and economic loss caused by the affected power grid equipment, and provide a basis for emergency decision-making.

Fuzzy dynamic power grid loss prediction can be divided into evaluations of multiple concurrent disasters and evaluations of comprehensive disaster chain effects. As shown in Fig. 4.43, multiple sources of information, such as meteorology, equipment, environment, and disasters, are fused with power grid equipment damage assessment models to evaluate the damage of power grid equipment under the concurrent effects of multiple disasters and under the comprehensive effects of disaster chains. The data fusion technology and methods as well as the disaster damage assessment model have been described earlier and will not be repeated here. This section will analyze and explore the fuzzy dynamic prediction of power grid equipment damage under the concurrent effects of multiple disasters and under the effects of disaster chains.

(1) Multi-hazard synergistic effects on power grid equipment damage prediction under fuzzy and dynamic conditions

A method of expert evaluation is used to predict the fuzzy and dynamic damage caused by multi-hazard synergistic effects on power grid equipment. Taking into account the actual conditions of power equipment design, construction and use, meteorological conditions, terrain and geological conditions, power equipment use time, maintenance frequency, disaster-resistant protective structures, etc. in a certain region, the degree of damage to power equipment (poles, lines, substations) caused by earthquakes, landslides, typhoons, heavy rain and flooding, and snow and ice disasters in the disaster-stricken area is evaluated. The weight value ω_{ij} of a single disaster damage is determined using the Pythagorean fuzzy set, and then the prediction result P_{d_i} of a single type of power grid disaster damage is obtained. The specific process is shown as follows:

(a) For power equipment within a certain region, the weight values of single disaster damage caused by typhoons, heavy rain, snow and ice, earthquakes, and landslides are evaluated separately. The membership degree μ_i and non-membership degree V_i of each disaster evaluation index are determined (where i = 1,2,3,4,5 represents earthquakes, landslides, typhoons, heavy rain and flooding, snow and ice, and j = 1,2,... represents different equipment), combined with Pythagorean fuzzy set theory, the hesitation degree and Pythagorean fuzzy entropy are calculated, and then the weight value of single disaster damage ω_i is obtained.

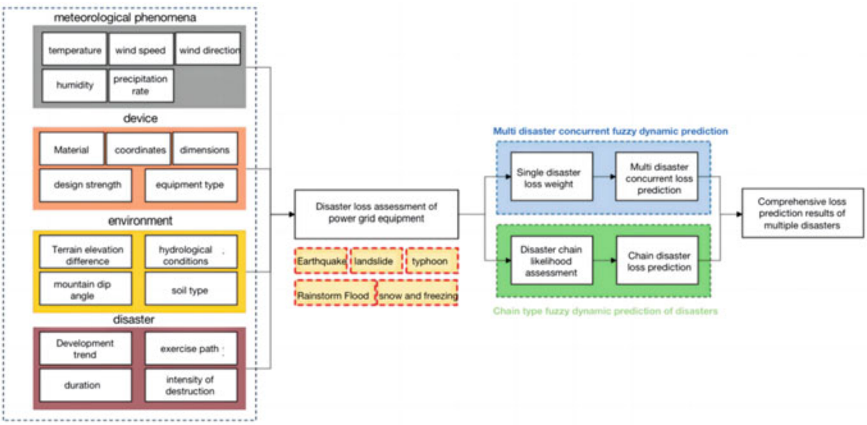


Fig. 4.43 Schematic diagram of fuzzy dynamic power grid loss prediction technology based on multi-source data

(b) The severity of damage caused by earthquakes, landslides, typhoons, heavy rain and flooding, and snow and ice to power grid equipment is separately predicted and calculated, and the results P_{ij} are obtained.
(c) Calculate the predicted damage of a single disaster to the power grid equipment.

$$P_{d_i} = \left[1 - \prod_{j=1,23} \left(1 - P_{ij}\right)\right] \times \omega_i \tag{4.109}$$

After the analysis of the occurrence of two or more disasters in the area, based on disaster rapid report information from meteorological agencies, earthquake bureaus, etc., the type of disaster is determined, basic information about the disaster is collected, and the impact range of a single disaster is assessed to predict the degree of damage to the power grid equipment. With the use of the single disaster damage weight value, the degree of equipment damage under the combined effect of multiple disasters is evaluated. For power grid equipment in a certain area, the overall probability of damage under the combined effect of multiple disasters can be expressed as P:

$$P = 1 - \prod_{i=1,2,\ldots} \left(1 - P_{d_i}\right) \tag{4.110}$$

In the equation, the value of i is determined by the actual type of disaster, with $i = 1, 2, 3, 4, 5$ representing earthquake, landslide, typhoon, torrential rain and flood, and rain and snow and ice disasters respectively. For a certain equipment, the degree of damage under the combined effect of multiple disasters can be expressed as:

$$P_{s_j} = 1 - \prod_{i=1,2,\ldots} \left(1 - \omega_i \times P_{ij}\right) \tag{4.111}$$

In summary, based on the research in Chap. 3, the degree of damage to power grid equipment caused by a single disaster can be evaluated. On this basis, the probability of damage to power grid equipment under the combined effect of multiple disasters can be calculated using Eqs. (4.109) to (4.111), and the prediction and assessment results of power grid equipment disaster damage under the combined effect of multiple disasters can be obtained.

(2) Chain-type disasters, combined with fuzzy dynamic prediction of power grid equipment damage

For the fuzzy dynamic prediction of the cascading effects of chain disasters on power grid equipment damage, based on the degree of power equipment damage P_d caused by a particular disaster, the probability ε of triggering secondary disasters or disaster chains is analyzed. With the results of the single disaster damage prediction combined, the damage degree of power grid equipment under the comprehensive effect of the disaster chain can be evaluated and expressed as P_H.

$$P_H = 1 - \left(1 - P_{d_i}\right) \times \left(1 - \varepsilon \times P'_{d_i}\right) \times \left(1 - \varepsilon' \times P''_{d_i}\right) \times \mathrm{L} \tag{4.112}$$

where P'_{d_i} is the degree of damage of the secondary disaster grid equipment; ε' and P''_{d_i}, is the prediction of the possibility of secondary disaster and the degree of damage of the equipment.

Equipment failure rate varies depending on the time of use, considering that the accuracy of equipment failure rate prediction can be improved. The distribution of equipment life cycle can be described by the Weibull distribution, and the failure rate function can be written as:

$$h(t) = \frac{1}{2\sqrt{t}}\left[\alpha + \beta(1 + 2\lambda t)\exp(\lambda t)\right] \tag{4.113}$$

where $h(t)$ denotes the failure rate of the equipment at t years of operation, $\alpha \geq 0$, $\beta \geq 0$ is the shape parameter, and $\lambda \geq 0$ is the acceleration parameter. Then the degree of damage P_S^* of a certain equipment considering the equipment failure rate can be written as:

$$P_s^* = 1 - \left(1 - P_{s_j}\right) \times (1 - h(t)) \tag{4.114}$$

The above analysis shows that for chain disasters, in addition to analyzing the damage of primary and secondary disasters to power grid equipment, it is also necessary to consider the causal relationship between primary and secondary disasters and establish a relationship formula for the primary-secondary disaster chain. The comprehensive evaluation of the impact of chain disasters on power grid equipment is then carried out.

In summary, this section has studied the fuzzy dynamic prediction technology for electric power grid equipment disaster damage under multiple concurrent disasters and chain disasters. A disaster damage assessment model has been constructed, which can achieve rapid assessment of electric power grid equipment disaster damage under multiple concurrent disasters and chain disasters.

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Chapter 5
Real-Time Interaction Technologies for Grid Emergency Information

5.1 Status of Research on Emergency Interaction Technologies

As an island nation, Japan experiences many large and small earthquakes, typhoons, tsunamis, and other natural disaster events every year, prompting Japan to become one of the countries that place the greatest emphasis on emergency management. In order to effectively respond to various disasters, Japan has built a series of emergency communication systems to serve disaster prevention and mitigation efforts and has achieved remarkable results. In Japan, besides the central disaster prevention wireless network and fire prevention wireless network, which are mainly governmental functions, there are also disaster prevention wireless networks which mainly involve various autonomous bodies and local residents, and the whole emergency communication network is very well developed.

Some foreign developed countries started earlier in the field of emergency communication and have formed their own distinctive emergency management mechanisms and technical support systems, and mature and full-featured emergency communication products have been tested for a long time in actual use, but the command and control of the communication systems at home and abroad are different and cannot be directly introduced for application. In addition, the imported equipment is not suitable for nationwide deployment since it is expensive and has high maintenance costs.

Emergency communications in China began in the 1970s and was initially used for strategic reserve work as an emergency communications backup for the government and the military in special situations. With the national work emphasis shifting to economic construction, special communications gradually evolved into emergency communications based on the policy of combination of ordinary and military application, and were developed rapidly in the 1990s.

At present, China's emergency communication business is at a stage of high-speed development. Since 2006, governments at all levels nationwide have started

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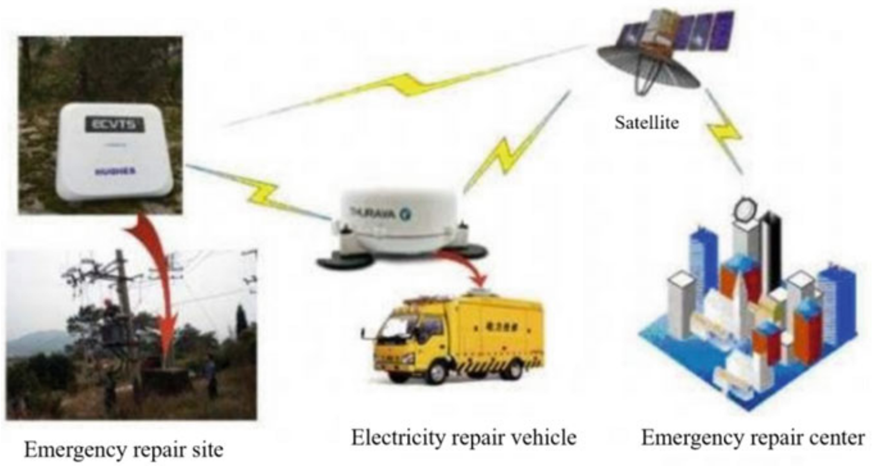

Fig. 5.1 Power emergency communication interaction system diagram

to comprehensively build emergency platform systems at the request of the State Council, with the provincial and municipal levels establishing emergency command centers and the county level deploying small mobile emergency platforms. Currently, some regions have completed the construction and deployment of large, medium and small emergency platforms, and played an important role in dealing with Wenchuan earthquake, Yushu earthquake, Zhouqu mudslide and other emergent public events, Fig. 5.1 shows the current power emergency communication interaction system in China.

However, the small mobile emergency equipment currently available in the country is either not well integrated and used with too much wiring erection work, or too large in size and weight to be portable, or the communication interface is single and not flexible enough to cope with complex on-site situations. Therefore, given that the current small mobile emergency equipment has many disadvantages, there is still much room for research and improvement.

5.2 Power Emergency Site Real-Time Interaction Technology

5.2.1 Audio and Video Codec Technology

Due to the high levels of maturity of coding and decoding technology, we plan to use the H.264 video coding and decoding algorithm and the G.729 audio coding and decoding algorithm for efficient real-time coding and decoding of remote assistance audio and video data streams. By adapting audio and video coding and decoding

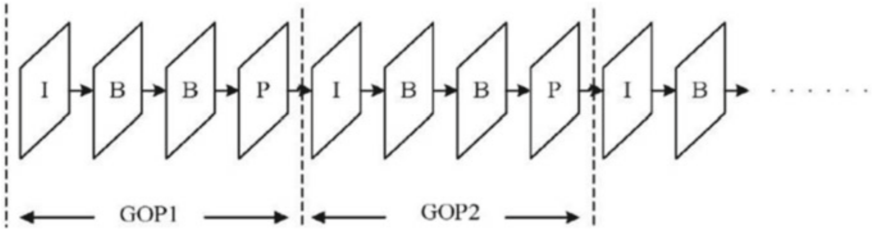

Fig. 5.2 Image group structure diagram

algorithms under different technical architectures, we can achieve support for cross-platform terminals.

(1) H. 264 video stream encoding and decoding technology

The H.264 video sequence is divided into groups of pictures (GOP), pictures, groups of slices, slices, macroblocks, sub-blocks, and blocks based on its coding hierarchical structure. The encoding and decoding process is as follows:

1) Image group

The video sequence is first divided into a series of picture groups, each of which contains multiple images. The number of images can be fixed or set according to actual needs. The arrangement of frames in each image can be the same or different. The structure of the picture group is shown in Fig. 5.2.

Each picture group contains only one I-frame and several B-frames and P-frames. The I-frame uses intra-frame prediction coding, which has a comparatively low compression efficiency, while the B-frames and P-frames mainly use inter-frame coding, which has a comparatively high compression ratio. Although the compression ratio of B-frames and P-frames is high, too many inserted B-frames and P-frames will lead to error accumulation and affect the encoding quality, especially in the case of video sequences with intense motion and scene changes, which are more likely to cause mosaic images. Therefore, the length of the picture group needs to be set according to the actual application, and the number and arrangement of inserted B-frames and P-frames need to be determined.

2) Image

The H.264 standard supports frame, field, and frame-field adaptive coding. When field coding is used, a frame is divided into two parts, the top field and the bottom field, which are encoded separately. An image is not just a physical image but a collection of top and bottom fields, frames, and so on. Since both unidirectional prediction (such as in P frames) and bidirectional prediction (such as in B frames) are commonly used in predictive coding, there are differences between the coding and display of images. During image display, P frames are displayed after the reference I frame, while B frames are displayed between the reference I frame and the P frames, as shown in the figure below. When predictive coding is used as a reference image, the P frames

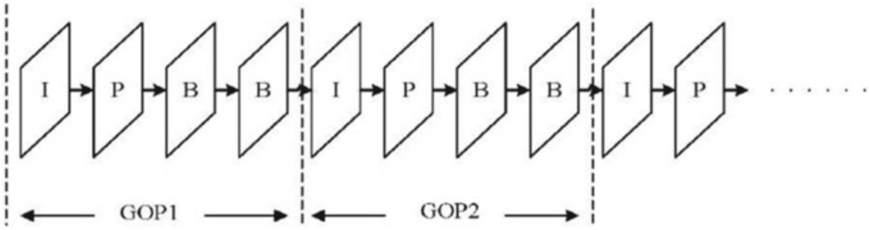

Fig. 5.3 Reference image sequence

come after the I frame which is used as a refrence frame, while B frames come after the I and P frames which are used as reference frames, as shown in Fig. 5.3.

3) Slice group

The concept of image type is related to encoding, while the slice is the largest encoding unit in H.264. An image can be divided into one or more slices, each of which contains several macroblocks, including I, P, B, SP, and SI types. The I slice only uses intra-frame prediction, the P slice can use intra-frame and forward inter-frame prediction, and the B slice can use intra-frame, forward frame, and bi-directional frame prediction. The SP and SI types are extended functionality for switching between different bitstreams. Each slice group contains one or more slices and indicates the mapping between slices and the image. The decoding end restores the decoded macroblocks into a complete image according to the mapping method of the slice group.

4) Macroblock

The macroblock is the basic coding unit of the H.264 standard with a size of 16 × 16 pixels. The encoding process of H.264 can be simplified as the process of encoding each macroblock in the image. Each macroblock corresponds to a slice, and the type of the slice determines the method of macroblock prediction coding.

According to the intra-frame and inter-frame coding methods, a 16 × 16 macroblock can be subdivided into several sub-blocks, each of which corresponds to a different prediction mode. Intra-frame prediction can use two different sub-blocks of 16 × 16 and 4 × 4, and four prediction modes can be used in the 16 × 16 mode, while nine prediction modes can be used in the 4 × 4 mode. During encoding, all predictions need to be calculated, and the optimal prediction mode for the macroblock is selected based on the error calculation standard. Compared with intra-frame prediction, inter-frame prediction is more complex. There are not only four modes of 16 × 16, 16 × 8, 8 × 16, and 8 × 8, but also three modes of 8 × 4, 4 × 8, and 4 × 4 for each 8 × 8 sub-block mode. During encoding, all partitions of each 16 × 16 macroblock are calculated for error, and the partition with the least error is selected for encoding.

The H.264 codec is composed of several functional modules, including prediction, transformation, quantization, and others, and its process structure is shown in Figs. 5.4 and 5.5.

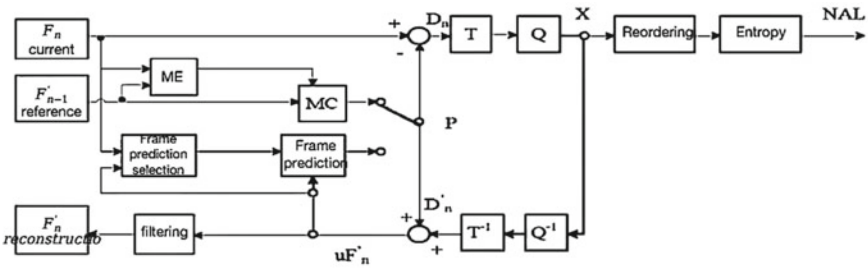

Fig. 5.4 H. 264 encoder structure

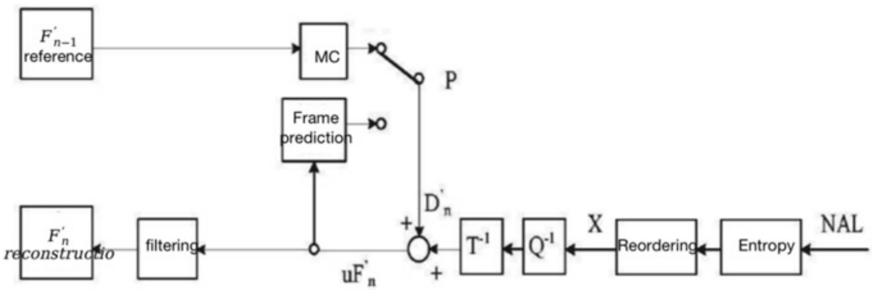

Fig. 5.5 H. 264 decoder structure

It can be seen from the functional module structure of the encoderthat H.264's encoder also uses a hybrid coding method that combines transformation and prediction. It processes the images of the input frame or field in macroblocks. If intra-frame prediction is used for encoding the current input image, the predicted value is obtained by motion compensation of the reference image that has already been encoded in the current slice. In order to improve prediction accuracy and compression ratio, the reference image actually used can be selected from past or future frames that have been encoded, decoded, reconstructed, and filtered. In other words, the frames that participate in encoding may be involved in decoding, filtering, and other reconstruction processes, and are used as reference frames for subsequent encoding.

The functional realization of the H.264 decoder is actually the implementation of the reconstruction chain in its encoder, which involves processing the input NAL data stream through entropy coding and other related preprocessing operations to obtain a set of transform coefficients X before inverse quantization. Then, similar operations to the reconstruction chain are performed to output the decoded image. A key to correctly reconstructing the decoded image is to pass the related parameters used in the encoding to the decoder for decoding, so the parameter sets SPS and PPS are very important for correct decoding in the decoder.

(2) G. 729 Audio Stream Encoding and Decoding Technology

G.729 is an 8kbit/s speech coding standard that uses Conjugate-Structure Algebraic-Code-Excited Linear Prediction (CS-ACELP). It was published by the International Telecommunication Union (ITU-T) in 1996.

The G.729 encoder uses the Code Excited Linear Prediction (CELP) encoding mode principle. The encoder runs on a 10 ms speech frame, which corresponds to 80 samples which sample at a rate of 8000 times per second. For each 10 ms frame, the speech signal is analyzed to extract the parameters of the CELP mode (linear prediction filter coefficients, adaptive and fixed codebook indices, and gain), which are encoded and transmitted. At the decoder side, these parameters are used to recover the excitation and synthesis filter parameters. The speech is reconstructed by filtering the excitation through a short-term synthesis filter. The short-term synthesis filter is based on a 10th-order Linear Prediction (LP) filter. The long-term or pitch synthesis filter is implemented by using a so-called adaptive codebook method. After calculating the reconstructed speech, it is further enhanced by a post-filter. The reconstructed speech is further enhanced by a post-filter after it has been calculated.

The audio coding principle used is shown in Fig. 5.6. As can be seen from the figure, the process of processing speech and obtaining transmission parameters is as follows: the prediction coefficients are obtained from the preprocessed speech signal. In the encoder, the reconstructed speech signal is used as the target signal for adaptive and fixed codebook search after being perceptually weighted. The target signal for pitch period analysis is obtained to determine the pitch period. The target search signal for the residual signal after removing the pitch period is obtained by using fixed codebook search. The adaptive and fixed codebook excitation is used to reconstitute the target signal through a synthesis filter. This process is the same as the speech synthesis process in the decoder, and the parameters are encoded and transmitted.

During decoding, the decoder first extracts the index of the parameters from the received bitstream. These indices are decoded to obtain the coding parameters corresponding to a 10 ms speech frame. These parameters include the long-term prediction coefficients, two fractional pitch delays, two fixed codebook vectors, and two sets of adaptive and fixed codebook gains. The LP coefficients are interpolated within each subframe and converted to LP filter coefficients. Then the following steps are performed for each subframe:

1) Construct the excitation by adding the adaptive codebook vector and the fixed codebook vector which are scaled by their respective gains.
2) Reconstruct speech by filtering the above excitation through the LP synthesis filter.
3) The reconstructed speech signal goes through a post-processing stage which includes an adaptive post-filter based on long-term and short-term synthesis filters, a high-pass filter, and a scaling operation.

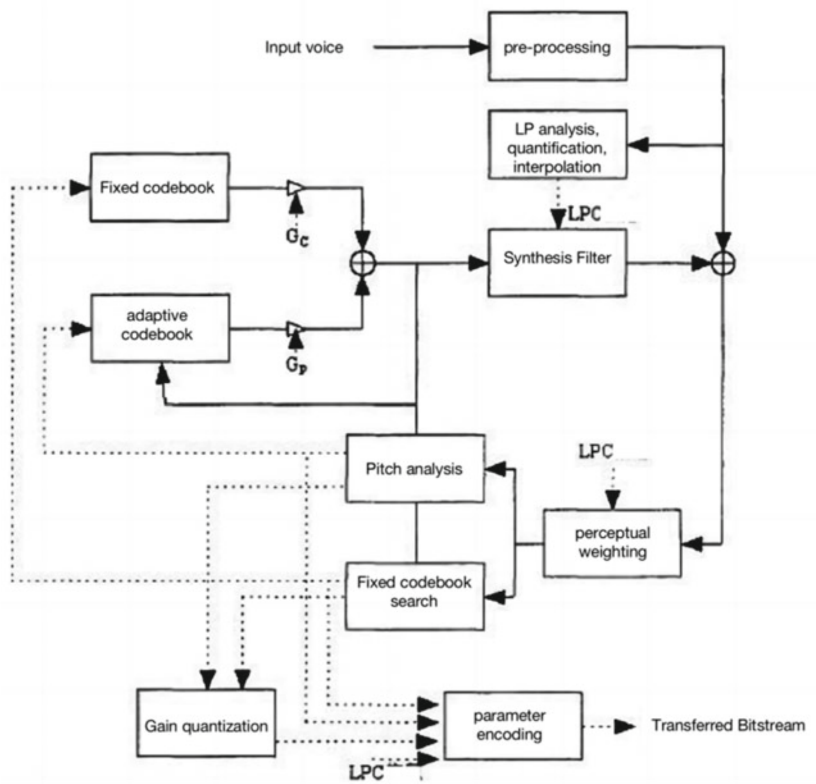

Fig. 5.6 Encoding principle of G.729 encoder

5.2.2 Audio–Video Synchronization Technology

How to fairly provide streaming media services and traditional data services on TCP/IP networks is a core issue that needs to be considered by the network transmission control protocol. In addition, the delay, jitter, network congestion and other factors in TCP/IP network transmission cause a mismatch between the sending speed of the streaming media sender and the receiving speed of the receiver, which has an important impact on the quality of real-time media services, leading to media jitter (discontinuity) and poor matching between media (asynchrony) during media playback at the receiving end. Research on real-time multimedia transmission and synchronization is an important step to ensure the quality of multimedia services and is one of the key technologies in multimedia research.

The multi-party audio and video synchronization technology based on relative timestamps adopts the method of separately processing the relevant media, that is, processing the audio and video streams separately. The usual method is to use the initial playback time and RTP timestamp to coordinate the playback of audio and video data on the receiving end. When the receiving end receives a frame of data, it calculates the difference between the timestamp of that frame and the initial RTP timestamp, as well as the difference between the current time and the initial playback time, to determine whether the frame should be played and whether it is synchronized. However, as the receiving end continues to receive new data, it is necessary to continuously calculate and compare the time difference between each frame of audio and video data. In this method, there is no direct synchronization relationship between audio and video, but only references their respective timestamps and controls the playback of their own data separately using the same local time. Additionally, when the playback rate of audio or video data falls behind, it is necessary to continuously process multiple RTP packets to find a new synchronization point, that is, to find a frame of data that can correspond to the local clock. Therefore, it is necessary to find a method that can directly reflect the synchronization relationship between the audio and the video, and can quickly find a new synchronization playback point when their playback rates are inconsistent. The video capture and the audio capture theoretically start at the same time, but due to the sequential execution of the program, the starting time of the video capture and that of the audio capture must be different, resulting in different encoding starting times. First, start the video capture thread, then immediately start the audio capture thread, and record the time difference between the video capture time and the audio capture time. Secondly, calculate the number of video frames that should be discarded based on the capture rate of the video and that of the audio, and then start the video and audio encoding threads. Video frames should be discarded before starting the encoding process. The system's video bitrate is 29.97 frames per second and the audio frame size is 10 ms. The encapsulated video RTP packets and audio RTP packets are respectively stored in the video send buffer and audio send buffer of the sender, the video packets and the audio packets of the same sequence number being sent at the same time. If timestamp method is used to transmit data, there is no need to change the data stream or attach a synchronization channel. The disadvantage is that the selection of relative timestamp and the determination of timestamp operation are rather complex, and an amount of overhead is needed for synchronization operation. In addition, when the transmission rate of the video or audio data packets lags behind, it is necessary to continuously process multiple RTP packets to find new synchronization points. The proposed method can directly reflect the synchronization relationship between the video and the audio, and when their transmission speeds are different, a new synchronization playback point can be found quickly. This solution introduces an index for the video package in the RTP packet header of the audio frame. This index indicates the sequence number of the first RTP package of the video frame played simultaneously with the audio frame and can be implemented through the extension structure of the RTP packet header.

The index relationship between the audio frames and the video frames is shown in Fig. 5.7. The number above the audio data packet is its own RTP sequence number, and the number below is the RTP sequence number of the corresponding video data packet. The reason for adding the index number to the audio packet is that on the one hand, people are more sensitive to changes in sound, and on the other hand, the

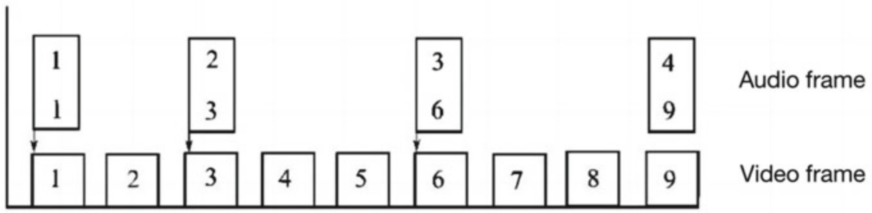

Fig. 5.7 Index relationship between the audio frames and the video frames

data volume of the video is larger than that of the audio, and usually the lack of synchronization is caused by the lagging of the video.

Using this synchronization scheme has the following three advantages: First, when the audio and the video at the destination are not synchronized, there is no need to process multiple RTP data packets continuously until a new synchronization point is found. This not only reduces the processing burden on the destination but also speeds up the synchronization process. Second, it is beneficial for the source to adjust the data transmission rate to adapt to changes in network bandwidth. When network congestion occurs, the sender needs to reduce the transmission rate. At this time, a frame dropping strategy can be used, which means only sending keyframes of the audio data index. This can adapt to network jitter faster. Finally, the index number is directly implemented through the extension structure of the RTP packet header. The method is simple to operate, less costly and is real-time. It does not require a synchronization clock and has good compatibility.

5.2.3 Audio and Video Transmission Technology

(1) Transmission control and congestion control technology

The system uses G.729A audio codec, H.264 video codec, and RTP real-time transmission protocol, and is divided into four modules: audio and video collection, encoding and decoding, transmission control, and playback, to solve the bandwidth management problem of audio and video streams during transmission. The following diagram shows the hierarchical structure of the system. At the sender end, the audio and video are sampled and encoded, and then packaged and sent out through the RTP protocol. Then, based on the network feedback information, the RTP protocol estimates the available transmission bandwidth of the network and adaptively adjusts the encoding output rate of the codec (including the adjustment of source code rate and channel code rate), so that the audio and video bitstreams can meet the restrictions on the current network transmission bandwidth. At the receiver end, the received audio and video streams are decoded, the audio and video signals are reconstructed, the current network transmission parameters (such as the packet loss rate during

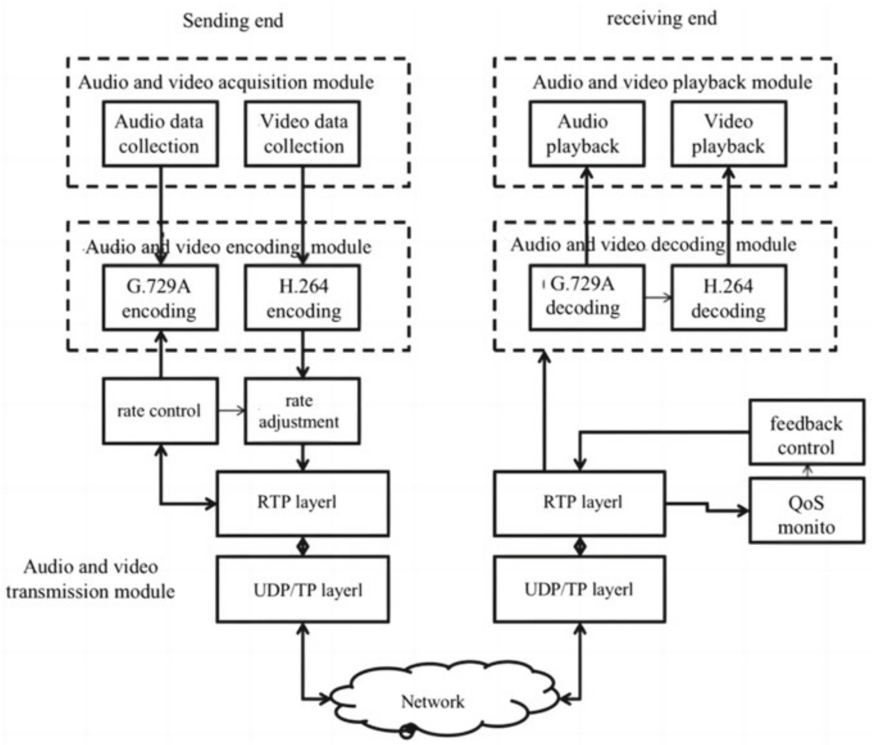

Fig. 5.8 Block diagram of audio and video real-time transmission system

transmission) are calculated, and feedback control information is sent as shown in Fig. 5.8.

In practical applications, network-based congestion control is quite challenging because the transformation of the entire Internet architecture cannot be completed overnight. Therefore, in the existing limited network conditions, it is particularly important to improve the quality of video transmission services and achieve efficient use of network resources as optimally as possible. Terminal-based congestion control treats the entire network as a black box, and obtains congestion information based on end-to-end measurement parameters. Then it adjusts the terminal's sending rate according to a certain strategy based on the congestion information, and reduces the load on the network congestion path to achieve control over network congestion. In this sense, end-to-end congestion control belongs to the domain of congestion recovery.

Real-time multimedia systems often use UDP for transmission. UDP has no congestion control mechanism. When TCP detects network congestion, it uses the AIMD (Additive Increase and Multiplicative Decrease) algorithm to reduce its sending rate by half. If TCP continues to detect network congestion, the sending rate will be continuously reduced until the data transmission is stopped. At this time, the application of UDP will take up all the bandwidth, causing congestion for the application of TCP. One solution is to replace the First-In-First-Out (FIFO) scheduling algorithm in Internet routers with algorithms similar to Random Early Detection (RED) to increase differentiated services for different types of data. For example, by using the Class-Based Queue (CBQ) protocol in routers, different bandwidths can be dynamically allocated to different types of applications to ensure Quality of Service (QoS) for various applications. Another method is to add congestion control mechanisms to UDP-based applications, which can ensure that UDP and TCP data streams coexist in a friendly manner (TCP friendliness). This method requires adding a congestion control mechanism to the top of UDP. This process mainly involves adjusting the encoding rate of the video stream to adapt to the network bandwidth. Because the network bandwidth is variable and unknown, it is not possible to directly set a transmission rate to adapt to the network status. Two methods are usually used for real-time adjustment: one is the window method, which gradually increases the transmission rate and then reduces the sending rate when packet collisions are detected (packet loss is detected) on the network. The other is rate-based method, which estimates the network bandwidth resources first, and then adjusts the target rate of encoding to adapt to the network status. Window-based solutions will introduce retransmissions similar to TCP, which is unacceptable. There are usually three solutions: rate control based on the sender, rate control based on the receiver, and hybrid control.

1) Rate control based on the sender

By adjusting the transmission rate at the sending end to adapt to the network, the packet loss rate can be greatly reduced when the transmission rate matches the network bandwidth. In implementation, a feedback channel is typically required to transmit network status information detected from the receiving end back to the sending end, which adjusts the transmission rate based on the network status information.

2) Receiver-based rate control

One typical representative of this type of rate control method is the Receiver-Driven Layered Multicast (RLM) algorithm. The RLM algorithm is the first practical adaptive algorithm based on layered video data transmission over the Internet and driven by the receiver. Its main idea is that the sender divides the video data into multiple layers and uses independent multicast groups to send each layer. When the data starts to be transmitted, the receiver only needs to join the first layer of data. Then, it periodically joins higher layers of multicast to probe the network bandwidth. If the receiver does not experience congestion for a period of time, it will continue to join higher layers of multicast groups. If packet loss is detected, the receiver will exit from the highest layer of data it is currently receiving and receive data at lower layers.

RLM is considered a promising direction for adaptive video transmission. Firstly, because it is compatible with the current "best-effort" Internet architecture; secondly, because it implements adaptive strategies at the receiver end, it has good scalability and can solve receiver heterogeneity problems. However, RLM has many problems, namely, it does not consider the fairness between data streams, nor does it consider the synchronization between the joining and departure of the receiver. Additionally, a failed trial can cause congestion for other data streams.

3) Hybrid Rate Control

The hybrid method of rate adjustment adjusts the rate based on feedback from the reverse channel by the sender, while the receiver adds or removes channels to transmit layered or non-layered images in multicasting. Unlike the sender-based method, the hybrid method uses multiple channels, and the rate of each channel is not fixed and can be adjusted according to the congestion status of the network.

We plan to adopt a host-based network-adaptive-sending-rate-control-method for congestion control in audio and video transmission. This method is built on an improved version of UDP, which needs to be improved to ensure real-time transmission of multimedia signals in the network. The UDP protocol used adds control bits in the packet header to provide more detailed descriptions of the packet, enriching the information of the UDP protocol. At the same time, a sequence number is added to the packet header, which allows the receiving end to reassemble the data when multiple UDP packets are used to transmit information, ensuring correct unpacking of the data. The method is to encapsulate additional header information for UDP datagrams, as shown in Fig. 5.9.

Packet Type (PT): 2 bits, indicating whether the transmitted packet is a video data packet or a feedback packet.
Frame Type (FT): 2 bits, indicating which frame is to be transmitted first.
Congestion Indication (CIn): 2 bits, indicating the congestion identifier of the feedback packet (e.g., 1 is used to indicate packet loss).
Reserved: 10 bits, indicating whether it is a timestamp or RTO.
Timestamp: 32 bits, used for RTT calculation.

The congestion control of video end-to-end is implemented by relying on the sender and the receiver, and control packets without data can be identified. Considering that the packet loss requirement of video streams is not strict and it is sensitive

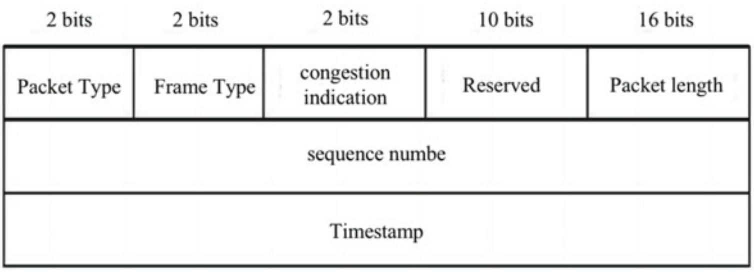

Fig. 5.9 Diagram of improved header information

to delay, feedback packets do not cause retransmissions. This method is very effective in detecting bandwidth and estimating RTT, and can adjust the transmission rate of video streams in a timely manner.

(2) Audio and video concurrent recording and storage technology

As for remote audio and video servers, a specific storage plan is required for the storage of media data. From the perspective of the file system, media data should be stored in a file-based manner. From a human perspective, what people are concerned with are segments of media data, such as recording data triggered by a specific event or recording data scheduled at a specific time, which can be summarized as a recording "segment".

The most intuitive approach is to use one "file" to represent one "segment," but it is not practical because the size of a segment is difficult to determine. For example, in the case of continuous recording for 24 h, the size of a segment can be infinitely large, but the file system usually has a maximum size limit for files. It is not feasible to put the entire segment data into one file, and oversized files are not conducive to system management and the use of playback and backup functions. For timed or triggered recordings that generate one "segment," since the length of this time period is difficult to define, the sizes of the files may vary greatly, which will cause inconvenience to the management of recording data. Too many small files may also reduce the efficiency of the file system. Therefore, it is necessary to consider merging small "segments" into one "file" for management.

A compromise approach was adopted based on the discussion above for the storage of media data on remote audio and video servers. Firstly, the size of each recording file was limited to 200 MB, and the size of a recording file could not exceed this limit. Then, several recording segments could be stored in this limited-size recording file. When the media data needs to be stored, a new segment would be created in the currently underused recording file and the media data would be written into this segment. If the size of the recording file was to exceed the limit of 200 MB during the writing process, the current recording segment would be ended, and a new recording file would be created, then a new segment would be created in the new recording file, and the storage process would continue.

With this design, the size of each video file is limited to 200 MB, which facilitates the management of these files in the system. However, inevitably, video segments that should have been stored continuously will be truncated into one or more segments due to the limit on the size of the file, which is particularly serious in the case of 24-h uninterrupted continuous storage. For this problem, the system provides search functionality for already stored video files, and the search criteria can be based on the recording time, triggering events, or a combination of multiple conditions. The resultant file records can be used for playback, video conferencing, downloading, and other functions. Considering that the system can manage a large number of encoding devices and store massive amounts of media data, users need to process media data based not only on the customized recording plan, but also on specific times or triggered events. Therefore, by providing time and event search, all video segments that users are interested in can be retrieved. Although video segments in

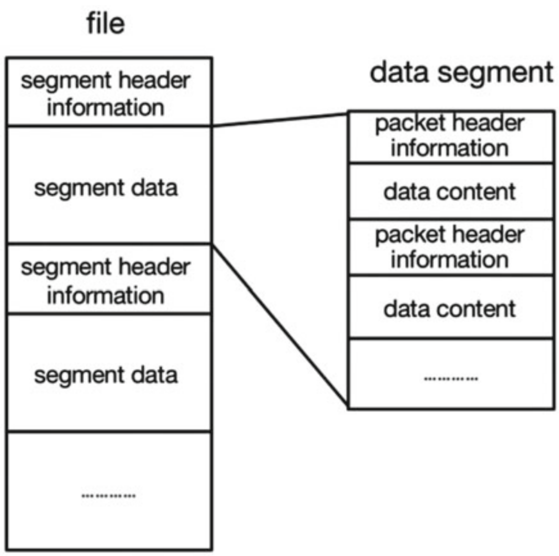

Fig. 5.10 The structure of media data files

the system may be truncated into multiple segments due to the limit on the size of the, overall, it will not greatly affect the user experience when users are processing video data. The search function is implemented by other modules in the system.

When the storage space is insufficient, users can choose two strategies: stop storage, which means the system stops storing the video data of that media source; or overwrite storage, which means the system finds the earliest recorded file of that media source, deletes it, and continues storing video data in a new file.

According to the above storage scheme, the media file storage structure adopted by this system is shown in Fig. 5.10.

The segment header information includes a start code (4-byte "SEGH"), device type, stream mode, video size, frame rate, keyframe interval, and segment length. Following the segment header is the segment's data content. When media data files are being analyzed, the next segment header can be located from the current segment header, thus traversing the entire media data file.

In the segment data content, the data is stored as individual data packets with package header information. The package header includes the arrival time of the data and its length.

We need to implement a search function for media data recording segments, so we have established an index table for recording segments in the database to facilitate data retrieval and speed up the search process.

As shown in Table 5.1, the server ID and media source ID are UUIDs, used to identify the server where the recording segment is located and the media source from which it originated.

The specific storage process is as follows: the storage object maintains a video data buffer, and the working state class registers the receiving callback with the SDK

Table 5.1 Index table for media data recording segments

Index ID	File path	Segment offset	Start time	End time	Trigger event type	Trigger event time	Server ID	Media source ID
.								

when starting the stream sending, and then pushes each received video data packet to the session buffer. The purpose of ensuring that the size of each write data is around 512 KB is to reduce the movement of the hard disk head in a multi-threaded environment. The larger the amount of data written each time, the lower the frequency of head movement. Before ending the writing of several data packets and waiting for the next writing, the recording segment index information in the database and the length of the segment data in the recording file will be updated. This is to make sure that the recording segment index in the database and the recording file records are relatively new and the lost data is relatively small in the case of abnormal situations such as power failure. By using the methods of search and file analysis, the video recording data stored before the system gets abnormal can also be found.

5.2.4 Audio–Video Processing Algorithm Model

(1) Audio noise reduction and video enhancement technology
1) Electric Power Field Audio Noise Reduction Technology

We research on key technologies for audio collection and noise reduction in power field in view of the large noise of various power equipment such as transformers in power field. We research on active noise reduction algorithms for audio based on the noise environment during power grid operations. We study the adaptive algorithm VSSLMS and the effects of adjusting parameters such as step size genetic factor, weight of instantaneous error energy, maximum and minimum values of algorithm convergence step size on reducing noise in the operation field. The specific design scheme is as follows:

There are many methods for audio noise reduction, which can be divided into active noise reduction and passive noise reduction according to whether there is a reference signal. According to the frequency band processed and whether the useful signal and noise are at the same frequency, noise reduction can be divided into classical filtering noise reduction and modern filtering noise reduction. Regardless of the method used, noise reduction still relies on filters. Adaptive filters are an important part of modern filters. Adaptive noise cancellation methods belong to active noise reduction methods, which utilize adaptive optimal filtering theory. The signal to be processed consists of a useful signal and background noise, and the background noise is correlated with the noise in the reference signal. The purpose of the adaptive noise cancellation method is to remove the background noise in the signal to be processed.

Therefore, adaptive noise cancellation technology mainly uses the reference noise signal obtained to process the background noise in the signal.

Adaptive filters have been widely used in channel equalization, echo cancellation, antenna reception, linear prediction, image recognition, and other fields. According to Wiener filter theory, the adaptive filter for noise cancellation requires an infinite number of taps to minimize the output error. In practice, it is impossible to make a filter with an infinite number of taps, so a finite impulse response (FIR) filter that meets the Wiener filter theory must be used, which means that the adaptive filter must have a finite length.

Passive noise reduction is the process of reducing noise from an input signal using an existing noise reduction model, without a reference noise signal. Active noise reduction, on the other hand, involves the use of adaptive algorithms to cancel out noise that is mixed with the useful signal, with the aid of a reference noise signal. The main difference between the two is that active noise reduction adjusts its parameters based on the input signal to remove noise, while it is not the case for passive noise reduction. Active noise reduction has a lower algorithm complexity, while passive noise reduction has a higher algorithm complexity. The output signal of active noise reduction has a higher signal-to-noise ratio, while that of passive noise reduction has a lower signal-to-noise ratio, especially when the background noise changes dramatically.

The basic principle of active noise reduction using the VSSLMS adaptive algorithm is shown in Fig. 5.11. In the figure, s(n) is the useful signal, v(n) is the background noise, and the expected signal d(n) is the signal to be processed, which is composed of the useful signal s(n) and the background noise v(n), and s(n) and v(n) are uncorrelated.

The input of an audio active noise reduction system consists of two signals: the first is the useful signal mixed with noise, and the second is the reference noise. Based on the VSSLMS adaptive algorithm, the noise reduction system utilizes the reference noise from the second signal to cancel out the noise in the first signal and output the useful signal. Compared to passive noise reduction, active noise reduction can adjust its parameters according to the changes in the input signal, and thus effectively remove noise. Compared to classical filters (high-pass, low-pass, etc.), the adaptive

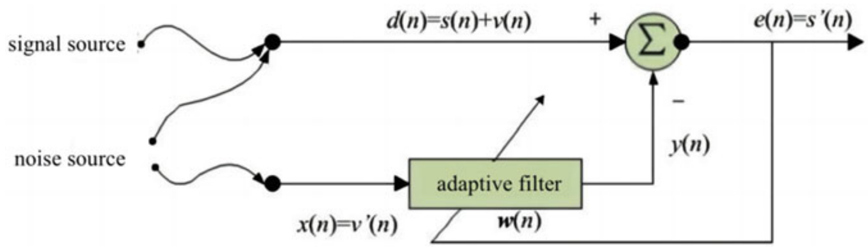

Fig. 5.11 Block diagram of adaptive algorithm for noise cancellation

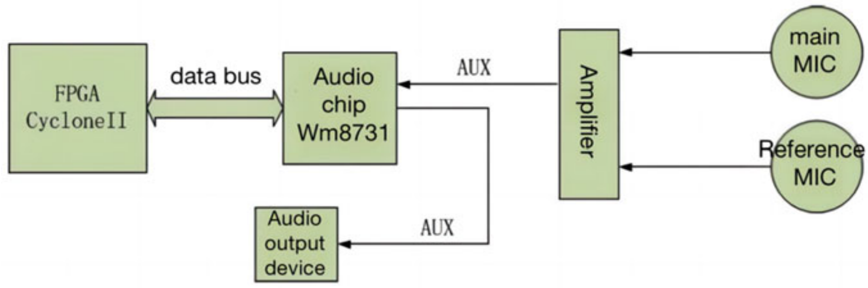

Fig. 5.12 Hardware platform diagram of active noise reduction system

filter of the active noise reduction system can remove noise at the same frequency as the useful signal.

The hardware platform for active audio noise reduction is shown in Fig. 5.12. The active noise reduction system is mainly composed of a hardware platform and Verilog HDL program. The main microphone is used to collect the useful signal mixed with environmental noise, while the reference microphone collects the environmental noise, corresponding to d(n) and y(n) in the algorithm, and the audio output is equivalent to e(n) in the algorithm.

2) Enhancing video quality in jittery mobile environments

The mobile video end used in this technical solution includes wearable and handheld devices that are used for audio and video interaction. For tasks such as object detection and tracking, the shaking of the camera video during movement creates two motion vectors in a mobile background, resulting in inconsistent image coordinate systems between adjacent frames. This lack of stability in the output image leads to errors when the video image is further observed, making it difficult to extract valid and accurate information. Therefore, in order to output stable video in real-time, it is necessary to use motion estimation algorithms, motion filtering, and image compensation techniques to enhance mobile video images in complex backgrounds where shaking occurs.

3) Motion estimation algorithm
a) Block matching motion estimation algorithm

Block matching is the most common method of translational motion estimation. The full-search block matching algorithm is considered to be the most accurate method of translational motion estimation. The algorithm is easy to understand and easy to implement in large-scale integrated circuits, so block matching is often used in engineering to estimate translational motion. The algorithm divides the image into non-overlapping sub-blocks of equal size based on the size of the image. When the sub-blocks are being made, it is necessary to ensure that the pixels in each block have similar motion trends, so it is not suitable to make the sub-blocks too large. Generally, the size of a sub-block is 16 * 16. The position of each sub-block in the next frame is found based on a matching criterion. Since most part of the image is background, the motion trend of most sub-blocks can be used as the motion trend of the background.

Assuming that the size of the reference frame is MxN and is affected by the translational jitter within the amplitude range of (±dxmax, ± dymax), the search range for the current frame is between (M ± dxmax) and (N ± dymax). The search block traverses each pixel within the dashed box, and the pixel values covered by the search block are processed using a 2D mean value. The best offset position satisfying the search criteria is found through calculation. The coordinate difference between the initial and final positions of the search block represents the motion vector (U,V) of the current video frame, where U is the horizontal offset and V is the vertical offset. Assuming that the image size is MxN, and fk1 and fk are the image blocks where the matching block and search block are located, the following criteria can be used to match the image blocks: Normalized Cross-Correlation Function (NCCF), Mean Square Error (MSE), and Sum of Absolute Differences (SAD).

In view of the three equations above, the normalized cross-correlation function (NCCF) is used as the matching criterion. It can be seen that when the two sub-blocks are the best matching sub-blocks, NCCF(i,j) reaches its maximum value, which can be as big as 1. When mean squared error (MSE) is used as the matching criterion, the MSE is the smallest, which can be as small as 0, when the two sub-blocks are the best matching sub-blocks. When the sum of absolute differences (SAD) is used as the matching criterion, the SAD is the smallest, which can be as small as 0, when the two sub-blocks are the best matching sub-blocks. From the block matching process, it can be seen that by using a full search method, the search block needs to traverse all pixels in the search area to determine the position of the optimal matching sub-block. The search process is very time-consuming and computationally intensive, making real-time processing difficult to achieve. Although many improved search methods have been proposed later to reduce the matching time of block matching, such as three-step search, diamond search, four-step search, etc., the increase in speed has also caused a decrease in motion estimation accuracy. In order to improve the speed of translational motion vector estimation, the grayscale projection algorithm has been proposed, which greatly improves the speed of translational motion estimation.

b) Grayscale projection motion estimation algorithm

The essence of the grayscale projection motion estimation algorithm is a kind of image dimensionality reduction matching algorithm. By accumulating the image data for each row and each column respectively, the image data is mapped to two one-dimensional image data about the row and column data. Through the cross-correlation calculation of the reduced-dimensional row and column data, the offset at which the minimum cross-correlation value is found is obtained. The global motion estimation offset is obtained based on the offset. The grayscale projection algorithm only performs cross-correlation operation on the reduced-dimensional row and column data, avoiding the cross-correlation calculation of each pixel in the image. It reduces the computation while improving the matching speed, making it a fast matching method.

Therefore, cosine filters are often used to filter the projection curves to reduce the interference of edge information. From the theory of the gray projection algorithm, we can infer that if the contrast of the image is not sufficient, the data accumulated in each row and each column will be very close. When cross-correlation calculations are being performed, there may be no "valley" present. Therefore, histogram equalization preprocessing of the image is often required before the gray projection algorithm is used to enhance the contrast of the image. The gray projection algorithm accumulates the entire image along each row and each column to achieve dimensionality reduction, which cannot avoid the influence of local motion. Currently, based on the assumption that the foreground moving object is generally located in the middle of the field of view, the use of the gray projection algorithm should be avoided in the middle area of the image to avoid local motion interference. Although the gray projection algorithm solves the problem of fast translational motion estimation, it has high requirements for illumination and image similarity, and the algorithm's robustness is poor. The development of phase correlation algorithm has well solved the robustness problem of the translational motion estimation algorithm.

c) Phase Correlation Motion Estimation Algorithm

The phase correlation algorithm is a robust frequency domain processing algorithm that not only has strong noise tolerance but also is insensitive to changes in brightness. It has low requirements for the similarity of image content, and as long as the degree of similarity can be 1/3, it can accurately estimate the motion between two frames.

The phase correlation algorithm is the only translational motion estimation algorithm based on frequency domain processing. It not only has strong noise resistance and anti-illumination changeability, but also has good performance on occlusion, and can estimate large translational motion. Currently, fast Fourier transform can be implemented in both hardware and software, greatly improving the computational efficiency of phase correlation, making it possible for engineering applications.

Currently, service systems are using phase correlation motion estimation algorithms to evaluate and estimate images. This approach not only incorporates the advantages of the grayscale projection algorithm, which solves the problem of fast translational motion estimation, but also effectively handles video images with low degree of contrast and image similarity. This algorithm has good robustness.

d) Motion filtering and image compensation

To obtain a stable and enhanced video, we need to separate the jitter from the motion of the camera device and only compensate for the jitter while preserving the original subjective motion.

There are two main methods for separating jitter motion from subjective motion of the camera device: one method uses filtering based on the frequency difference between jitter motion and subjective motion, while the other method simulates the subjective motion of the camera device through curve fitting. In practice, due to the diversity and complexity of camera device motion, it is difficult to simulate the real camera device motion trajectory, and curve fitting is rarely used. In most image stabilization algorithms, filtering is still used.

In the filtering method, the mean filter is the simplest filter, but in this system, we will use a recursive filter combined with bilinear interpolation to compensate for the image.

The recursive filter is an optimal autoregressive data processing algorithm widely used in engineering applications. In this system, the recursive filter is used for motion filtering to separate the desired motion of the camera from the jitter, preserving the expected camera motion and treating the camera jitter as noise. Based on state equations and observation equations, the recursive filter does not simply take a weighted average or arbitrarily select one of the estimated values from the state equation and the predicted values from the observation equation as the output result, but rather determines the final output result through the minimum mean square error matrix.

Image compensation is a process of transforming the original image based on the difference between the actual motion trajectory and the motion trajectory after motion filtering, thereby obtaining a stable video that satisfies the smoothed motion trajectory after motion filtering. When new pixel coordinates is being computed, it is common to encounter situations where the new pixel coordinates are floating point numbers. In such cases, interpolation is commonly used to handle the situation.

The recursive filter will be used to distinguish between the subjective motion of the camera and high-frequency jitter noise. The bilinear interpolation method will be used to achieve the requirements of the stabilization algorithm in terms of preserving edge information and algorithm complexity. Therefore, the bilinear interpolation method is chosen to perform the reverse image shift compensation on the image.

(2) Audio and video adaptive adjustment optimization

Due to the instability of mobile network environments such as 3G, 4G, WiFi, etc., real-time data transmission over the Internet can result in: (1) Delay (the time it takes for audio and video data packets to be transmitted from the sender to the receiver. The larger the delay, the more serious the damage to the quality of communication); (2) Delay jitter (i.e., the difference in delay between different data packets. Delay jitter can cause discontinuous audio and affect the quality of communication).

Therefore, it is necessary to regularly adopt various strategies on mobile terminals to optimize and process the audio and video. The specific measures are as follows:

1) According to the timing algorithm, the network environment is searched at regular intervals, and when the network bandwidth drops below certain threshold values, the following measures are taken for processing.
2) The video resolution and audio sampling rate can be dynamically allocated based on certain threshold ranges, and adaptively processed according to the bandwidth status.
3) Recovery measures for packet loss include requesting the remote end to resend the lost packet by using TCP packets with the NACK (Negative Acknowledgement) feature, which meets the standard.

   If the request is not received by the remote end due to delay, the TCP packet should be considered lost.

   If the request is received by the remote end, the TCP packet will be recovered.

Otherwise, the previous link will be disconnected and the attempt to decode the video will result in frame loss until the next video frame arrives. Meanwhile, increasing the TCP packet buffer size can partially solve this problem.

4) Jitter buffer processing measures. Although the jitter buffer can cause a delay of approximately 100 ms, it can improve the quality of the video. After caching TCP packets, the NACK packet is used to request lost packets, and the lost TCP packets are recovered. The jitter buffer also records the cached frames based on the TCP sequence number to achieve frame compensation. This may cause some delay, but it will result in a smooth video at the frame rate, such as 24 or 25 frames per second, which is calculated based on the TCP timestamp.
5) When a TCP packet is lost, it may result in frame loss in the video. The video system tries to avoid packet loss, but sometimes it is inevitable and results in frame loss. These lost frames will be transmitted to all endpoints when the video stream is split. When reconstruction technology is being used, the system will render the stream on the terminal and send a request for new packets to repair the video frames. Only the lost TCP packets will interrupt the display, and they will be immediately recovered.
6) Using a circular dynamic queue to cache the audio and video frames can achieve the goal of optimizing the audio and video on mobile devices in unstable network conditions.

(3) Video target tracking and labeling technology

Tracking of moving targets in a mobile environment relies on continuous learning of the locked target to obtain its latest appearance features, thus refining the tracking in a timely manner to achieve optimal state tracking.

At the initial stage, a comprehensive scanning is performed on each frame image based on a static target image provided, to find all appearances similar to the target object. Positive and negative samples are generated from the results of detection. As the target moves continuously, the system can continuously detect and obtain changes in the target's angle, distance, depth of field, and other aspects, and identify them in real-time. After a period of learning and training, the target can be accurately captured and labeled. The specific processing techniques include:

1) Motion Object Detection Based on Feature Classification

Motion object detection based on feature classification includes two processing steps, namely the learning process and the decision process, as shown in Fig. 5.13.

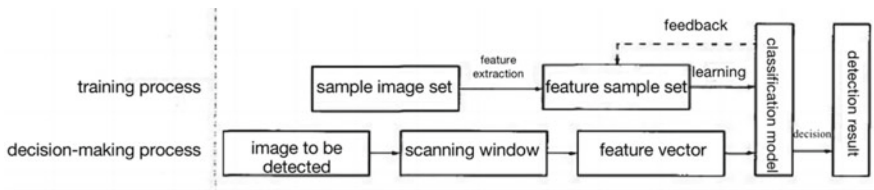

Fig. 5.13 Diagram of Feature-based Object Detection using Classification

The basic idea of the learning process in feature-based motion object detection is to select or construct a type of image feature that is conducive to describing the target of interest. Through a feature extraction algorithm, a set of labeled image samples is mapped to a feature space to form a feature sample set. Then, by using the sample set as input, the corresponding pattern recognition classifier is supervised and trained, and a trained detection classifier is ultimately obtained.

The basic idea of the decision-making process is to first identify all the regions in the current image that may contain the object of interest, and then use the trained classifier to quantify the possibility of the existence of the object in these regions. Finally, a decision strategy is used to evaluate the output of the classifier, and ultimately achieve the detection of the object.

The two key points of feature-based classification for motion object detection are image features and classification models, where the construction of the classification model is closely related to the dimension of the feature vector.

For image features with small dimensions, such as color histograms, color moments, HOG, LBP, etc., a distance-based decision method is generally used. That is, the optimal linear decision threshold is calculated using the intra-class distance of the training target samples, and the detection of the target in the scene is achieved by comparing the distance between the feature of the target image and the average feature of the target sample. Common distance measures for features include Euclidean distance, Minkowski distance, Chebyshev distance, Mahalanobis distance, Canberra distance, and cosine distance. The use of distance-based classification methods for low-dimensional image features has the advantages of high computational efficiency and ease of implementation, but the classification performance is generally not ideal due to the simple decision-making method. Another way to classify low-dimensional features is to use pattern recognition classifiers such as k-nearest neighbor (K-NN) classifiers, Bayesian classifiers, decision tree classifiers, support vector machines (SVM), and neural network classifiers.

For high-dimensional image features, specific methods need to be adopted to select the components with strong discriminatory ability from the feature vector, in order to reduce the computational complexity of the training and decision-making processes. Generally, there are two types of methods that can be used to select feature components. One is the feature extraction method, which reduces the dimensionality of the feature vector through linear transformations by employing decorrelation strategies. Feature extraction methods generally include principal component analysis, linear discriminant analysis, and Sammon projection, among others. The other type is ensemble learning models in machine learning, which achieve decision-making on the features by combining weighted weak classifiers corresponding to the feature components. The weight of the weak classifier reflects the importance of the feature component to the decision. Common ensemble learning methods include Boosting algorithm, Bagging algorithm, and AdaBoost algorithm.

2) Object tracking based on classification

Motion object tracking based on classification, also known as detection-based motion object tracking, is a popular object tracking technique in recent years. The core

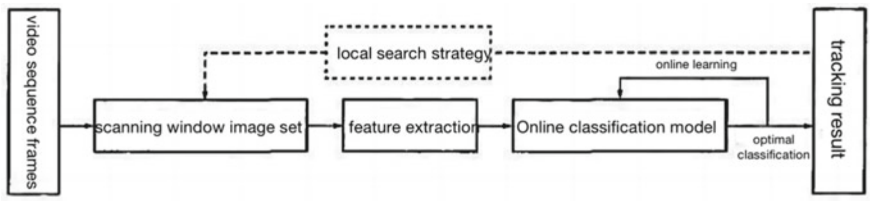

Fig. 5.14 Flowchart of classification-based motion object tracking

of such algorithms is to find a boundary between the scene background and the motion object image to separate the foreground object from the local background. Specifically, an online learning feature classifier is used to quantize and classify the feature vectors extracted from the current region of interest, and the region with the best classification output is selected as the target region. This type of algorithm can continuously update the classifier using the feature vectors obtained from the current frame's best classification region, which greatly improves the algorithm's adaptability to the changes of the target shape. The process of motion object tracking based on online learning classification is shown in Fig. 5.14.

Typical classification-based object tracking methods include On-line AdaBoost, Online MilTrack, and TLD (Tracking Learning Detection).

In this study, multiple feature fusion methods were used to establish a directed scene motion pattern model for mobile operations in the power grid based on the characteristics of power grid equipment operations. A target detection method based on scene motion pattern was employed to process input images. Combined with video annotation technology, dynamic video features were extracted between consecutive image frames to ensure the consistency of annotation and video timing.

(4) Audio–video assisted graphic guidance information overlay technology

The technical solution of the system supports online annotation editing function, which can add text, pen, 2D vector graphics and other elements. Backend technical experts can add text or annotated vector graphics to any position of the video screen in real-time according to their needs. On-site maintenance personnel can see these annotations synchronously, which is convenient for remote command. During the layer editing process, it will not affect the synchronous playback of live video and audio or the quality of the image.

There are three common methods for displaying text: dot matrix display, font image display, and real-time generation of text images for loading and display. They are suitable for different languages and different application scenarios. Next, we will introduce these three display methods respectively.

1) Text dot matrix display

The information of computerized characters is stored in font patterns, which record the shape of the characters using binary bits. Each bit in each byte of the font pattern corresponds to a dot in the character grid. For example, the way the letter 'A' is

bit code	character pattern information
0 0 0 0 0 0 0 0	0x00
0 0 0 0 0 0 0 0	0x00
0 0 0 1 0 0 0 0	0x10
0 0 1 1 1 0 0 0	0x38
0 1 1 0 1 1 0 0	0x6c
1 1 0 0 0 1 1 0	0xc6
1 1 0 0 0 1 1 0	0xc6
1 1 1 1 1 1 1 0	0xfe
1 1 0 0 0 1 1 0	0xc6
1 1 0 0 0 1 1 0	0xc6
1 1 0 0 0 1 1 0	0xc6
1 1 0 0 0 1 1 0	0xc6
0 0 0 0 0 0 0 0	0x00
0 0 0 0 0 0 0 0	0x00
0 0 0 0 0 0 0 0	0x00
0 0 0 0 0 0 0 0	0x00

Fig. 5.15 Record mode in font module

recorded in a font pattern is shown in the following figure. The dot matrix display method reads the font pattern information and sets the corresponding values at the corresponding positions in the image based on the 0's and 1's in the font pattern dot matrix. The advantage of this method is that it is simple and convenient to display while supporting multi-language operation techniques and various development platforms; the disadvantage is that it requires pre-reading of the font pattern information, and the effect of display is simple and cannot use rendering effects supported by operation techniques, as shown in Fig. 5.15.

2) Using font images for display

This method involves first creating a font resource image and then establishing an index table for the quick positioning of the displayed text. When text needs to be displayed, the image can be directly pasted. The advantages of this method are that the font resources are relatively small, the display is convenient, and it supports multi-language operation techniques. The disadvantage is that it is not suitable for displaying a large number of Chinese characters.

3) Real-time generation of text images for loading and display

This method involves first extracting the TextMetrics and ABC structures of the characters to obtain the display size of the characters, and then creating an image (Bitmap) based on this size. Then the text is outputted, and finally, the contour information of the character is dynamically superimposed onto the image at the

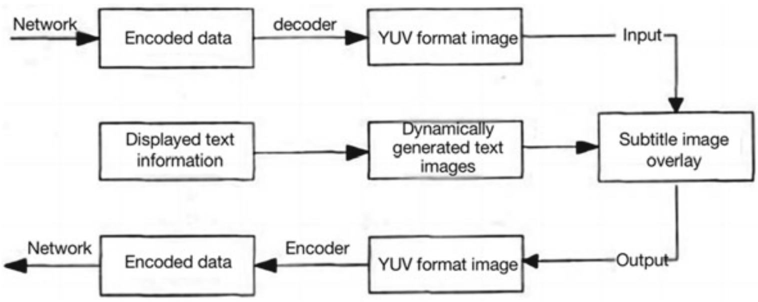

Fig. 5.16 Flowchart of Text Overlay on Multi-channel Distribution Controller

corresponding position. The advantage of this method is that it does not require a separate font resource and can directly use the fonts supported by the operating system, namely, the fonts that have already been installed. However, the drawback is that real-time image generation requires CPU time and memory consumption, resulting in lower execution efficiency.

From the above analysis, we can see that each of the three methods has its own advantages and disadvantages, and is suitable for different application scenarios. Considering the special nature of the wearable device technology and the complexity of Chinese encoding, we generally use the third method, that is, real-time generation of text images and loading for display in the specific implementation of overlaying text on the multi-channel distribution controller.

The specific approach for SFU to overlay text is as follows in the technical scheme: SFU first decodes the terminal video data received from the network into YUV format (or RGB format), then uses the text display method mentioned earlier to overlay text on the YUV (or RGB) image data, encodes the overlaid YUV (or RGB) data, and finally sends the encoded video data with text display to the network, so that the terminal can display the image with text after receiving it. The specific operational flow is shown in Fig. 5.16.

From the above analysis and design, it can be seen that the most complex part of text display in this technical solution is the process of dynamically generating text images. Once the text images are generated, text display can be accomplished through image overlay. This method produces text with good compatibility and smooth text edges, resulting in a clean and polished appearance, thanks to the rendering effects supported by mobile operating techniques. However, this method using SFU to overlay text requires a certain amount of CPU time and memory, which is its drawback. If standardization organizations can define a standardized protocol that enables text overlay functions to be performed by video terminals, this problem can be avoided.

The collected images are combined into a continuous sequence of frames to create video content that can be viewed with the naked eye. The image collection process is mainly done by devices such as cameras, which capture raw data in YUV format that is then compressed and encoded into formats such as H.264 for distribution. Common video container formats include MP4, 3GP, AVI, MKV, WMV, MPG, VOB, FLV, SWF, MOV, RMVB, and WebM.

Images, due to their strong visual impact and relatively large size, constitute the main part of video content. The main challenges in image acquisition and encoding are: poor device compatibility, sensitivity to delays and stutters, as well as various video image processing operations such as watermarking logos, and drawing vector graphics for annotations.

The raw data is obtained after the video or audio has been captured. In order to enhance some on-site effects or add additional effects, the data is generally processed before being encoded and compressed, such as adding watermarks such as timestamps or company logos, and editing annotations of vector graphics.

Vector graphics are typically represented in a vector structure. Vector structures precisely represent geographic entities such as points, lines, and areas by recording coordinates. The coordinate space is continuous, allowing for precise definitions of any position, length, and area. Its precision is only limited by the accuracy of digital devices and the digitization bit length. In general, vector structures are much more precise than raster structures.

The characteristics of vector structure are clear positioning and implicit attributes. The positioning is directly stored based on coordinates, while the attributes are generally stored in the header or in specific locations within the data structure. This characteristic makes the overall graphics algorithm more complex than the raster structure, and some algorithms are even difficult to implement. However, there are also advantages. In computing the length, the area, the shape, the graphic editing, and the geometric transformation operations, the vector structure has high levels of efficiency and accuracy. On the other hand, vector structures are relatively difficult to use for operations such as overlaying and domain searches.

Vector data is composed of point objects, line objects, and polygon objects. Each type of object has its own internal structure, which can be further categorized as point data, line data, and polygon data.

Points, also known as point entities, correspond to point objects of geographic features. Points are objects with a specific location and a dimension of 0. Points are the simplest type of vector data and a 2D point can be represented by a (x, y) coordinate pair, while a 3D point can be represented by (x, y, z).

Line data, also known as line entities, corresponds to the line objects in video broadcasting technology. Lines are spatial components commonly used in one dimension, representing the spatial properties of objects and their boundaries. At least two points determine a straight line, where each point is called an endpoint or node, and lines can have multiple nodes as needed. Line data is commonly used to represent static phenomena such as roads and rivers. Line data can also be used as a data layer to help display dynamic data such as car travel routes, driving directions between two addresses, and flight paths. Depending on the level of detail required, the number of points that make up a line can be densified or generalized.

Polygon data, also known as area entities, correspond to polygon objects in video streaming technology solutions. Polygon entities describe phenomena such as lakes, islands, and land parcels. They usually record the boundaries of area features and are therefore also called polygon data. A polygon is composed of multiple lines. One difference between lines and polygons is that the former is open while the latter is closed.

The technology solution has conducted a detailed analysis of the requirements for graphic modeling. The demand for graphic modeling in the power industry differs from that of ordinary drawing software, and an understanding of the power industry modeling process is required for its requirements analysis. The drawing of basic graphic elements and the business graphic element editor have been analyzed for their requirements. The analysis of editing graphic functions mainly includes the editing of graphic elements and canvas, layer operations, and attribute editing.

The technical solution is aimed at providing a robust graphics drawing platform that supports both basic graphics editor functions and specific requirements of the electric power industry, such as topological connections, topology coloring, and power industry business graphic editors. By using the graphic editor, various graphics, such as main circuit diagrams and protection circuit diagrams, can be edited for different substations based on their specific situations. Additionally, the graphics platform should have an intuitive user interface. When drawing and controlling graphics, a separation between rendering and selection is used. The main idea is to draw the rendering part and selection part separately when creating a graphic element. The rendering part refers to the specific basic graphics that can be seen with the naked eye, including the outline, fill image, color, and so on. The selection part is used to control the graphic element, such as dragging the control point to change the size of the graphic element or dragging the graphic element to change its position. This technical solution involves using multithreading to control this process. A separate rendering thread is responsible for rendering the rendering part, and another selection thread is responsible for rendering the selection part. After creating a graphic element, the user can see the work completed by the rendering thread. However, the selection thread also draws a graphic element at the same location in a different way, and this element is specially processed so that the user cannot see it. When the user selects or drags an already drawn graphic element with the mouse, the work done by the selection thread is used. The selection thread senses the position of the mouse when it is moved over a graphic element, based on the color of the pixel point where the mouse is located, which is the color drawn by the selection thread.

From a functional perspective, there are two necessary parts. If only one rendering part is used, it is obviously impossible to distinguish each element. Because this technology solution involves using the method of distinguishing elements by the pixel color of the mouse position, different elements can obviously be of the same color, so a single rendering thread cannot use color to distinguish the differences between them.

5.2.5 Friendly Neighborhood Mutual View and Interaction Technology

Mobile emergency neighbor communication refers to the method of using mobile emergency terminals, wireless communication networks, embedded GIS, etc., to establish a mobile emergency location service network, and share location, information, and files within the network, as well as visualize the neighbor locations during emergency situations.

(1) Implementation of neighbor-to-neighbor visual communication technology

Terminal networking: Relevant emergency terminals are incorporated into the same mobile emergency location service network and corresponding networking rules are set.

Information reporting: Emergency terminals obtain their own location, multimedia information, and custom text information, establish a connection with the central server through a wireless communication network, and upload them to the central server.

Information Push: The central server pushes the locations and information of other emergency resources, as well as central dispatch instructions, to the relevant intelligent PDA terminals within the network based on the pre-set networking rules.

Neighbor Expression: Based on embedded GIS, intelligent PDAs locate and display the positions of other emergency resources, measure their relative position and distance, and display received files, messages, and instructions.

Mobile monitoring and command: As a result, a mobile emergency location service network has been initially constructed, which can realize functions such as information sharing within the network, neighbor location visualization, and mobile command.

(2) Neighbor position and information interaction

After various emergency resources are included in the mobile emergency location service network, their positioning and communication terminals establish a data link with the central server via GPRS or Beidou communication. The terminal reports its own location and information to the central server, requests for neighbor viewing, and obtains or updates the neighbor list from the central server. The central server pushes the location and information of other emergency resources in the network to the intelligent PDA according to the neighbor rules and the application period and positioning frequency.

The PDA establishes a heartbeat connection with the central server and reports its own location to the server at set time intervals. The heartbeat program formulates satellite search and program running strategies based on GPS satellite visibility and emergency working hours, and effectively manages the power consumption of the PDA.

After obtaining its own position, the Beidou terminal reports its location to the Beidou vehicle-mounted terminal connected to the center server via a serial port through the Beidou communication network, and then enters the mobile emergency location service network through the communication server. For small and medium-sized emergency departments, vehicle-mounted Beidou terminals can replace command-type Beidou terminals, effectively saving construction costs.

The emergency command center can send location and short messages to emergency personnel holding smart PDAs in the mobile emergency location service network through GPRS or BeiDou communication link. Emergency personnel with smart PDAs can also establish voice and text communication with friends through the mobile emergency mutual viewing common software. In addition, based on the friend list, group members can choose to send messages to multiple friend groups.

Developing mobile emergency neighbor view software based on embedded GIS components is crucial for locating and displaying the positions and information of emergency terminals and neighboring terminals. The key technology for expressing the positions of neighboring terminals is power-saving management, as well as effective management of the limited memory of the PDA under high-frequency location refresh to prevent memory overflow.

5.3 Real-Time Interaction Technology Between Emergency Site and Emergency Command Center

5.3.1 Power Emergency Communication Vehicle Technology

This chapter focuses on the construction of the electric power emergency communication vehicle system, and gives the main functions of the system according to the overall requirements of the system. According to the overall requirements of the system, the main functions of the system are given, and the design of the carrier platform subsystem, electronic information subsystem and comprehensive security subsystem is completed. The design of the carrier platform subsystem, electronic information subsystem and integrated security subsystem is completed.

With the continuous development of power emergency communication technology, State Grid Zhejiang Electric Power Co., LTD. (hereinafter the "Zhejiang Electric Power Compony") has put forward new requirements for the new power emergency communication technology: (1) Based on the existing power emergency network in Zhejiang Province, improve the structure of the power emergency network and establish a perfect electric power emergency communication platform suitable for Zhejiang Province. (2) Support multi-service function, and support power emergency communication's access to image, voice, video and other information. (3) Emergency communication platforms meet technical requirements and construction costs are controlled. (4) High system adaptability, system capacity and functionality should have a certain degree of scalability to meet the needs of future systems.

The services carried by the power emergency communication system in Zhejiang Province include data services, voice services and multimedia services. (1) Data

Services: It mainly includes the real-time monitoring service for the data transmission and monitoring between the fault site—provincial emergency communication center and data transmission and monitoring between the provincial emergency communication center and the national emergency communication, which is a distributed transmission method because the bandwidth of the transmitted data channel is not large, so a distributed transmission method is used. (2) Voice services: Provide the voice communication between Zhejiang Electric Power Company, substations and power plants to ensure smooth communication between each department and ensure that voice can be used for command. The transmission rate required for voice service is not high, but the real-time and reliability of voice is required. (3) Multimedia Service: to provide the video communication between the provincial company and the municipal bureaus in emergency situations, as well as to provide the video communication between substations and power plants, and to ensure the video communication between various departments and the scene of fault.

As a special network for dealing with emergency events, the power emergency communication network must have fast response, strong network architecture and economy. The unexpectedness of accidents often result in the lack of a readily complete communication system on site, so the power emergency communication network provides real-time and reliable information transmission, including data, voice and multimedia services, providing a scientific basis for emergency center staff.

The security requirements of the power emergency communication network include the security of the network, the security of the equipment and the security of the data. The power emergency communication network, as a special network for handling power emergencies, needs a highly reliable and self-healing network to ensure the stable and reliable operation of the communication network; The safety of equipment is an important part of the safety of the power emergency communication system. The key equipment, such as power supply, main control, switches, etc., must have relative stability; Data security is an important guarantee of information security, so the system should ensure the security and originality of the data in the operating system and the database, while being able to resist malicious attacks and information theft.

The design goal of this system is to establish emergency communication in the case of natural disasters and emergencies, to ensure the smooth communication between the emergency center and the scene, and the system consists of a satellite ground fixed station, emergency command vehicle, emergency communication vehicle and single soldier system. This is shown in Fig. 5.17.

This report focuses on the application of 4G technology in electric power emergency communication, while the emergency communication vehicle mainly uses a combination of 4G and satellite communication technology, and the command vehicle uses satellite communication technology, so the following mainly focuses on the design and research of the emergency communication vehicle. Broadband wireless network emergency mobile command vehicle system means a broadband wireless base station and other equipment involved in the system integration and installed in a carefully modified communications vehicle chassis, and the base station

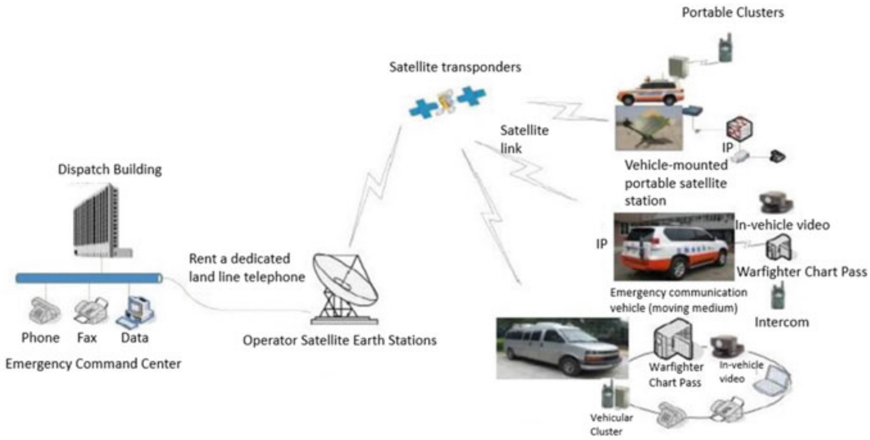

Fig. 5.17 System network topology diagram

system can be used for a wide range of mobile coverage. That can form a coverage radius of 2–5 km emergency broadband wireless communication system for emergency command, and connect a large number of data communication equipment (including computers, laptops, PDAs, IP phones or cell phones and video equipment, etc.) within the coverage area into an emergency interoperable data communication network, that is, the emergency broadband wireless network is realized based on vehicle-mounted broadband wireless base stations. The system can be connected to the higher-level communication network through the vehicle-mounted microwave communication system or satellite communication system, to realize the connection of mobile broadband wireless network and private network, and constitute an integrated network with the higher-level or neighboring command center to quickly complete the communication tasks of data transmission and command and control.

A set of motion 4G-satellite communication system is formed by 4G communication technology, satellite communication technology, multimedia and vehicle modification and other technologies. Based on the combination of 4G technology and satellite communication, the command communication vehicle could communicate with the single system in 4G signal coverage and finally transmit the signals back to the general command through the satellite base station on the communication vehicle. An emergency command platform, which is supposed to achieve real-time information collection and handle power emergency site, could be realized with the requirement of a technologically advanced and highly reliable command vehicle in good practicality. As the command communication system of the emergency center of Dongguan Power Supply Bureau, the emergency command vehicle completes the functions of emergency command, information collection, information transmission, video conference and so on. The command vehicle system realizes the communication of audio, data and video with the emergency command center and is divided into communication subsystem, audio subsystem and auxiliary system according to the functions. In terms of overall layout, the command vehicle is divided into the driving area, command area and operation area according to the functions. Driving area: being modified on the basis of the original design of the car to ensure driving convenience and comfort. Command area: the area used for commanding staff to command on site, and for issuing instructions for emergency emergencies. The command vehicle is capable of accommodating space for 6 staff members, including 4 commanders and 2 operators. Operation area: the area used for staff to realize commands and detect equipment, to carry out tasks such as the transmission of command messages, the reading of command cases, and the issue of commands. The matching electrical equipment is safe and reliable, able to cope with the impact of environmental factors, including high temperature, high wind, rain and snow, etc., able to drive and work normally in different road conditions, and able to organize command work in the scene of fire and earthquake. We should ensure that the command vehicle is beautiful, comfortable and practical after modification.

The construction principles of the 4G command and communication vehicle are as follows:

Advancedness: Make full use of the combination of 4G technology and satellite communication technology to ensure the advanced nature of the command system and guarantee the life cycle of the system. The system is flexible, easy to operate, and has a certain degree of fault tolerance.

Expandability: The system is scalable and system upgradeable, with a modular design for reserved space for system upgrade and transformation, and is able to support different interfaces.

Applicability: Ensure that the command vehicle has mobility, flexibility and the ability to guarantee staff safety in different environments, and realize the interaction between information and the site and the general command.

Economy: The command vehicle achieves maximum economy and rational allocation of resources for the hardware and software of the command vehicle.

Security: The security of the system includes information security and electrical security. Information security for the setting of user privileges, to prevent illegal and over-level operation of users, and to ensure the backup and recovery function of information. Vehicle system should provide safe and reliable power supply and consumption.

The main functions of the 4G Emergency Command Vehicle include:

Command and dispatch: Using 4G and satellite communication means to receive instructions from the general command, command the emergency operation at the site, dynamically monitor the site, ensure the orderliness and rationality of the site command, and realize video and voice communication in the process of emergency command.

Data functions support a variety of data terminals in wired and wireless ways. Basic data services: support.

VLAN, support for real-time data and non-real-time data. Voice function: The emergency communication vehicle adopts satellite technology to realize the communication with the command center, ensuring the smoothness and reliability of the communication link. Synchronization between the voice and video images without delay is also required. The video function needs to support a variety of video services such as video surveillance, conversation, and conference. Video monitoring: allowing the command center staff to observe the site amount in real-time, the video information can also be sent to the terminal equipment sink, so that the terminal can see the video information on site. Video conversation: The terminal can have a direct video conversation with the dispatcher or between terminals. Video conference: Through the video exchange function, multi-party video conference function can be realized.

GPS function

GPS real-time positioning: Through GPS, you can grasp the location of the terminal in real-time, and then send the location information to the communication network through wireless network.

Historical track playback: The system saves the position information and forms an accurate movement track through the playback of the track. The system saves the time and position information, so you can grasp the time and position information in real-time.

Mileage statistics: The current form mileage can be calculated for statistics.

(4) Instant messaging function

The system inherits the business of communication and supports dialogue and communication between correspondents, which is mainly text. Besides, point-to-point and point-to-multipoint text message sending and receiving are implemented. The system is also supposed to retrieve the online status information of contacts with different query criteria.

(5) Cluster scheduling function

Cluster scheduling service is divided into voice service and data service. Meanwhile voice and data can be jointly scheduled. Data services need to include real-time data such as video and non-real-time data such as file transfer.

(6) Communication security

The system has 4G and the means of satellite communication. The command communication vehicle has 4G coverage, and the information received by 4G is transmitted to the general command via satellite communication to ensure remote communication.

The command operation subsystem is to monitor, store and play audio and video information, provide decision support and basis for commanders, and provide hardware and software support for on-site meetings. The command operation subsystem consists of the audio, the video and the centralized control system, and these three subsystems are introduced as follows. Audio system: When the audio system receives the audio signal, the signal is switched, amplified, stored and being processed in other ways. Then the signal is sent to the conference video system to meet the needs of command and video conferencing. The conference table in the communications van is equipped with a MIC interface for easy access to microphones and computers. The audio signal inside the vehicle can be connected to other vehicles and can also receive the audio signal from the conference system. The audio matrix switcher and the mixer are the core of the audio system, the switcher can switch the audio signal to the output port, while the mixer can amplify the signal, mixing and processing the signal in other ways. The storage of the audio signal of the emergency communication vehicle is accomplished by using a hard disk recorder, which can realize the storage of 4-way audio signal. Video system: The video system will receive signals from cameras installed in the car, and the roof, as well as from the video conferencing system, and then switch and display the video signal to meet the needs of command and video conferencing. The emergency communication vehicle is equipped with a video VGA interface, which can be connected through the output interface of the computer, and the video conferencing system can receive the video signal from the scene. The video matrix and VGA are the keys to the video system, where the video signal is transmitted in multiple channels and displayed on multiple screens. Video is stored on a hard disk recorder, which can store up to 4 signals.

The centralized control system is designed for the control of the display equipment and the audio and video equipment, which mainly realizes the centralized control of the hardware of the emergency communication vehicle and provides technical support for the intelligent command system. The centralized control system concentrates the operation contents on one screen, and the staff can complete the control of related equipment according to the options, which makes the work more efficient. The interactive interface of the centralized control system needs to be simple in design. The centralized control system of the emergency communication vehicle in Dongguan City is mainly composed of the host, the touch screen, the relay, the infrared emission and the software. The connection diagram of the centralized control system is shown in Fig. 5.18, which realizes the control of the power supply of the equipment in the emergency communication vehicle, the control of the camera platform outside/inside the vehicle, and the switching and recording of the audio/video system.

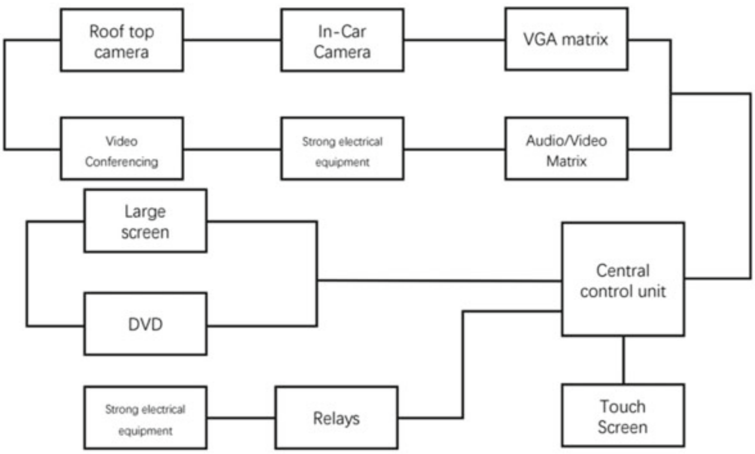

Fig. 5.18 Centralized control system connection diagram

The computer subsystem is the basis for receiving, transmitting and processing information, and provides a hardware platform for safe and stable operation of emergency command. The design of the computer subsystem of the emergency communication vehicle of Dongguan City uses 2 Gigabit switches, one of which is the command confidential network and one is the unclassified public network. The two switch networks are independent of each other to ensure the security of the system. The confidential command network is the core of command communication, which is composed of computer terminals, switches, firewalls and printers, and the emergency command system and information database can be directly connected to the confidential command network. The Command Classified network is responsible for most of the signal transmission, which is tethered to the command station by satellite systems or fiber optics after passing through the firewall. The unclassified public network is for the query and processing of public information, offering access via public wireless network. A wireless router is set up in the emergency communication vehicle, and portable devices inside or outside the vehicle can be connected to the unclassified network through the public network. The design of dual-network composed of the classified and the unclassified ensures the security of the command system. The classified network is used for the command network, and the firewall is responsible for isolating malicious attacks and viruses. Moreover, the computer subsystem is equipped with reliable devices, each equipped with rich interfaces to meet the scalability of the system. In order to reduce the large space occupied by the devices due to the computer system, an integrated host and monitor are used in this report. The design of the system also includes a secrecy machine that encrypts the transmitted signals and prevents illegal methods and modifications to the signals.

The communication subsystem is an important part of the emergency communication vehicle. It can achieve communication between the site and the command center through cable, satellite, 4G, shortwave, etc., and achieve interoperability between provinces and municipalities through the transfer between the command networks. It can transmit real-time information on the emergency site to the destination, providing guarantee for the emergency command.

5.3.2 Power Emergency Communication Hardware System

(1) The basic characteristics of shortwave communication

Shortwave communication frequency: Shortwave communication refers to radio communication with a wavelength of 100–10 m (frequency of 3–30 MHz), which is sometimes called high frequency communication, and occupies an important position in the field of traditional radio communication. Military shortwave radios in the battlefield can be used to transmit telegraph messages, voice, data, etc., and are an important means of military communications. Shortwave communication is the only way to achieve ultra-long-range communication in a simple device, low-powered personal portable radio. Short-wave communication has unparalleled anti-destructive ability and autonomous communication ability, and can quickly establish communication sites. Short-wave radio waves can cover mountainous areas, deserts, oceans and other special areas, which is not possible with general mobile communication systems, and compared to satellite communications, the cost is very low, easy to maintain, and has great competitiveness in the field of emergency communications. Modern mobile communication facilities are emerging, and cellular networks, 4G networks and other base station-centric networks are prevalent, but shortwave is still alive and well in aerospace, military and maritime communications, and is growing rapidly.

The propagation of short waves: There are two basic propagation paths of short waves, one is the ground wave, and the other is the sky wave. Ground wave propagates along the earth's surface, and its propagation distance depends on the characteristics of the surface medium. The conductivity of the medium on the sea surface is most favorable for wave propagation, and the short-wave ground wave signal can propagate along the surface for about 1000 km; the conductivity of the medium on the land surface is poor, and the wave decay is large, and the short-wave signal can only propagate along the ground for a few tens of kilometers at most. But the main propagation path of short waves is sky waves. It is the reflection of ionosphere for propagation. When the atmosphere is irradiated by sunlight, a layer of charged air is formed, called the ionosphere, which ranges from 60 km to about 2000 km above the ground. The ionosphere is divided into four layers, namely, D, E, F1 and F2. The D layer is 60–90 km high and reflects frequencies of 2–9 MHz during the day. The E layer is 85–150 km high, and this layer has less reflection effect on short waves. The F layer has the greatest reflection effect on short waves and is divided into two layers, namely, F1 and F2. The F1 layer is 150–200 km high and works only during daytime, while the F2 layer is more than 200 km high and is the main body of the F layer, which supports shortwave propagation during daytime and nighttime. When the short wave enters the ionosphere, it will be bent by refraction, and when the wave penetrates to a certain depth in the ionosphere, it will turn around and propagate downward, and finally return to the ground, and the radio wave returning to the ground will be reflected back to the sky, and then be reflected back to the ground, and so on, using the reflection of the ionosphere in the atmosphere to spread to places thousands of kilometers away.

The current status of shortwave communication: Due to the irreplaceable nature of shortwave communication in military communication, shortwave communication has started to receive attention again since 1960s As a result of a variety of new technology applications, such as channel adaptive technology, differential frequency hopping technology, broadband direct sequence spread spectrum technology, channel coding technology, channel balancing technology, shortwave group technology, many problems of shortwave communications have been solved and with the rapid development of microcomputers, mobile communications and microelectronics technology, microprocessors, digital signal processing, and constantly high quality of shortwave communications and data transmission rate, shortwave communications and equipment has been greatly developed.

Problems faced by shortwave communications:

1) The reliability of communication is yet to be improved. The sky wave propagation of short-wave communication is extremely unstable because of the ionospheric changes and multipath propagation. On the one hand, the height and the concentration of the ionosphere change with the regions, seasons, time, sunspot activities, and other natural factors. On the other hand, they are also changed by the ground nuclear tests, high-altitude nuclear tests and high-power radar and other human factors, which means the frequency of short-wave communication must also be changed accordingly. Especially at dawn and dusk, the ionosphere electron density changes greatly, and it is necessary to change the frequency in time, otherwise it will lead to communication interruptions.
2) The data transmission rate is not high enough. Due to the carrier frequency, the traditional shortwave communication has the problem of low data transmission rate (no more than 600bit/s), and the communication method is generally frequency coded. The modern communication requires more and more information, including the requirements for images, data, audio and video, which cannot be achieved for the limited channel capacity of shortwave, so the data rate of modulation on the limited carrier frequency needs to be further improved.
3) Anti-interference capability. Because of its important performance in field communication and battlefield applications, shortwave communication plays an irreplaceable role in communication command. But it is also very vulnerable to enemy interference and confrontation, so how to improve the system's anti-jamming ability is a huge challenge.
4) Networking. As communication becomes more and more networked, shortwave communication is gradually developing in the direction of networking. However, compared with the microwave band, its channel capacity is more limited. How to achieve high efficiency system networking, optimize network structure, and improve network response speed for the limited data rate of shortwave is the key issue.

The current situation of shortwave network: According to the network form, shortwave network can be divided into centralized control, distributed control and the combination of the two mixed control network. Centralized control is to use some special network nodes as the central base station, other nodes belonging to the subordinate position, and the interaction of all information is completed through the unified resource allocation of the base station. The advantages of this network form are simple and reliable control, convenient management, and high channel utilization, but the disadvantage is the poor resistance to destruction, especially once the node of the base station is destroyed, the whole network will be paralyzed. Affected by the central role of the base station, the network coverage area depends on the communication range of the base station, and the expansion of the network appears to be very difficult. The advantage of distributed control network, also called centerless network, is that each node in the network is on an equal footing, and its advantage lies in the self-organizing ability and self-restoring ability of the network, so that the destruction of any node will not cause the failure of the overall network. The disadvantage is that the network management is difficult and the network protocol is very complex. The hybrid network adopts both network structures, and the layout of the network is designed according to the specific situation.

(2) System solutions for emergency communication networks

1) the choice of shortwave frequency band: Considering that the emergency communication situation often involves complex terrain, traffic inconvenience, and long-distance communication, one of the most direct solutions is to expand the distance of direct communication. In addition, due to the specificity of the actual situation after the disaster, it is often the case that the distance between two neighboring nodes is several kilometers to tens of kilometers, or even blocked by mountains or buildings, etc. Therefore, it is very important to ensure the nodes' ability to communicate over long distances and across obstacles. Based on this consideration, we choose the wireless communication frequency as short wave. Compared to microwave communications, shortwave wavelength is longer, with excellent bypass and diffraction capabilities, you can easily achieve communication across obstacles. Because the means of shortwave transmission mainly depends on ionospheric reflection, and in clear daylight, it may even reach hundreds of kilometers of communication distance with less power, which is out of the reach of microwave communication which can only rely on straight-line transmission to achieve line-of-sight communication. Compared with long-wave communication, the volume of short-wave transceiver antenna is relatively small, and it is easy to make simple, efficient, and portable antenna, while long-wave communication generally need to build a huge tower antenna to improve efficiency, and it is extremely inconvenient to construct the antenna. In addition, because the frequency is too low, the data transmission rate is very low. The biggest disadvantage of shortwave communication is its much lower frequency compared to microwave communication and the lower data transmission bit rate that can be achieved.

2) The choice of centerless network form: the conventional communication method belongs to the centralized control network, including cellular phone, Internet, telephone network, etc.. Although these communication networks work well and deliver high performance in normal circumstances, these networks invariably require establishing information exchange control center and data forwarding base station. The structure of the base station or the control center is generally very complex, and need to deal with all the data of the whole area or the whole network. Once a base station fails, it will cause the information in the whole area to be closed. Once the control center fails, it will lead to the failure of all the base stations associated with it, and the larger area will be in isolation, which is the biggest drawback of the centralized network. In contrast, another kind of distributed network, i.e., centerless AdHoc network, is established without relying on the centralized data forwarding of base stations and control centers, but any node can send and receive information directly, and indirectly accessible nodes can choose Ḁ some nodes to forward information for them. At the same time, the nodes of the centerless network do not require

special complex design as base stations, so they can be fully powered up and ready to use, and the network is not damaged by power failure. Considering the difficulty of establishing base stations and control centers in disaster situations, the centerless network is the first choice for post-disaster emergency communication networks. The centerless network has the following characteristics: (1) No central node. The network is a peer-to-peer network. Each network node has the same hardware structure in the network, and the network status is equal. The node can join and leave the network at any time, and the failure of any node does not affect the operation of the whole network, which has strong resistance to destruction. (2) Self-organization. Once a node is powered on, it can search for surrounding networks and join them, and quickly set up an independent and perfect network. (3) Multi-hop routing. Network nodes can communicate between any two points, and the communication between two distant points usually need to go through a number of nodes forwarding, commonly known as “multi-hop”. This is essentially different from the structure of the traditional central network in which nodes only communicate with routing. (4) Dynamic topology. The network has a strong dynamic topology and self-healing ability. With the movement of nodes the change of the strength of the signal, and the joining and exit of nodes, etc., the network can be adjusted according to the self-organization protocol, update the routing information to adapt to the changes in the network structure.

3) The proposed reference model of shortwave networking system: In 1981, the International Organization for Standardization recommended a network system architecture development system interconnection model, referred to as OSI. As a result of the establishment of this network standard, every network standard since then has been aligned with OSI. The network system model proposed in this report refers to the IEEE802.15.4 standard and the architectural idea of Zigbee protocol stack defined by Zigbee Alliance, which divides the shortwave networking system into four layers: physical layer, media access control layer, network layer and application layer.

   The physical layer includes hardware facilities such as wireless transceivers and hardware codecs, etc. The media access control layer mainly defines the types of data frames, frame structure, basic data sending and receiving and answering methods, etc. The network layer is mainly responsible for the topology of the network. The application layer defines the commands, network maintenance methods, path selection methods, exception handling methods, etc. according to the user’s functional requirements.

4) Implementation of network node device structure: Each standard network node of the centerless network designed in this system has equal status, except for the difference of ID number and upper layer attribute setting, its underlying devices are identical and can be copied directly, and each node can be used when it is powered on. The node of the standard centerless network in this design consists of the following eight parts: transceiver antenna, transceiver, hardware codec, USB interface converter, embedded platform, application software, display and keyboard, etc., and battery backup.

(3) Emergency communication network hardware design scheme

There are six main components in the overall physical layer hardware solution, which are transceiver antenna, receiver module, transmitter module, FPGA codec module, USB communication module and power module. The antenna is the basis of microwave signal transmission and reception; the receiver module is responsible for signal reception, conditioning and demodulation; the transmitter module is responsible for signal modulation, conditioning and transmission; The FPGA module is responsible for signal coding and decoding, error detection and error correction; the USB communication module is responsible for the communication between the underlying circuit and the upper computer. The hardware environment for proper system communication can be ensured by the above modules.

The modulation and demodulation part, modulator FSK modulation circuit, FSK modulation circuit is mainly based on Analog AD9954 and the AD9954 is a highly integrated DDS device developed using advanced DDS technology, which is a DDS chip specifically for signal modulation. With a core conversion rate of up to 400MSPS and a built-in high-speed, high-performance D/A converter and ultra-high-speed comparator, it can be used as a digitally programmable frequency synthesizer capable of generating up to 200 MHz analog sine waves. The AD9954 contains 1024×32 static RAM, which can be used for high-speed modulation and supports several sweep modes. The AD9954 provides a customizable linear sweep mode of operation with fast frequency conversion and good frequency resolution via the AD9954's serial port input control word. Applications range from sensitive frequency synthesizers, programmable clock generators, FM modulation sources for radar and scanning systems, and test and measurement devices. Its main features are built-in 400MSPS clock, including 14-bit DAC, phase, amplitude programmable, 32-bit frequency conversion word, available serial control, built-in ultra-high-speed analog comparator, automatic linear and non-linear sweep, internal integration of $1024 \times$ 32-bit RAM, 1.8 V power supply, 4–20 times the frequency multiplier, support for most digital inputs in the 5 V input level It can realize multi-chip synchronization, etc.

For digital signal transmission, high-speed modulation and demodulation is a challenge. The conventional signal source is generated by the phase-locked loop. The phase-locked loop is a slow and stable process, so it is impossible to achieve high-speed frequency jump, and the phase-locked loop signal source is mostly used for analog modulation such as FM. DDS devices solve the problem of high-speed modulation of short-wave frequencies. Since DDS is basically a digital device, its output waveform is directly synthesized by DA converter, and the modulation speed is not a bottleneck, it can achieve the above modulation speed in the short-wave band.

5.3.3 Communication Monitoring Software System

This chapter introduces the software design and implementation of the wireless self-organizing network communication/monitoring system for emergency and disaster relief. Firstly, it introduces the construction of the system software platform environment, including the construction of the cross-compiling environment, bootloader porting and Linux kernel porting, which provides a good foundation for the system software design and implementation; Secondly, it introduces the process of designing and implementing the software part of the self-organizing terminal, including video, voice, text, file, picture and other functional modules; Finally, we introduce the routing protocols in the network and the principle of dynamic source routing protocol (DSR) used in this system and the process of implementing it on the wireless self-organizing terminal. The parts of the wireless self-organizing communication/monitoring system software are shown in Fig. 5.19.

(1) System software platform environment construction

Linux is an open source, Unix-like operating system that includes a kernel, system tools, and a complete development environment. The embedded Linux system is a dedicated computer system designed and developed for specific applications based on embedded technology and computer technology by using many features of Linux itself and applying it to the embedded environment. The embedded Linux system structure is divided into user level, kernel level and hardware level. The user application implements the calls to the Linux driver and file system through the Linux system call interface, and the called device driver finds the corresponding hardware

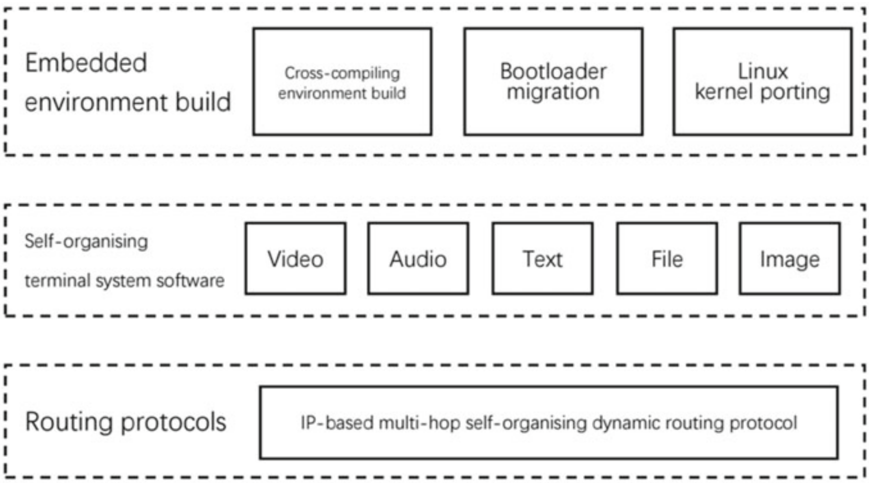

Fig. 5.19 Software block diagram of wireless self-organizing communication/monitoring system

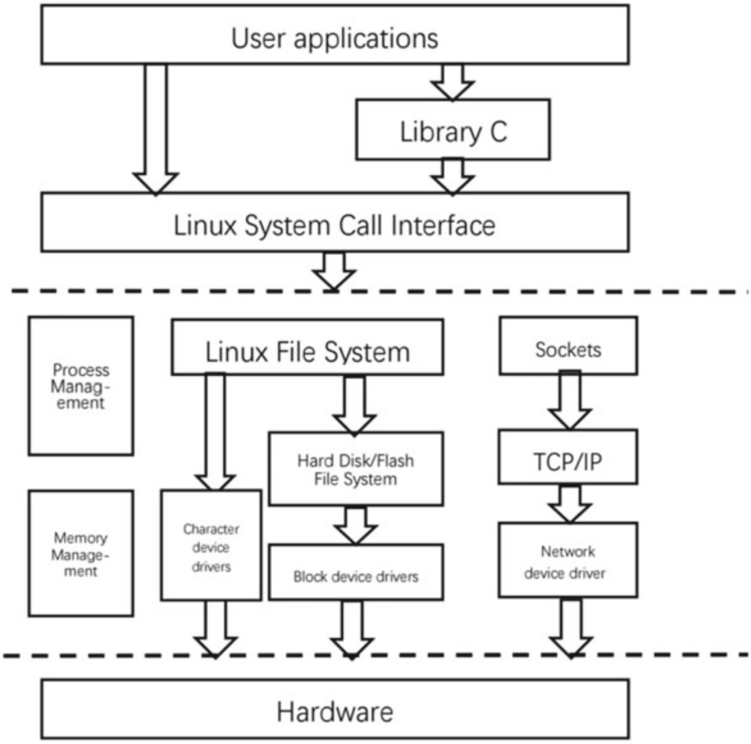

Fig. 5.20 Embedded Linux system architecture

module of the embedded development board and implements the calls to the hardware level part of the embedded Linux system to realize the functions required by the user. The embedded Linux system architecture is shown in Fig. 5.20.

(2) Establishment of cross-compilation environment

Since embedded systems do not have development capabilities, a development environment needs to be set up first for embedded software development. This report studies a wireless self-organizing network communication/monitoring system for emergency and disaster relief, and the ARM Linux platform is chosen to run the corresponding program, which is called the target machine; The developed programs need to be written, compiled and debugged on the X86 Linux platform, which is called the host. As shown in Fig. 5.21, the task of generating an ARM platform runtime program on the host is accomplished with the help of the host's cross-compilation toolchain, a complex compilation environment that includes a compiler, a connector, and an interpreter.

The cross-compilation tool chain used by the host computer is arm-linux-gcc-4.5.1, and the target machine is connected to the host computer by a serial cable to

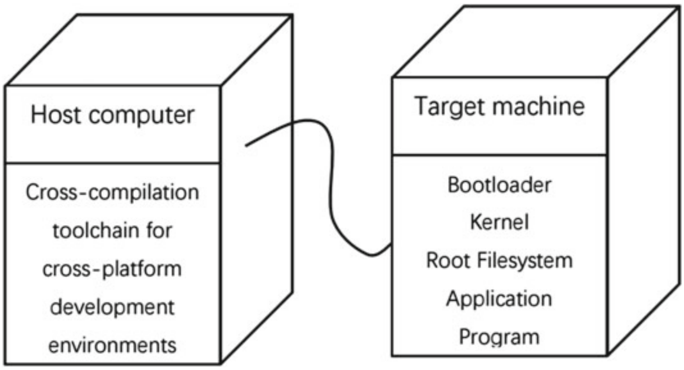

Fig. 5.21 Functional structure of the host and target machine

realize the cross-compilation development of embedded Linux software. arm-linux-gcc-4.5.1 Installation Install as follows:

1) Copy the arm-linux-gcc-4.5.1.tgz zip file to the specified folder #mv
2) arm-linux-gcc-4.5.1.tgz /cd/home/cai/
3) Unpack the file #tar zxvf arm-linux-gcc-4.5.1-C
4) After adding the cross-compiler tool chain path to the environment variable path, enter the command arm-linux-gcc -v in the window to view the software version, default path and other details of the installed cross-compiler tool.

(3) Bootloader porting

In traditional computer architectures, the system is usually booted by the BIOS (Basic Input Output System) and the operating system bootloader present in the MBR, while in embedded Linux systems, the bootloader is used to boot the system. The bootloader is a relatively small program cured in the embedded system, whose main role is to guide the operating system and user programs to run properly.

The bootloader program is related to the embedded system hardware platform, processor architecture, CPU architecture, development board peripheral hardware devices, each part of the difference will affect the bootloader program. The more common bootloader programs in embedded Linux systems are Red boot, ARM boot, U-boot, Super boot, etc. Usually, users need to choose the right bootloader according to the device used.

The bootloader is generally started in two phases. The first phase is implemented using assembly and is mainly responsible for initializing the CPU architecture-dependent hardware and making calls to the code in the second phase; The second stage of the bootloader code is implemented in C. The main function is to check the system memory map status and set the kernel boot parameters as well as load the image and root files.

(4) Linux kernel porting

The main advantage of an embedded Linux system is its kernel's cuttable nature, which allows the Linux system to maximize the performance of the hardware system after a proper cut and port. The embedded Linux kernel is divided into five different parts based on their functions: memory management, process scheduling, virtual file system, network interface, and inter-process communication. The functions of each part are described separately below.

Memory management: control and coordinate each process to safely share the main memory area, manage the physical memory of the entire Linux system reasonably and effectively, and respond positively and quickly to each subsystem's request for memory allocation. The Linux system supports virtual memory, which can be requested through the disk to get extra memory, and other programs are temporarily stored in the disk. In the state of memory shortage, the system's memory management realizes the transformation of process virtual memory and physical memory.

Process scheduling: Process scheduling controls access to the CPU for each process on a Linux system. When a process is needed to start, the process scheduler prioritizes the processes according to their priority and starts the most important processes first.

Virtual File System: The virtual file system uses a file model to represent different file systems. This model shields the specific differences between file systems and allows the Linux system kernel to support multiple file systems.

Network Interface: The network interface provides Linux system support for multiple network standards and hardware devices, and the parameters of the network interface can be configured to enable information communication between different network devices.

Inter-process communication: There are various ways to communicate between processes, including pipes, sockets, semaphores and shared memory, etc. These mechanisms enable user space synchronization, data exchange and sharing between different processes.

Embedded Linux system, it is necessary to provide corresponding drivers for each hardware device of the self-assembled network system to link the kernel with the hardware devices to ensure the normal operation of the system. The system uses Linux 3.5.0 kernel version, the specific migration steps are as follows:

1) Kernel preparation

   Download the Linux-3.5.0.tgz source tarball, unzip the tarball, and go to the unzipped folder: #tarzxvf linux-3.5.0.tgz Modify the Makefile file so that ARCH = armCROSS_COMPILE = arm-linux-, i.e., select the arm structure type CPU and arm-linux-gcc cross-compile toolchain.

2) Kernel configuration

   Go to the unpacked Linux-3.5.0 folder and execute the make menuconfig command to configure the embedded Linux kernel.

3) Kernel compilation

Once the embedded Linux kernel parameters are configured, the kernel is compiled by executing the make command at the command line of the Secure CRT software, and the Zimage kernel image is generated under the default path.

(5) System software interface design

The design and the implementation of the wireless self-organizing network communication/monitoring system software for disaster relief mainly contain: software interface, communication signaling, video, voice, text, file, picture module. The following part describes the implementation process of each part respectively.

The self-configuring terminal interface of a wireless self-configuring communication/monitoring system for emergency and disaster relief is designed and implemented in Qt, a C+ + graphical user interface development framework from Qt Compony, which widely supports Linux, OSX, Windows, Android, Black Berry, IOS and other platforms.

Qt uses a modular code base to make porting easier for users, who only need to port the appropriate modules. Qt divides all functional modules into three parts: Qt Essentials, Qt Add-Ons, and Qt tools. The module framework is shown in Fig. 5.22.

Base Module: Defines the basic functionality of Qt for various platforms and is the core of Qt.

Extension modules: additional modules designed for Ḁ special features, available only on Ḁ platforms, such as Bluetooth, Qt Graphical Effects, Communication Qt Serial Port, etc.

Development Tools Module: Development tools needed in the interface design process, such as Qt designer, etc. Qt, a C+ + program development framework, includes GUI toolkits and development modules for networking, OpenGL, sensors, communication protocols, databases, Web technologies, XML and JSON, etc.,

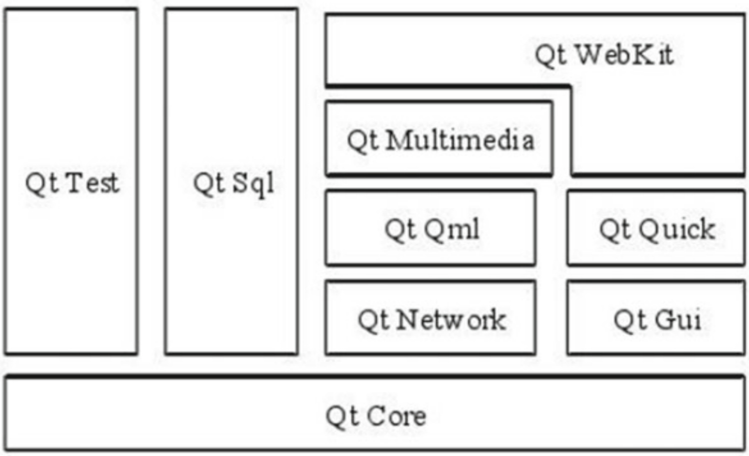

Fig. 5.22 Qt framework

providing a convenient development environment for users, database, Web technology, XML and JSON development modules, providing users with a convenient development environment.

Signals and slots are used in Qt instead of callback techniques. When a specific event occurs, a signal is fired. A slot is a function that is called corresponding to a specific signal, and Qt has several predefined slots internally that can be subclassed to add their own slots to handle signals of interest. Signals and slots are safe mechanisms, the parameter type of a signal must match the parameter type of its receiving slot for signaling to occur. Signals and slots are loosely coupled; the class that emits the signal does not need to care about the class that receives it.

Qt's signal slot mechanism allows the slot to receive the exact signal parameters and call them at the right time. Qt has unique advantages over other development tools:

1) With good cross-platform features, Qt supports Windows 95/98, Windows NT, Linux, SunOS, Digital NUIX, SCO and other operating systems, the same code can be compiled and run on all supported platforms, and it will show the unique interface style of the platform according to the different platform features.
2) Qt is object-oriented and very convenient for development users. Good packaging mechanism makes the Qt framework highly modular and reusabile.
3) Qt has a rich API interface and contains at least 240 C++ classes in the library, as well as template-based file, serialization, I/O device, and data/time classes.
4) Qt supports rendering of 2D/3D graphics on the interface and supports Open GL to provide users with good visual effects.
5) Qt supports extensive documentation development.

The interface of the self-assembling terminal of the wireless self-assembling network communication/monitoring system for emergency and disaster relief is implemented in Qt language. Considering the usage scenarios of the self-assembling terminal, the interface of the self-assembling terminal is designed to be simple and easy to operate. The interface is divided into six major parts: information, video, voice, camera, file and attributes, which realize multi-hop wireless transmission of text information, video data, voice signal, picture and file respectively, and the attributes page shows the configuration of each parameter of the self-grouping terminal. The following is a detailed description of each part respectively.

(6) H.264 based video transmission

The video transmission of the wireless self-assembling communication/monitoring system for emergency and disaster relief uses H.264 encoding and the V4L2 programming framework to provide good video service for emergency and disaster relief personnel.

1) H.264 encoding

H.264 is a new generation of digital video compression coding format jointly developed by the International Organization for Standardization (ISO) and the International Telecommunication Union (ITU), which is based on the MPEG-4 coding method. Better image quality. Its advantages are mainly reflected in the following aspects: low bit rate: compared with other coding technologies such as MPEG-2 and MPEG-4, the amount of data encoded with H.264 technology is 1/8 of that encoded with MPEG-2 technology for the same image quality. High quality video picture: H.264 is able to provide high-definition picture quality even at low bit rates, providing smooth HD video transmission at lower bandwidths. Powerful network adaptability: H.264 itself provides network abstraction layer services, and files can be transmitted smoothly on various networks (e.g. Internet, GPRS, WCDMA, CDMA2000, etc.).

Hybrid coding structure: H.264 adopts a hybrid coding structure, using a mixture of DCT transform coding and DPCM differential coding to improve coding efficiency. Error recovery function: H.264 effectively solves the problem of packet loss during network transmission, which makes H.264-encoded image data suitable for transmission in wireless networks. The H.264 video coding technology uses a layered design structure, namely the VCL video coding layer and the NAL network abstraction layer, to separate the compression of the video stream from the network transmission of the packets. The video encoding layer is responsible for compressing and encoding the video stream data, which is the core of H.264 encoding, while the network abstraction layer is responsible for encapsulating the encoded data according to network standards to ensure that the data can be transmitted over multiple networks. The H.264 layered model is shown in Fig. 5.23.

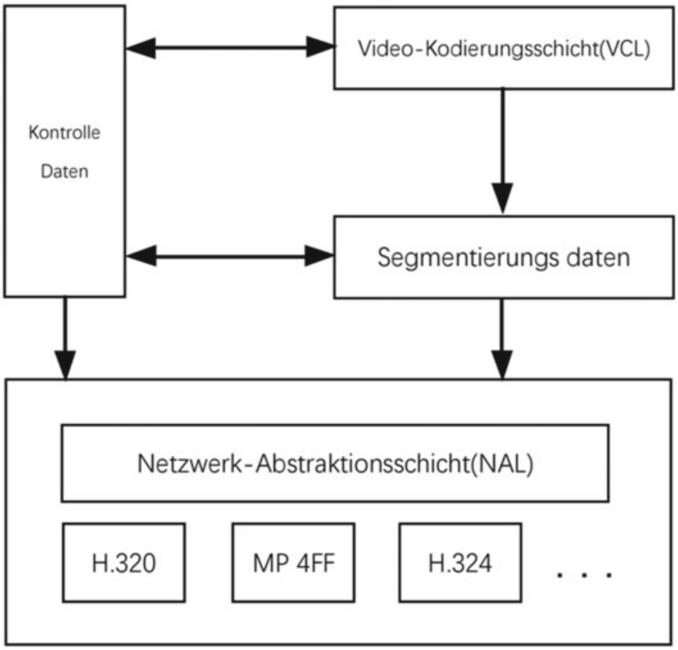

Fig. 5.23 H.264 layered model

The video coding layer mainly consists of video encoder and video decoder. Different methods can be chosen for coding, such as inter-frame coding or intra-frame coding for efficient compression of video streams, and the coding process consists of 5 parts: inter-frame and intra-frame prediction, transform and inverse transform, quantization and inverse quantization, loop filtering, and entropy coding. The network abstraction layer is responsible for encapsulating data using the network segmentation format, including group frames, logical signaling, and end-of-sequence signals, etc. The basic unit of the NAL layer is the NALU, which is composed of a fixed syntax sequence with variable byte lengths that vary depending on the transmitted data. The NALU mainly contains the NAL header information and the RBSP byte stream.

2) V4L2 Framework

The wireless self-organizing communication/monitoring system uses V4L2 framework to implement the video data capture function of USB camera. V4L2 is a dedicated video framework for Linux devices, which provides driver support for all video data capture on Linux system, and users can directly call API functions to operate on board multimedia devices. V4L2 is compatible with most existing drivers and is widely used in embedded devices, personal computers, and mobile terminals.

V4L2 uses pipeline to implement video data acquisition. The video acquisition program is implemented by calling the ioctl() function, which has three main parameters, namely, device descriptor, control command character and control command parameter. The function interfaces such as open, read, mmap, write, etc. are commonly used in the video capture process, and the common control command characters are shown in Fig. 5.24.

VIDIOC_REQBUFS: allocate memory
VIDIOC_QUERYCAP: query driver
VIDIOC_S_FMT: Video capture format setting
VIDIOC_QBUF: read video data from the cache
VIDIOC_DQBUF: put data back into the buffer queue
VIDIOC_STREAMON: start video display

The video data acquisition process of V4L2 is shown in the figure below.

3) H.264 encoding implementation

The video coding of the wireless self-organizing network communication/monitoring system for emergency and disaster relief uses hardware codecs and is implemented using Samsung series processors. In the acquisition and transmission stage, the USB camera captures YUV422 format images, which are first converted into digital streams by analog-to-digital conversion, then converted into NV12 format images by FIMC (camera controller integrated in the main control chip), and finally converted into H.264 format streams by MFC (Samsung Multimedia Hardware Processor).

The Tiny4412 core board used in this system is integrated with the Samsung Multimedia Hardware Processor MFC module, which supports MPEG-2, MPEG-4,

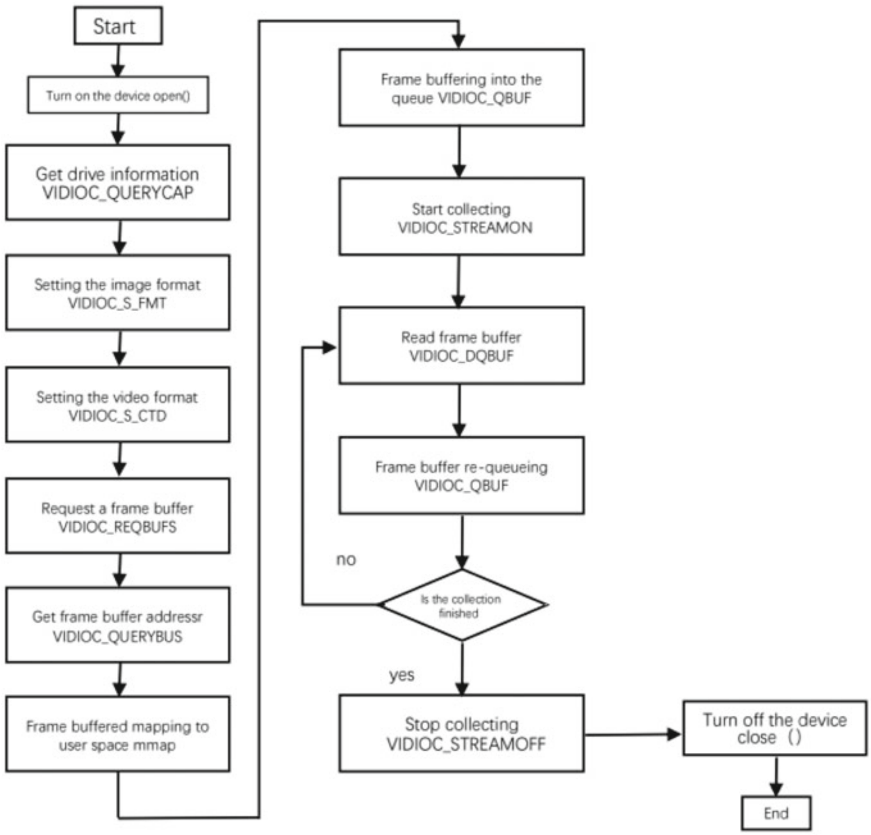

Fig. 5.24 Video capture process

H.263, H.264 and other codec formats and is a low-power, high-performance video codec. In addition, the traditional software codec uses the CPU to undertake the coding and decoding work, which supports many kinds of codes but increases the workload of the CPU and affects the normal operation of other parts; By adopting hardware codec, the GPU is responsible for codec tasks, which takes up very little CPU resources, greatly reducing CPU workload and improving codec speed and smooth operation of the whole system. The coding flow of the MFC module is shown in Fig. 5.25.

4) RTP transmission

Streaming media is a format in which the audio and video data is compressed and encoded for real-time transmission over a network. The files transmitted over the network by streaming technology are generally video and audio files. The audio and video transmission in the network mainly includes two kinds of transmission methods: downloading and streaming. Due to the limitation of network bandwidth

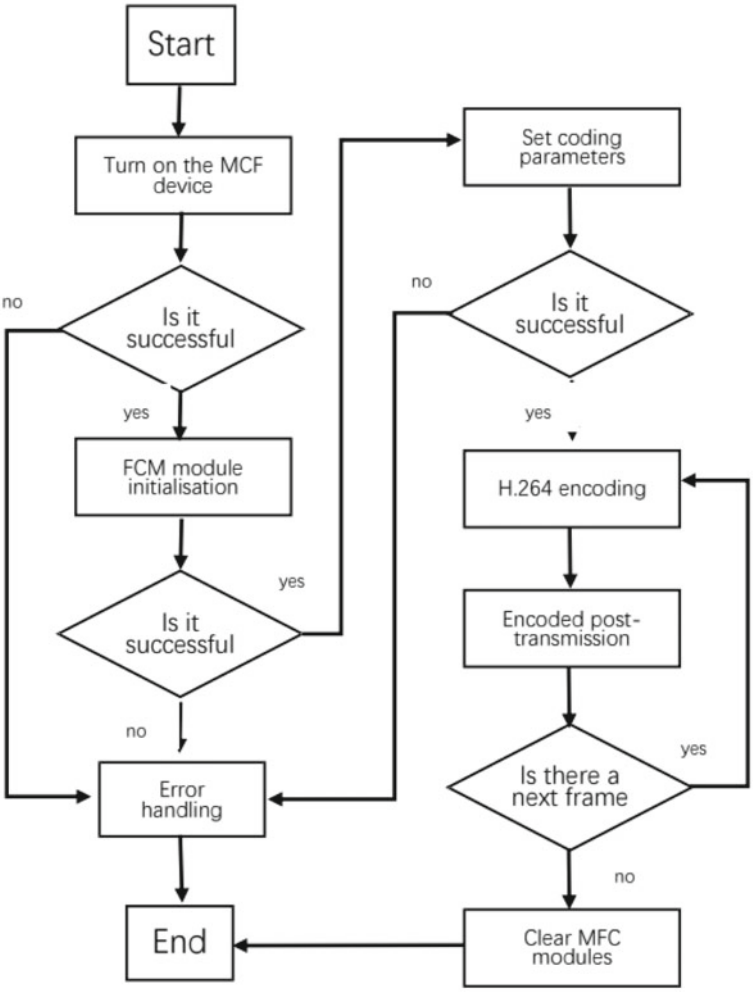

Fig. 5.25 MFC coding flow

at this stage, it takes some time to download video files from the network, which leads to a great delay, while with streaming technology, the playback of audio and video files can be realized after only a few seconds of start-up buffering, which greatly ⫽ uplifts the user experience. The video transmission of a wireless self-organizing communication/monitoring system for emergency and disaster relief is implemented using RTP, the full name of which is Real-time Transport Protocol. The RTP protocol is commonly used in streaming media transmission systems to provide real-time end-to-end transmission services for streaming data transmission of the system. The RTP standard contains two sub-protocols, the RTP protocol and the RTCP protocol. Data Transfer Protocol RTP, responsible for the real-time transmission of data over the network, provides information such as timestamps, sequence numbers and load formats to enable synchronization and packet sequence detection; The control protocol RTCP is used to provide Quality of Service (QoS) feedback for RTP, collecting statistics on the number of bytes transferred, number of lost packets, network latency time, and other streaming media transfer stages. The RTP and RTCP protocols work in tandem to provide a reliable mechanism for real-time network delivery of streaming media. RTP datagram contains two main parts: RTP message header and RTP data load. The header format is fixed and contains the information for streaming media transmission; the data load part is the audio and video data to be transmitted.

5) Video transmission interface

The video transmission of the self-assembled terminal of this system is full-duplex communication, i.e. both sides send and receive the video at the same time during the communication phase, which ensures the mutual understanding of the situation between rescue and relief personnel when a disaster occurs. The right side of the interface is divided into four parts, the first part is the network technical indicators, reflecting the network conditions during transmission, respectively, throughput, time delay and jitter values, throughput reflects the number of successfully received data per unit of time, time delay reflects the time required to transmit messages or packets from one end of the network to the other, jitter reflects the degree of variation in the delay of messages or packets; The second part is the short code input box of the target terminal node, input the short code corresponding to the other terminal node, and click the video button to realize the communication signaling request; The third part is the last-hop address display box, which displays the last-hop address of the packets received during the communication process. The system supports multi-hop transmission of services and adopts the basic idea of Dynamic Source Routing Protocol (DSR), which is an IP-based multi-hop self-organized dynamic routing protocol implemented in embedded Linux, so that the display of the last-hop address can accurately know the path through which data is transmitted; The fourth part is the send and exit buttons for video. After entering the short number of the target terminal node, clicking the video button will perform the communication signaling request and communication connection establishment, and clicking the exit will quit the current task. The left video frame is the video display area, divided into two display parts. The upper right corner of the video frame shows the screen captured and sent by the camera of this terminal, and the remaining area of the video frame shows the video stream data received by this terminal. The video service supporting full-duplex communication and multi-hop transmission can provide powerful communication guarantee for the rescue operation in the disaster area.

(7) G729-based voice intercom

Voice intercom is an important way of information communication, and the wireless self-organizing network communication/monitoring system for emergency and disaster relief realizes the voice intercom function between terminals. Good quality of voice communication has always been the goal that people pursue. With the development of technology, compressing the transmission bandwidth of the signal and increasing the transmission rate of the channel play an important role in the process of voice communication. Speech coding is the coding of the original speech signal collected by the hardware device. It converts the analog signal into digital signal to achieve the purpose of compressing the voice signal and high communication quality, and also facilitates the transmission of voice signal. There are three common speech coding methods: waveform coding, parametric coding and hybrid coding. Waveform coding is a direct conversion of the time-domain waveform of the speech signal into a digital code sequence. The technique targets the waveform of the collected analog speech signal and quantifies it in layers according to a certain sampling frequency, and at the receiving end, the received digital speech signal is decoded and restored to the original analog speech signal, and the speech signal obtained at the receiving end maintains the same waveform as the original signal. Waveform coding has high quality of voice call and higher coding rate, with the disadvantage that the compression of the voice signal is inefficient and takes up a larger transmission bandwidth. Parametric coding, also known as sound source coding, is to abstract the human body into a fixed vocal model, to encode the speech signal after extracting the characteristic parameters of the model, and to work on the recovery of speech at the receiving end in combination with the mathematical model. Parametric coding is characterized by a high compression rate and occupies a small transmission bandwidth, with the disadvantage that the coding rate is low and is affected by the noise in the surrounding environment. Hybrid coding is a combination of waveform coding and parametric coding, combining the advantages of both into one to make up for the shortcomings of each, and adding waveform coding technology on top of parametric coding technology to realize the joint improvement of both compression efficiency and voice call quality, which has good effect on voice transmission in practice. Voice communication in mobile communications is generally implemented by choosing hybrid coding techniques.

In view of the application scenario of wireless self-assembled communication/monitoring system and the development platform used, and considering the limited resources and processing capability of the embedded system, and based on the requirements of low code rate, low complexity and real-time, the G729 speech coding technology is the final choice for this system through a comprehensive comparison of several speech coding technologies discussed above. G729 speech coding technique is a linear predictive coding using conjugate structure arithmetic coding excitation. At a sampling frequency of 8 kHz, a speech signal of a length of 10 ms is coded to work. Each frame includes 80 sampled signals. The speech samples are analyzed and the CELP model is extracted. The CELP model consists of linear prediction coefficients, adaptive codebook indexes and gains. These parameters are transmitted to the receiver by coding, and at the receiver, the speech signal is reconstructed by decoding.

The system uses the ALSA architecture to implement the work of capturing the original sound signal. The full name of ALSA is Advanced Linux Sound Architecture, which provides support for audio on Linux systems, and the modular design efficiently supports all kinds of interfaces from entry-level to professional-level audio devices. The system can easily call the on-board devices for voice signal acquisition through the functions in ALSA. On the left side of the interface is the input box of the short code of the other party and the configuration information of this terminal. Enter the corresponding short code of the self-assembled terminal that needs voice communication in the short code input box, and click the call button to realize the request of voice communication signaling and voice communication connection, and realize the collection and playback of voice signal through the standard 3.5 mm headset and microphone external to the wireless self-assembled terminal. Both parties enter the voice communication interface. The wavy line on the right side indicates that the voice signal is currently being collected, the timer below accurately records the time of voice communication, and the exit button at the bottom serves to exit the current voice communication and interrupt the connection. The voice communication interface of the wireless self-assembling network communication/monitoring system for emergency and disaster relief is friendly, simple to operate and functional, which can provide a strong guarantee for information communication in complex geographical environment.

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Chapter 6
Grid Emergency Decision Technology

6.1 Power Disaster Contingency Posture Map

6.1.1 Mechanisms for the Evolution of Situational Emergencies

From the perspective of system theory, the so-called mechanism refers to the operation mechanism and working principle of the system, and in fact, it is the operation mode of the internal components of the system and the operation rules and principles of the mutual connection and interaction between the elements. As a complete system, emergencies also have their own evolutionary mechanism. The evolution mechanism of emergency events can be divided into two aspects: occurrence mechanism and development evolution mechanism, among which the development evolution mechanism can be divided into four aspects: spread, derivative, transformation and coupling.

(1) Mechanism of emergencies

Emergencies generally occur under the combined action of intrinsic causes, direct causes and indirect causes in a specific time, space and external environment. The essential cause of emergencies is composed of the self-defects of people, things and the environment, of which human defects include human physical defects and consciousness defects, material defects include defects in the self-aspect of things and defects in the state of things, and environmental defects include natural environment defects and socio-economic environmental defects; The direct cause of the emergency is composed of unsafe factors of people, things and the environment, among which human insecurity factors refer to people's unsafe behavior, material insecurity factors refer to the unsafe state of things, and environmental insecurity factors mainly refer to the negative impact of the environment; The indirect causes of emergencies are mainly caused by inadequate daily management, including

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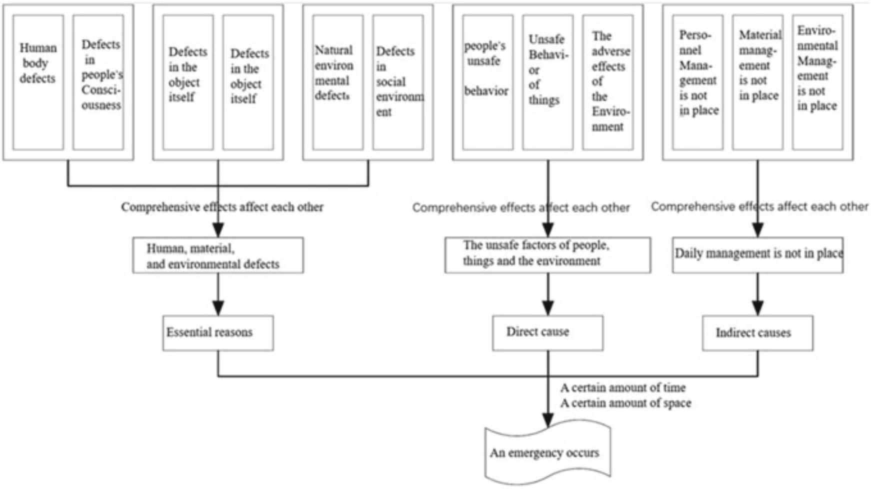


Fig. 6.1 Mechanism of sudden incident occurrence

inadequate personnel management, inadequate material management and inadequate environmental management, as shown in Fig. 6.1.

The mechanism of emergency can be divided into two types according to the continuity of the change of the event itself: one is caused by qualitative change to a certain extent. This change is more of a continuous and gradual change process; the other is caused by mutation, which is caused by the sudden change of some factors or the external environment, which is more of a discontinuous and abrupt process. In reality, most of the emergencies are combinations of the above-mentioned two types, including not only the process from quantitative change to qualitative change, but also the sudden changes. In fact, regardless of the type of occurrence mechanism, it is due to the defects of the thing or the environment, which leads to the long-term existence of some potential risks. These potential risks suddenly break out in a specific time, space, environment and inducements, leading to the occurrence of emergencies.

(2) The development and evolution mechanism of emergencies

After their occurrence, emergencies will evolve under the action of internal and external factors, leading to the development of emergencies in different directions, and some secondary disasters or derivative accidents may develop. Therefore, in order to timely and effectively deal with emergencies, make the development and evolution of the events develop in the expected direction, and minimize various losses, it is necessary to understand the development and evolution mechanism of the emergencies. Generally speaking, the development and evolution mechanism of emergencies can be specifically divided into four aspects: spread, derivation, transformation, and coupling, as shown in Fig. 6.2.

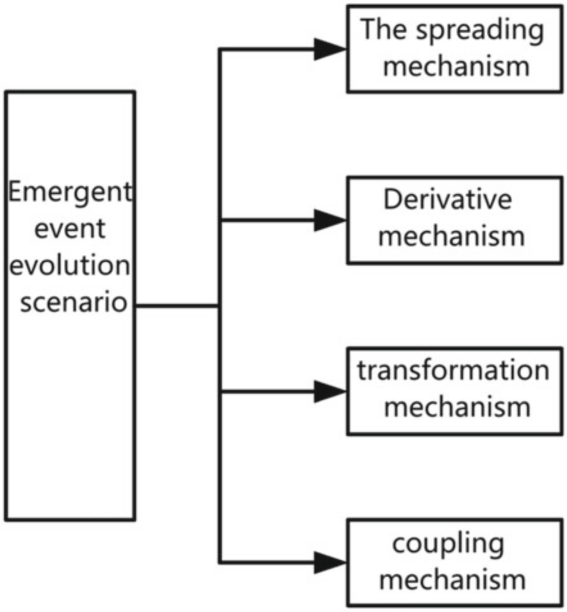


Fig. 6.2 Evolution mechanism of sudden incident development

1) Spread mechanism

The so-called emergency spread refers to the occurrence of an emergency, leading to more incidents of the same kind. This "more" can be spatial expansion, such as fire in power equipment, or time transmission or extension, such as debris flow, which may cause spread and damage to other power facilities over time. The spread mechanism is more of an expansion of the state of affairs, and the initial emergency will not die out because of the occurrence of subsequent events, but exist at the same time. Emergency contagion can also be the spread of online virtual environments, such as the spread of online rumors. Due to the rapid propagation speed, the wide-range influence, and large number of contacts, the spread on the internet is more harmful since it has rapid propagation speed, wide-range influence, and large number of contacts on the Internet, as shown in Fig. 6.3.

2) Derivative mechanism

The so-called emergency derivation refers to the situation where the occurrence of an emergency event results in other types of more serious events due to excessive, harmful or improper response measures. For example, in order to cope with the traffic congestion caused by heavy snow, snow melting agents are sprinkled in a large area, leading to environmental pollution; Oil disinfectants to eliminate oil spills at sea may cause marine pollution; In 2011, the earthquake and tsunami in Japan destroyed

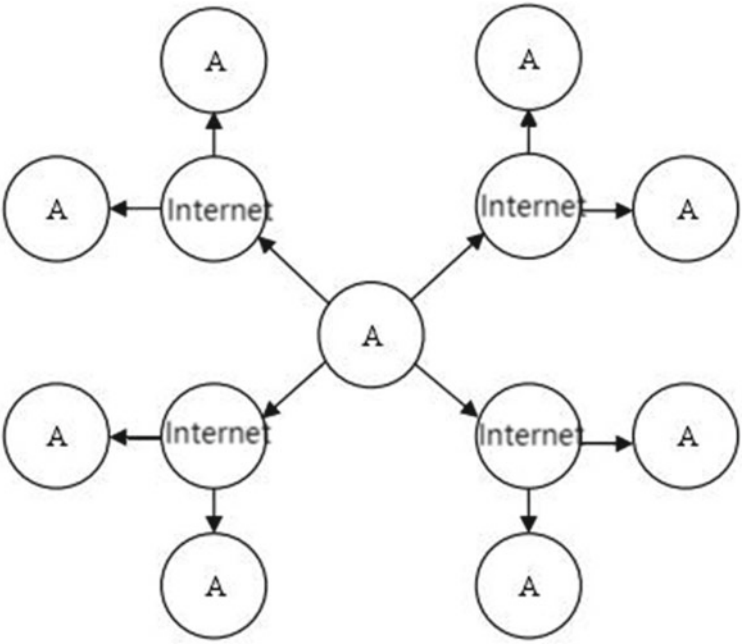


Fig. 6.3 Schematic diagram of the emergency network spread

the power system of the Fukushima nuclear power plant, and the destruction of the power system caused power outages.

Then the power outages make the cooling water unable to be replenished in time, and the drop in water level causes the nuclear fuel rod to be exposed to the surface of the water to meltdown, which eventually leads to a large amount of radioactive material leakage, resulting in a nuclear leakage accident. There are generally three development models for emergency derivation, as shown in Fig. 6.4 shown.

3) Transformation mechanism

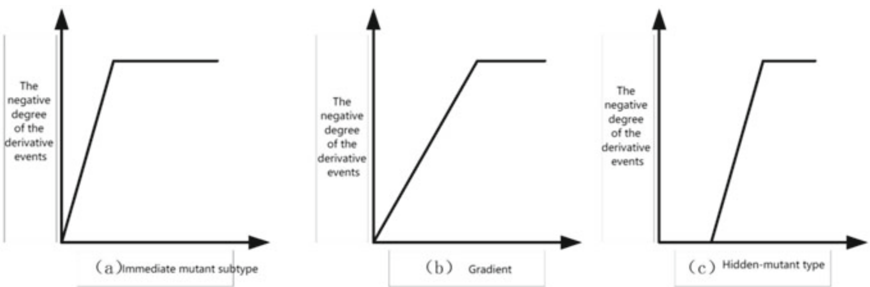


Fig. 6.4 Three patterns derived from the outbursts

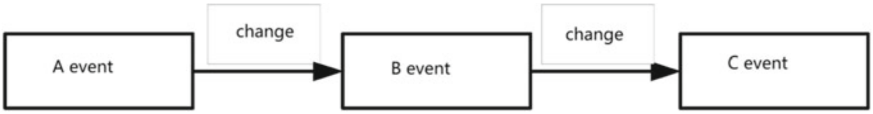


Fig. 6.5 Incident transformation mechanism

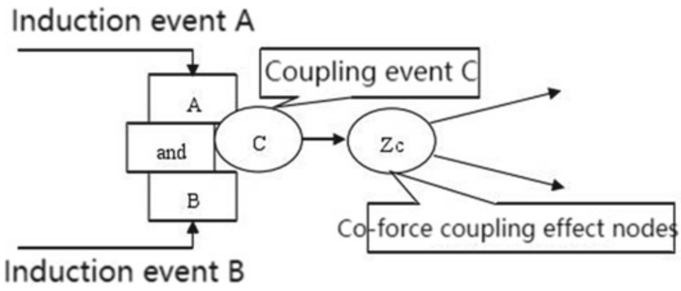


Fig. 6.6 Mechanism of burst incident coupling

The so-called emergency transformation refers to the situation where emergencies are transformed into different types of new disaster events under the action of their own factors or external environmental factors (as shown in Fig. 6.5). The most important feature of the transformation mechanism is "replacing the old with the new", that is, the occurrence of event **A** directly leads to the occurrence of event **B**, while event **A** disappears after event **B** occurs. For example, typhoon-induced rainstorm disasters are the embodiment of the mechanism of emergency transformation, and typhoon disasters are transformed into torrential rain disasters.

4) Coupling mechanism

The so-called emergency coupling refers to the phenomenon that two or more factors interact and influence each other, thus leading to the occurrence of emergencies or serious events. According to the characteristics of the object, it can be divided into event and event coupling, event and factor coupling, and factor and factor coupling. That is, when incident **A** induces incident **B**, **C** and **D**, incident **A** does not die, they interact with each other instead, as shown in Fig. 6.6.

6.1.2 Analysis of the Evolution Patterns and Pathways of Emergencies

The situation of an emergency also evolves over time after its occurrence. Therefore, it is necessary to understand the scenario evolution law and evolution path in order to construct the scenario network model, predict the future development trend and influence factors of emergencies, so as to make coping strategies.

(1) The evolution law of the emergency situation

The evolution law of emergency situation is the front and basis of analyzing the evolution path of emergency situation. However, due to the characteristics of being sudden, unpredictability, dynamics and serious consequences, the evolution process of emergencies is very complex and the law are difficult to find. In addition, in the whole process of emergency development and emergency response, the event scenario is also affected by external factors such as external environment and human intervention, which increases the complexity of the evolution of the whole event scenario. Although the evolution process of the emergency situation is complex, it does not mean that there is no regularity. After careful analysis, there is still a certain regularity. According to the scenario elements, the emergency response scenario can be divided into five element dimensions, namely the disaster-causing body, the disaster-bearing body, the external environment, the emergency resources and the emergency activities, of which the disaster-causing entity and the disaster-bearing body belong to the emergency object, the external environment and emergency resources belong to the external constraints, and the emergency activity belongs to the behavior and action of the emergency subject on the emergency object. If the emergency is regarded as a complete system, this division method mainly clarifies the components of the system from a static perspective.

The evolution of emergency scenarios is generally a dynamic process. Therefore, it is not only necessary to clarify the components of the scenario, but also more important to clarify the relationship and interaction between the components. In reality, emergency activities generally act on both the disaster and the carrier, the disaster and carrier can be combined together from a dynamic perspective to form the situational state elements, so that the complexity of the model can be reduced by reducing the number of elements. From this perspective, the scene evolution process of an emergency can be divided into the following four key elements: (1) scene state, represented by the letter **S**, mainly refers to the state of the emergency object, including the disaster state and the disaster object; (2) the emergency activity, represented by the letter **B**, refers to the disposal behavior and measures taken by the emergency subject to change the emergency state; (3) the external environment, represented by the letter **H**; (4) the emergency resources, represented by the letter **M**, which belongs to the external constraints of emergency activities. The interaction between these four key elements constitutes a basic unit, as shown in Fig. 6.7.

Since emergency resources do not directly act on the state of the scenario, emergency resources are considered as a constraint variable rather than an input variable in Fig. 6.7. In Fig. 6.7, **S** stands for the current situation. Under the influence of the external environment (**H**) and the intervention of the emergency activity of the emergency body (**B**), as well as under the constraints of emergency resources (**M**), the state of the situation changes and go into the next state ($\mathbf{S_1}$), namely converting from the situation **S** to the situation $\mathbf{S_1}$, realizing a complete process of situation evolution, called a basic unit of a sudden situation evolution.

Suppose an emergency undergoes situation conversion n times from its occurrence to its disappearance, the state of the situation is denoted as $\mathbf{S_0}, \mathbf{S_1}, \mathbf{S_2}, \ldots, \mathbf{S_{n-1}}, \mathbf{S_n}$.

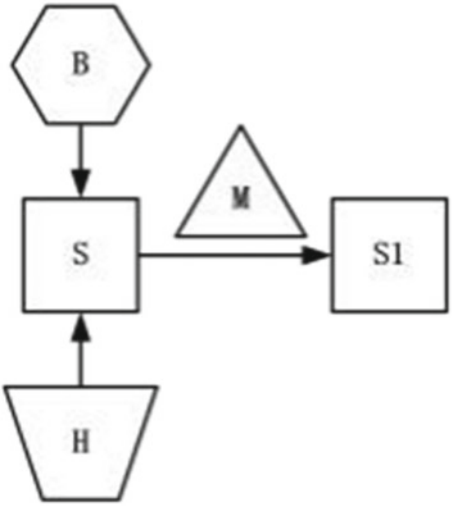


Fig. 6.7 Schematic diagram of the basic unit of the evolution of sudden incident scenarios

$\mathbf{S_0}$ is the initial state, and $\mathbf{S_n}$ is the state of disappearance. The time for each scenario is denoted as $\mathbf{t_0}, \mathbf{t_1}, \mathbf{t_2}, \ldots, \mathbf{t_{n-1}}, \mathbf{t_n}$. $\mathbf{B_i}$, $\mathbf{H_i}$, and $\mathbf{M_i}$ respectively denote the emergency activities, the external environment and the constraints of emergency resource, **i (1, 2, …, n)**. Then the evolution law of the emergency scenario can be expressed as shown in Fig. 6.8.

In Fig. 6.8, $\mathbf{S_0}$ is the initial state of an emergency, the time of its occurrence is $\mathbf{t_0}$. Under the intervention of emergency activity $\mathbf{B_1}$, the influence of external environment $\mathbf{H_1}$ and the constraint of emergency resource $\mathbf{M_1}$, the state of the scenario changes, and enters the next state. Due to the different constraints of external environment and emergency resources, as well as different emergency activities, the evolution of the scenario is unpredictable, so the next state has multiple possibilities.

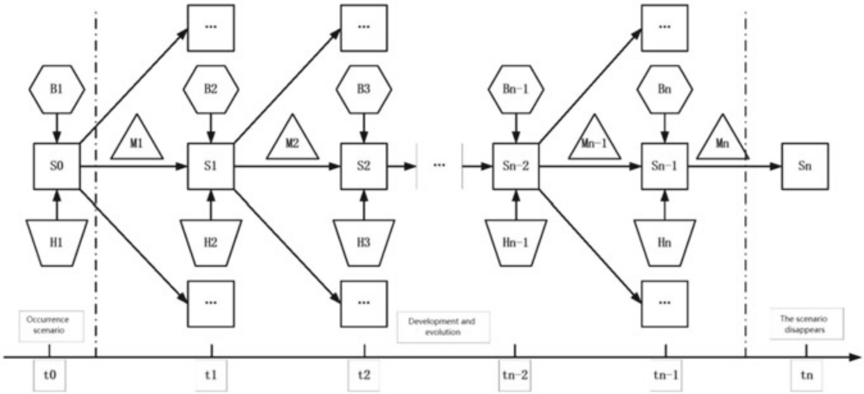


Fig. 6.8 The evolution of incident events

Assuming at the time $\mathbf{t_1}$, the state of the scenario is denoted as $\mathbf{S_1}$, then under the intervention of $\mathbf{B_2}$ and the influence of $\mathbf{H_2}$ and $\mathbf{M_2}$, the state of the scenario evolves again and a new state appears, and so on. Finally, at the time $\mathbf{t_n}$, the situation disappears, the whole decision-making process of the emergency ends, and the evolution process of the scenario ends.

(2) The evolution path of the emergency scenario

The so-called evolution path of emergency situation, in short, is the change trajectory of the emergency situation between the occurrence and the end of the situation, which also means expressing the current state of the emergency situation, the relationship between the situations, the evolution of the situation and the possible result of the evolution of the situation. By analyzing the evolution path of the scenario, we can accurately grasp the current state of the emergency situation, predict the development trend of the future situation, and make timely and correct decisions for the decision-making subject for practical reference.

After the occurrence of an emergency, if there is no intervention of the emergency subject, and it is only affected by the external natural environment, the evolution of the situation will generally develop and change according to its own laws and trajectory, showing the overall randomness and unique life periodicity. However, once the emergency occurs in reality, there will soon be an intervention of the emergency subject, so as to add human factors on the basis of the external environment. Therefore, the situational evolution should be influenced by human intervention, external environment and resource constraints, and its own evolution law and trajectory will be broken, presenting a new development and evolution law and evolution path.

Since the evolution of emergency scenarios is a continuous process, the emergency response is also a continuous process. The emergency decision-making subject makes emergency decisions and takes measures according to the state of the situation at the moment, so as to change the current state of the situation and enter the next state. Before making an emergency decision on the next state, the effect of last emergency decision-making is generally evaluated, and the results are generally divided into two types: meeting the expectations or failing to meet them. Meeting the expectation means that the emergency decision has the due effect, the situation has been controlled and developing in a good direction; Failing to meet the expectations means that the emergency decision is not effective or not obvious, and the situation is very serious or even worse. The decision-making subject should decide whether to make the next emergency decision before adjustment according to the evaluation results at any time. Because the results of each assessment are divided into two situations: meeting the expectations and failure, the evolution path can be divided into two directions: optimism and pessimism. Drawing on the principle of binary tree in computer data structure, the evolution path of emergency scenario can be formed as shown in Fig. 6.9.

In Fig. 6.9, there are 23 states of a scenario, where $\mathbf{S_0}$ is the initial state after the occurrence, and $\mathbf{S_1}$ to $\mathbf{S_{22}}$ is the developmental evolution scenario. Each scenario state $\mathbf{S_i}$ ($\mathbf{i}$ from $\mathbf{0}$) under the action of emergency activity $\mathbf{B_{i+1}}$ and external environment $\mathbf{H_{i+1}}$, under the constraint of emergency resource $\mathbf{M_i}$, the state changes

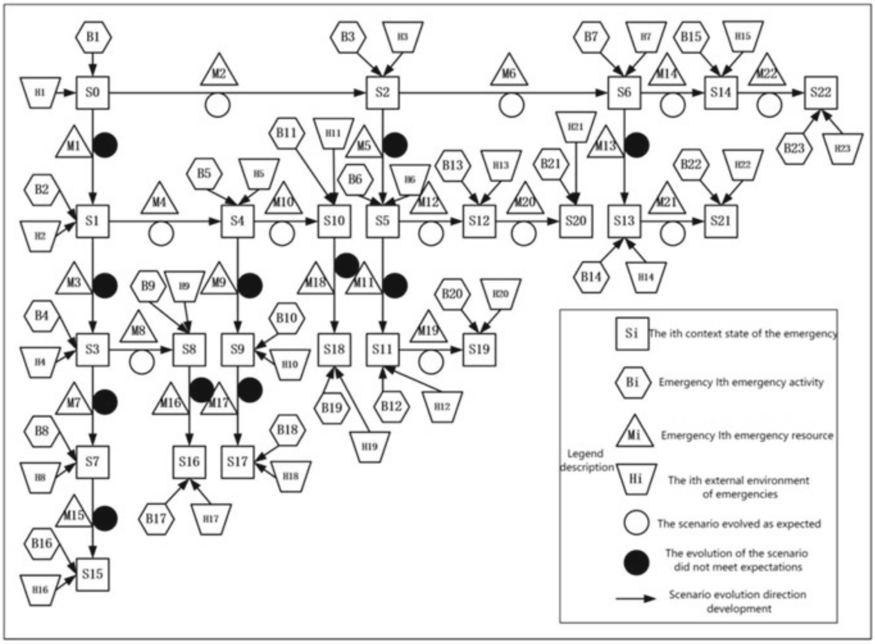


Fig. 6.9 The evolution path diagram of sudden incident scenarios

to achieve scenario evolution. Each scenario evolution has two paths: the optimistic path (meeting the expectation) and the pessimistic path (failing to meet the expectation), where the horizontal right arrow (→) indicates meeting the expectation, the scenario evolution develops in the optimistic direction, and the vertical downward arrow (↓) indicates that the scenario evolution develops in the pessimistic direction. From this, Fig. 6.9 forms a most optimistic scenario evolution path: $\mathbf{S_0} \rightarrow \mathbf{S_2} \rightarrow \mathbf{S_6} \rightarrow \mathbf{S_{14}} \rightarrow \mathbf{S_{22}}$, and a most pessimistic scenario evolution path: $\mathbf{S_0} \rightarrow \mathbf{S_1} \rightarrow \mathbf{S_3} \rightarrow \mathbf{S_7} \rightarrow \mathbf{S_{15}}$. It can be seen from the above analysis that assuming after an emergency occurs, it totally undergoes situation evolution n times, that is to say, in addition to the initial situation, there are **n** states of situation, then theoretically speaking, there are 2n situation evolution paths. Each emergency decision determines the emergency in different directions, forming different evolution trajectory and evolution path, and there are only one most optimistic path and most pessimistic path. The most optimistic path is the best case, where every decision can meet the expectation; the most pessimistic path is the worst case, where every decision fails to meet the expectation. Therefore, due to the dynamic nature of the development of emergencies, the emergency decision-making subject should be very cautious when making every decision, and try their best to make the emergencies develop and evolve along the most optimistic path.

6.1.3 Construction of Electric Power Grid Disaster Emergency Situation Analysis Model and Scenario Simulation

According to the analysis of the emergency scenario evolution law and evolution path, it can be concluded that there are obvious causal link between different states of the situation. As the input variables, the current $\mathbf{S_i}$, $\mathbf{B_{i+1}}$, $\mathbf{H_{i+1}}$ are the causes; As the output variables, $\mathbf{S_{i+1}}$ and $\mathbf{B_{i+1}}$ are the results; $\mathbf{M_{i+1}}$ are the constraints of causal conversion between input variables and output variables. Based on this, we plan to adopt the dynamic Bayesian network theory to construct the emergency scenario network.

(1) Dynamic Bayesian network

Bayesian network (Bayesian Networks, **BN**), also known as reliability network, causal network or probability graph model, is an acyclic graph composed of representative variable nodes and directed edges connecting nodes (as shown in Fig. 6.10a). It is one of the most effective models in the field of uncertain knowledge expression and reasoning. The Bayesian network can be composed of three parts, expressed as: (**X**, **A**, **P**). **X** is the set of nodes in the network, and the elements in the set are random variables. **A** is the set of directed edges in the network, indicating the causal relationship between the nodes, expressed by $\mathbf{x_i} - \mathbf{x_j}$. $\mathbf{x_i}$ is called the parent node (the cause), $\mathbf{x_j}$ is called the child node (the result). **P** is the set of network parameters, and it is the probability value of the network node, expressed by $\mathbf{p_i}$, and represents the conditional probability distribution of node $\mathbf{x_i}$.

The mathematical basis of Bayesian network inference is the full and conditional probability formulas. If **x** is the set of causes or parent nodes of causality in a Bayesian network, **y** is the result or child node of causality in a Bayesian network, there is **x** → **y**, where the set **x** contains **n** elements and each element is denoted as $\mathbf{x_i}$, $\mathbf{x_i}$ ($\mathbf{i = 1, 2, \ldots, n}$). The full probability formula is:

$$\begin{aligned} P(y) &= P(yx) = P(yx_1 + yx_2 + \cdots + yx_n) \\ &= P(yx_1) + P(yx_2) + \cdots + P(yx_n) \end{aligned} \tag{6.1}$$

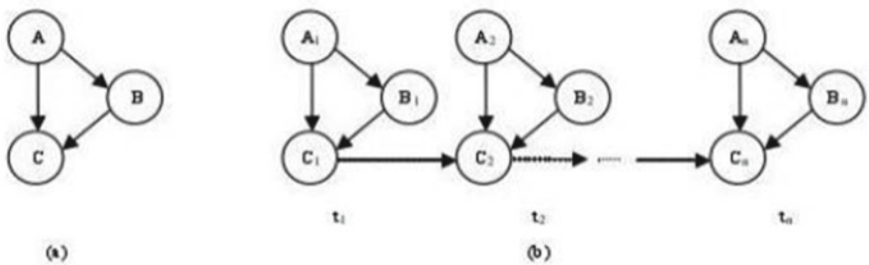


Fig. 6.10 Schematic diagram of Bayesian Network (**a**) and Dynamic Bayesian Network (**b**)

As can be seen from Eq. (6.1), the full probability formula essentially pushes the result based on the cause. The posterior probability of the child node is calculated only given the prior probabilities and the conditional probability of the parent node to the child node. Another mathematical basis is the conditional probability, and the formula is as follows:

$$P(x \mid y) = \frac{P(xy)}{P(y)} \tag{6.2}$$

Taking Eq. (6.1) into Eq. (6.2) gives the following basic formula of the Bayesian network:

$$P(x_i \mid y) = \frac{P(x_i y)}{P(y)} = \frac{P(x_i)P(y \mid x_i)}{\sum_{j=1}^{n} P(x_j)P(y \mid x_j)} \tag{6.3}$$

As can be seen from Eq. (6.3), Bayes' formula is essentially the opposite of the full-probability formula, which is to infer the probability of a cause when the result has already occurred.

Since Bayesian network inference all implies a former assumption of conditional independence, namely, for the set of parent nodes of a given node, this node is independent of all its non-descendant nodes. Therefore, the joint probability of all nodes represented by the Bayesian network can be expressed as the product of the conditional probabilities of each node, such as (6.4):

$$\begin{aligned} P(x_1, x_2, \ldots, x_n) &= \prod_{i=1}^{n} P(x_i | x_1, x_2, \ldots, x_{i-1}) \\ &= \prod_{i=1}^{n} P(x_i | P_a(x_i)) \end{aligned} \tag{6.4}$$

$\mathbf{P_a(x_i)}$ is the parent node set of $\mathbf{x_i}$.

The so-called dynamic Bayesian network (Dynamic Bayesian Networks, **DBN**) actually adds the time factor on the basis of the static Bayesian network, which makes the temporal reasoning and event development maintain the consistency and continuity in time, thus more in line with the objective reality. In essence, dynamic Bayesian networks can be regarded as an expansion of static Bayesian networks on the time axis (as shown in Fig. 6.10b). Assuming there are **T** time segments, **n** hidden nodes and **m** observation nodes, and $\mathbf{x_{ij}}$ represents the state of the **i**-th hidden node of the **j**-th time segment, it follows that:

$$P(x_{11}, x_{12}, \ldots x_{T1}, x_{T2}, \ldots x_{Tn} \mid y_{11}, y_{12}, \ldots y_{1m}, \ldots y_{T1}, y_{T2}, \ldots y_{Tm}) = \frac{P(x_{11}, x_{12} \ldots x_{T1}, x_{T2}, \ldots x_{Tn}, y_{11}, y_{12} \ldots y_{1m}, \ldots y_{T1}, y_{T2}, \ldots y_{Tm})}{\sum_{x_{11}x_{12},\ldots x_{T1}x_{T2},\ldots x_{Tn}} P(x_{11}, x_{12}, \ldots x_{T1}, x_{T2}, \ldots x_{Tn}, y_{11}, y_{12}, \ldots y_{1m}, \ldots y_{T1}, \ldots y_{T2}, \ldots y_{Tm})} \tag{6.5}$$

Since the dynamic Bayesian network itself also meets the conditional independence assumption, there are:

$$P\begin{pmatrix} x_{11}, x_{12}, \ldots x_{T1}, x_{T2}, \ldots x_{Tn}, \\ y_{11}, y_{12}, \ldots y_{1m}, \ldots y_{T1}, y_{T2}, \ldots y_{Tm} \end{pmatrix} = \prod_{i,j} P(y_{ij}|P_a(y_{ij})) \prod_{i,k} P(y_{ik}|P_a(y_{ik})) \tag{6.6}$$

After bringing formula (6.6) into formula (6.5):

$$P(x_{11}, x_{12}, \ldots x_{T1}, x_{T2}, \ldots x_{Tn} \mid y_{11}, y_{12}, \ldots y_{1m}, \ldots y_{T1}, y_{T2}, \ldots y_{Tm}) = \frac{\Pi_{ij} p(y_{ij}|P_a(y_{ij}))\Pi_{i,k} p(y_{ik}|P_a(y_{ik}))}{\sum_{x_{11}, x_{12}, \ldots x_{T1}, x_{T2}, \ldots x_{Tn}} \Pi_{ij} p(y_{ij}|P_a(y_{ij}))\Pi_{i,k} p(y_{ik}|P_a(y_{ik}))} \tag{6.7}$$

$$i \in [1, T], j \in [1, m], k \in [1, n]$$

In Eq. (6.7), $\mathbf{x_{ij}}$ is a valued state, the first subscript **i** of each variable represents the time segment, the second subscript represents the **j**-th hidden node in the time segment; $\mathbf{y_{ij}}$ is the observation value, and $\mathbf{P_a(y_{ij})}$ is the set of parent nodes of $\mathbf{y_{ij}}$.

According to the basic principle and calculation process of the dynamic Bayesian network, it is necessary to construct the dynamic Bayesian network in three steps.

1) Determine the network node variable

A Bayesian network is composed of nodes. In order to build an emergency scenario Bayesian network, it is first necessary to select key elements according to the composition of the emergency scenario elements, so as to form node variables. After the node variable is determined, the value type and value domain of the node variable are also determined according to the actual situation.

2) Determine the relationship between the node variables

After the node variables are determined, the causal relationship between the node variables is determined according to the evolution law and path of the emergency scenario, and connected with directed line segments to form a directed acyclic graph network structure.

3) Allocation probability

After the Bayesian network structure is built, we need to assign probabilities to the nodes. There are two main types of node variables that need to allocate probability: one is the node variable without the parent node to determine the prior probability according to professional knowledge or experience, and the other is to determine the conditional probability for the node variable with the parent node.

The construction of a dynamic Bayesian network is a three-step process, and although it seems simple to describe, it is still very difficult in the actual operation process and requires a lot of professional knowledge. Therefore, for example, the determination of node variables, the description of causality and the allocation of probabilities require the assistance of experts in relevant professional fields. In addition, these three steps are not completed at once, and may require repeated refinement and correction.

(2) Construction of the emergency situation analysis model

According to the dynamic Bayesian network construction steps of the emergency scenario mentioned above, it can be divided into the following three aspects.

1) Determination of network node variables

The determination of network node variables is the first and most important step in constructing a dynamic Bayesian network. The construction of emergency scenario dynamic Bayesian network is essentially a modeling process for the real world, and modeling is an abstract representation of the real-world process. Through modeling, the key elements that have an important influence on the objective system are abstracted, and the data of these key elements becomes variables. Therefore, determining the network node variables is actually abstracting the key elements of the objective system. The accuracy of the key elements directly determines whether the model can truly reflect the real system and the credibility of the final conclusion.

Due to the complexity and professionalism of the emergency scenario evolution, the determination of network node variables can be completed in steps: the first step is to collect the scenario elements according to the previous chapter; In the second step, the field experts will score the scenario elements and find out the key elements with the help of the technology of computer image recognition and matching. In the third step, based on the nature of the key elements, the types of the variables, namely, being continuous or discrete variables, are determined. Since the situational elements of emergencies are generally discrete, the transformed variables should also be discrete, which can be Boolean variables, order variables, or integer variables.

When an emergency occurs, we need to make decisions in a very short time in a tense environment, therefore, in order to avoid greater losses caused by decision-making errors, we generally adopt the pessimistic decision-making criterion, that is, considering more from the worst case. When the key elements are being selected through expert scoring, the score threshold should not be set too high to avoid resulting in the omission of some key scenario elements. The score threshold should even be set a little lower. Although some sub-key elements may be included to increase the total amount of elements, so as to increase the difficulty of modeling solution, it is better than missing some key elements, at least there will be no mistakes in matters of principle.

2) Determination of the causality of the node variables in the network

After the network node variables are determined, that is, the key elements of the model are determined, the next step is to determine the relationship between the key elements. Since the node variables within the Bayesian network are all causal, the main task of this link is to determine the causality of the key elements and draw them with directed edges to form a complete emergency scenario network. Although causality is the most common relationship in the real world, due to the

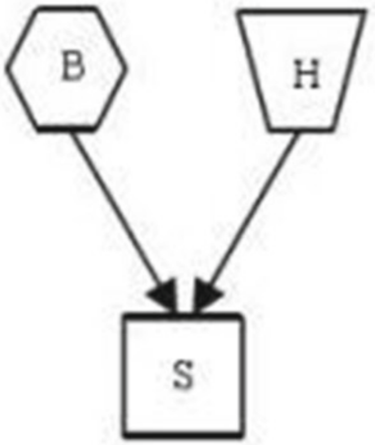


Fig. 6.11 A Bayesian network at some point

complex evolution process of emergency scenarios and the many situational elements involved, the determination of the causal relationship between various elements is also a complex project, which also needs to be completed with the knowledge of field experts and some technical means.

According to the key elements of the situation in the analysis of the situation evolution law, they are divided into four categories: Situational status (**S**), emergency activities (**B**), external environment (**H**), and emergency resources (**M**). Among these four types of elements, emergency activities and external environment act on the state of the situation as the reasons, that is to say, the state of the situation is the result, and emergency resources act as the constraint of the interaction between them. Therefore, the state of the situation, the causal relationship between emergency activities and the state of the situation are mainly analyzed in this paper (as shown in Fig. 6.11), and emergency resources are not considered in the construction and solution of the scenario network in this paper.

The evolution of the emergency scenario is a continuous, dynamic process. Assuming that the whole evolution of the emergency scenario is divided into **T** points, denoted as $\mathbf{t_0}$, $\mathbf{t_1}$, $\mathbf{t_2}$, **...** $\mathbf{t_n}$ respectively, and $\mathbf{T_0}$ is the initial moment of the occurrence, the dynamic Bayesian network can be represented in Fig. 6.12.

In Fig. 6.12, as for the initial scenario state $\mathbf{S_0}$, it enters the state $\mathbf{S_1}$ after the node variables $\mathbf{B_1}$ and $\mathbf{H_1}$ have been entered, then $\mathbf{S_0}$, $\mathbf{B_2}$ and $\mathbf{H_2}$ become the input node variables of $\mathbf{S_1}$, and so on. It can be seen that the whole dynamic Bayesian network can be divided into two parts from the perspective of input variables. One part is the initial scenario network, the situation state is $\mathbf{S_0}$, only with nodes **B** and **H** as input variables. The other part is the development scenario network. Starting from the situation state $\mathbf{S_1}$, there are three input node variables, namely emergency activity **B**, external environment **H** and the situation state **S** of the preceding moment.

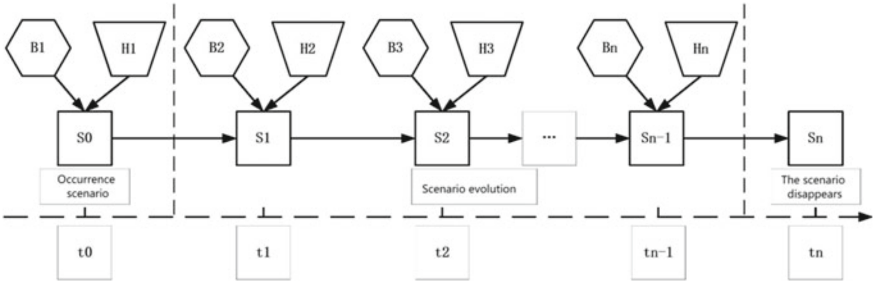


Fig. 6.12 Dynamic Bayesian networks for the evolution of the emergency scenario

(3) Situation analysis of power grid disaster emergencies and scenario deduction

After the construction of the emergency scenario network is completed, the scenario can be deduced. The so-called scenario deduction is to predict the scenario state of the next moment according to the scenario state of the current moment. Due to the uncertainty of the scenario evolution, the situation state at the next moment can only be expressed by probability. If the variables of the current scenario state are denoted as **e S_1**, **e S_2**, **e S_2**, **e S_2**, **… e S_n**, the input scenario variables are denoted as **i S_0**, **i S_1**, **i S_2**, **… i S_k**, and the output scenario variables are denoted as **o S_0**, **o S_1**, **o S_2**, **…**, **o S_i** etc., the emergency scenario deduction model based on the dynamic Bayesian network is as follows, as shown in Fig. 6.13.

In Fig. 6.13, as for the scenario state variable **e S_1**, its input scenario variables are **i S_0**, **i S_1**, **i S_2**, **…**, **i S_k** etc. With the prior probability for all input scenario variables, namely **P(i S_0)**, **P(i S_1)**, **P(i S_2)**, **…**, **P(i S_k)**, etc., and the conditional probability, namely **P(e S_1 | i S_0, i S_1, i S_2, …, i S_k)**, then **P(e S_1)** can be calculated, and so

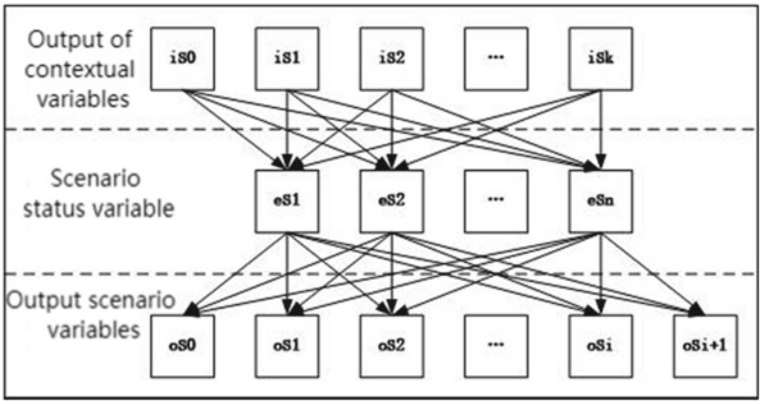


Fig. 6.13 Emergency scenario deduction model

on. **P(e S_1)**, **P(e S_2)**, **…**, **P(e S_n)** can be calculated respectively. If **i S_0**, **i S_1**, **e S_1**, **e S_2** act as the input scenario variables, the probability of the next moment scenario variable **o S_0**, namely **P(o S_0)**, can be deduced based on the conditional probability **P(o S_0 | i S_0, i S_1, e S_1, e S_2)**, and so on. And the probability of **P(o S_0)**, **P(o S_1)**, **P(o S_2)**, **P(o S_i)**, etc. can be calculated respectively, which means a scenario deduction is completed.

In the process of scenario deduction, there are two probabilities to be set in advance. One is the prior probability of the input scenario node variable without a parent node; the other is the scenario node variable with a parent node which needs to estimate the conditional probability. Whether the setting of these two probabilities is reasonable directly determines the accuracy of the final deduction result. In general, the prior probabilities are obtained based on historical experience or historical statistics, while the conditional probabilities need to be given by expert estimates.

(4) Determination and calculation method of scenario deduction probability

After the construction of emergent scenario dynamic Bayesian network is completed, in order to successfully realize the state of deduction, we must first determine the prior probability of part of the network node variable or expert estimate probability, and then use the prior probability or expert estimate probability to calculate the state of probability, so as to deduce the probability of the next scenario state, complete the process of the scenario deduction. Specifically, it can be divided into two steps: the determination of prior probability or expert estimation probability and the calculation of scenario state probability.

1) Determination of the prior probability of some network node variables

The network node variables that need to determine the prior probability or the expert estimate probability include two aspects: first, the prior probability for the node variable without the parent node is determined, and the conditional probability needs to be determined for the node variable with the parent node.

a) Determination of the prior probability

The so-called prior probability refers to the probability obtained based on historical experience or analysis, which belongs to the unconditional probability. In Fig. 6.12, the node variables **B_i** and **H_i** **($i = 1, 2, \ldots n$)** have no parent nodes, so their prior probability needs to be determined in advance, i.e., the probability distribution of **$P(B_i)$** and **$P(H_i)$** **($i = 1, 2, \ldots, n$)** needs to be determined in advance.

b) Determination of the expert estimation probability

As for those node variables with a parent node, such as the node variable Si in Fig. 6.12 **($i = 0, 2, \ldots n$)**, you need to determine the conditional probability based on historical empirical data or expert estimation methods. Due to the particularity of emergencies, there may be less historical experience data for reference, so more expert estimation methods are used. In order to overcome the limitations of expert knowledge and the influence of personal preferences, the arithmetic mean of the estimated results of multiple experts is generally used as the final estimation result.

2) The calculation method of scenario state probability

In order to illustrate the calculation method of scenario state probability, we take Fig. 6.12 as an example to intercept the network node variables at the points of $\mathbf{t_0}$ and $\mathbf{t_1}$ to illustrate the calculation method of scenario state variable $\mathbf{S_0}$ and $\mathbf{S_1}$.

a) Calculation of the initial scenario state probability $\mathbf{P(S_0)}$ (time $\mathbf{t_0}$)

Step 1: Determine the types of network node variables and their values set, as shown in Table 6.1

Table 6.1 Collection of variable types and values of network nodes

Node variable name	Node variable type	Collection of node variable values
Emergency activities (B)	Boolean variable	{True(T), False(F)}
External environment (H)	Binary order variable	{positive(Pos), negativity(Neg)}
Scenario Status (S)	Boolean variable	{True(T), False(F)}

Step 2: Determine $\mathbf{P(B_1)}$ and $\mathbf{P(S_0 \mid B_1, H_1)}$.
hypothesis:

$$\begin{gathered}
\mathrm{P}(B_1 = \mathrm{T}) = 0.9, \mathrm{P}(B_1 = \mathrm{F}) = 0.1; \\
\mathrm{P}(\mathrm{H}_1 = \mathrm{Pos}) = 0.7, \mathrm{P}(\mathrm{H}_1 = \mathrm{Neg}) = 0.3; \\
\mathrm{P}(\mathrm{S}_0 = \mathrm{T} \mid \mathrm{B}_1 = \mathrm{T}, \mathrm{H} = \mathrm{Pos}) = 0.8; \\
\mathrm{P}(\mathrm{S}_0 = \mathrm{T} \mid \mathrm{B}_1 = \mathrm{T}, \mathrm{H}_1 = \mathrm{Neg}) = 0.7; \\
\mathrm{P}(\mathrm{S}_0 = \mathrm{T} \mid \mathrm{B}_1 = \mathrm{F}, \mathrm{H}_1 = \mathrm{Pos}) = 0.5; \\
\mathrm{P}(\mathrm{S}_0 = \mathrm{T} \mid \mathrm{B}_1 = \mathrm{F}, \mathrm{H}_1 = \mathrm{Neg}) = 0.3;
\end{gathered}$$

Step 3: Calculate $\mathbf{P(S_0)}$.
According to the full probability formula, there are:

$$\mathsf{P}(\mathsf{S}_0 = \mathsf{T}) = \mathsf{P}(\mathsf{B}_1, \mathsf{H}_1) * \mathsf{P}(\mathsf{S}_0 = \mathsf{T} \mid \mathsf{B}_1, \mathsf{H}_1) \tag{6.8}$$

Since the premise of the Bayesian network assumes that conditional independence,

$$\mathsf{P}(1, \mathsf{H}_1) = \mathsf{P}(\mathsf{B}_1) * \mathsf{P}(\mathsf{H}_1) \tag{6.9}$$

Therefore, bring formula (6.9) into formula (6.8)

$$\mathsf{P}(\mathsf{S}_0 = \mathsf{T}) = \mathsf{P}(\mathsf{B}_1) * \mathsf{P}(\mathsf{H}_1) * \mathsf{P}(\mathsf{S}_0 = \mathsf{T} \mid \mathsf{B}_1, \mathsf{H}_1) \tag{6.10}$$

Further expansion gives you that:

$$\begin{aligned}
P(S_0 = T) = {} & (\mathrm{B}_1 = T) * P(\mathrm{H}_1 = \mathrm{Pos}) * P(\mathrm{S}_0 = T|\mathrm{B}_1 = T, \mathrm{H}_1 = \mathrm{Pos}) \\
& + P(\mathrm{B}_1 = T) * P(\mathrm{H}_1 = \mathrm{Neg}) * P(\mathrm{S}_0 = T|\mathrm{B}_1 = T, \mathrm{H}_1 = \mathrm{Neg})
\end{aligned}$$

$$
\begin{aligned}
&+ P(B_1 = F) * P(H_1 = Pos) * P(S_0 = T|B_1 = F, H_1 = Pos) \\
&+ P(B_1 = F) * P(H_1 = Neg) * P(S_0 = T|B_1 = F, H_1 = Neg) \\
&= 0.9 * 0.7 * 0.8 + 0.9 * 0.3 * 0.7 + 0.1 * 0.7 * 0.5 + 0.1 * 0.3 * 0.3 \\
&= 0.504 + 0.189 + 0.035 + 0.009 \\
&= 0.737
\end{aligned}
$$

According to the calculation of: $\mathbf{P(S_0 = F) = 0.263}$.

b) $\mathbf{t_1}$ Calculation of situational state probability at time $\mathbf{P(S_1)}$

Step 1: Determine the type of network node variables and their set of values, as above.

Step 2: Determine it $\mathbf{P(B_2)}$, $\mathbf{P(H_2)}$ as well as $\mathbf{P(S_1 \mid S_0, B_1, H_1)}$.

According to the above calculation results are:

$$P(S_0 = T) = 0.737, P(S_0 = F) = 0.263$$

hypothesis: $P(B_2 = T) = 0.92$, $P(B_2 = F) = 0.08$;

$$P(H_2 = Pos) = 0.75, P(H_2 = Neg) = 0.25;$$

$$P(S_1 = T|B_2 = T, H_2 = Pos, S_0 = T) = 0.8;$$

$$P(S_1 = T|B_2 = T, H_2 = Pos, S_0 = F) = 0.65;$$

$$P(S_1 = T|B_2 = T, H_2 = Neg, S_0 = T) = 0.7;$$

$$P(S_1 = T|B_2 = T, H_2 = Neg, S_0 = F) = 0.45;$$

$$P(S_1 = T|B_2 = F, H_2 = Pos, S_0 = T) = 0.5;$$

$$P(S_1 = T|B_2 = F, H_2 = Pos, S_0 = F) = 0.4;$$

$$P(S_1 = T|B_2 = F, H_2 = Neg, S_0 = T) = 0.35;$$

$$P(S_1 = T|B_2 = F, H_2 = Neg, S_0 = F) = 0.2;$$

Step 3: Calculate $\mathbf{P(S_1)}$.

According to the full probability formula, there are:

$$P(S_1 = T) = P(B_2, H_2, S_0) * P(S_1 = T \mid B_2, H_2, S_0) \tag{6.11}$$

Similarly, since the premise of the Bayesian network assumes conditional independence.

$$P(B_2, \mathrm{H}_2, \mathrm{S}_0) = P(B_2) * P(H_2) * P(S_0) \tag{6.12}$$

Therefore, bring formula (6.12) into formula (6.11):

$$\mathrm{P}(S_1 = \mathrm{T}) = \mathrm{P}(B_2) * \mathrm{P}(H_2) * \mathrm{P}(S_0) * \mathrm{P}(S_1 = \mathrm{T} \mid \mathrm{B}_2, \mathrm{H}_2, \mathrm{S}_0) \tag{6.13}$$

Equation (6.13) further follows:

$$\begin{aligned}
\mathrm{P(S_1 = T)} &= \mathrm{P(B_2 = T) * P(H_2 = Pos) * P(S_0 = T) * P(S_1 = T|B_1 = T, H_1 = Pos, S_0 = T)} \\
&+ \mathrm{P(B_2 = T) * P(H_2 = Pos) * P(S_0 = F) * P(S_1 = T|B_2 = T, H_2 = Pos, S_0 = F)} \\
&+ \mathrm{P(B_2 = T) * P(H_2 = Neg) * P(S_0 = T) * P(S_1 = T|B_2 = T, H_2 = Neg, S_0 = T)} \\
&+ \mathrm{P(B_2 = T) * P(H_2 = Neg) * P(S_0 = F) * P(S_1 = T|B_2 = T, H_2 = Neg, S_0 = F)} \\
&+ \mathrm{P(B_2 = F) * P(H_2 = Pos) * P(S_0 = T) * P(S_1 = T|B_2 = F, H_2 = Pos, S_0 = T)} \\
&+ \mathrm{P(B_2 = F) * P(H_2 = Pos) * P(S_0 = F) * P(S_1 = T|B_2 = F, H_2 = Pos, S_0 = F)} \\
&+ \mathrm{P(B_2 = F) * P(H_2 = Neg) * P(S_0 = T) * P(S_1 = T|B_2 = F, H_2 = Neg, S_0 = T)} \\
&+ \mathrm{P(B_2 = F) * P(H_2 = Neg) * P(S_0 = F) * P(S_1 = T|B_2 = F, H_2 = Neg, S_0 = F)} \\
&= 0.92 * 0.75 * 0.737 * 0.8 + 0.92 * 0.75 * 0.263 * 0.65 \\
&+ 0.92 * 0.25 * 0.737 * 0.7 + 0.92 * 0.25 * 0.263 * 0.45 \\
&+ 0.08 * 0.75 * 0.737 * 0.5 + 0.08 * 0.75 * 0.263 * 0.4 \\
&+ 0.08 * 0.25 * 0.737 * 0.35 + 0.08 * 0.25 * 0.263 * 0.2 \\
&= 0.406824 + 0.090735 + 0.109164 + 0.027221 + \\
&+ 0.02211 + 0.006312 + 0.005159 + 0.001052 \\
&= 0.669
\end{aligned}$$

According to the calculation of: $\mathrm{P}(S_1 = \mathrm{F}) = 0.331$.

6.2 3D Visualization Command Technology

6.2.1 3D Visualization Technology

Compared with the traditional 3D visualization system, the major problems of the large-scale 3D visualization system lie in the huge amount of data, the transmission waiting time beyond the acceptable range, being very suitable for external storage drawing; the large-scale 3D visualization system is mainly used in large projects such as smart city and field security. Its requirements for reliability is high. It requires convenient and stable data docking services, and the system design and implementation are relatively complicated. The main performance evaluation indexes of a large-scale 3D visualization system include initial model waiting time, initial transmission data amount, system CPU occupancy rate, system memory footprint, page completion time and so on.

(1) Data segmentation technology

The idea of data segmentation is to decompose a large-scale 3D scene model into a collection of slices with a quadtree or octree structure. The root node of the tree structure is a version of the scene with less detail. The child node below the root node divides the whole scene into four or eight blocks of the same size, for a representation with more details. Each of these blocks will also have four or eight subblocks, thus further dividing the entire scene. Large-scale terrain and scenes can be rendered with segmented data. Theoretically, the total amount of data is no longer limited. At the same time, the screen spatial error of the scene can be accurately controlled and the GPU can be better utilized. In the tree structure, the geometric error is twice that of the next layer with less high precision.

Data segmentation has achieved great success in virtual earths, games and other applications that require large-scale scene rendering. Even though the GPU is improved and the hardware capabilities are improved, with the development of scene scale, the data segmentation idea is still very suitable for large-scale rendering. The process of splitting the data is not related to its rendering process, and in practice, slices can be created from any scene model. But the slice must have the following characteristics: Uniform segmentation: Balance is crucial for the final generated scene tree structure. Otherwise, it will lose the advantage of tree structure and decrease the performance sharply.

Geometric error with monotonicity: For each slice, the greatest geometric error must be known. The geometric error is the maximum of the difference between all nodes in the full detail model and the nearest corresponding point in the detail reduction model, which must depend monotonically on the associated slice hierarchy. That is, rendering the sub-slices of all A slices will get A smaller error compared to rendering only the slice. Geometric errors were calculated as the slice was created.

Known enclosure box: Each slice must have a known enclosure box. The enclosure box is used together with the geometric error to calculate the screen space error of all pieces of A.

A quadtree is a tree-like structure, with four subblocks at each node. It divides the 2D spatial data into four equal subspaces, and so on, until the recursive termination condition is reached. The structure of the quadtree is relatively simple. The structure of the conventional quadtree is shown in Fig. 6.14. The leaf node stores spatial data, the intermediate node and the root node do not store data.

The octree is a generalisation of the quadtree in 3Ds, a tree-like structure used to manage and describe 3Ds. Each node of the octree has eight child nodes, and the combination of the spatial division of child nodes is the spatial division of the parent nodes. The octree structure can be expressed as the following steps: (1) Set the maximum recursive depth or minimum segmentation size. (2) Find the **x**, **y**, **z** direction boundary of the scene to establish the first cube, that is, the root node. (3) Put 3D spatial metadata into a cube that can be included without child nodes. (4) If

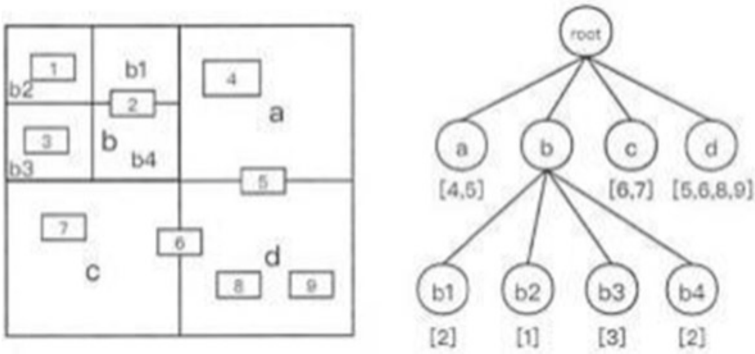


Fig. 6.14 Schematic representation of the quadruple tree

the recursive termination condition is not reached, continue eight equal points and allocate all the spatial data contained in the node to the eight child nodes. (5) If it is found that the data assigned by the child node is not zero and is the same as the data of the parent node, the child node stops subdivision to avoid infinite segmentation. (6) Repeat process 3 until the maximum recursive depth is reached. The whole process is shown in Fig. 6.15.

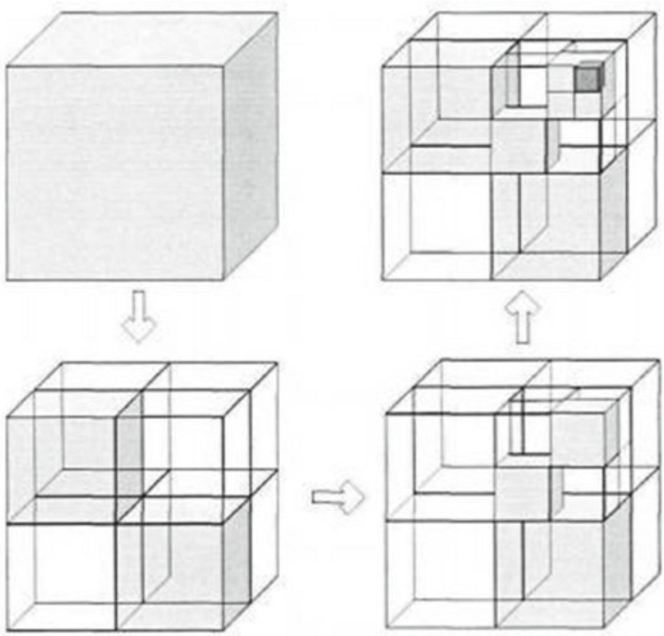


Fig. 6.15 Schematic diagram of the octree segmentation process

(2) Dynamic scheduling technology

The 3D scene model of a large-scale 3D visualization system has a huge amount of data. Although compression can greatly reduce the storage space, it is far from enough to store the local memory. No matter how the hardware conditions develop, this is not a good solution. Moreover, the space span is large, loading too much useless data will undoubtedly cause unnecessary waste of resources, and will lead to long startup time of the application. In external memory drawing technology, only a small subset of the data set is in the system memory at any time, and the rest of the data is temporarily stored in external memory, such as a hard disk or network server. According to the perspective parameter, the new datasets are loaded into the system memory, and the expired datasets are removed from the memory, which is the process of dynamic scheduling. The goal of dynamic scheduling is to seamlessly load the required new data into the working data set by using the external memory drawing technology.

In order to dynamically schedule the node slices in the tree structure, it is first necessary to set the maximum screen spatial error **rho** that can be tolerated, and the rho value can be adjusted to achieve good display results at different hardware levels. Rendering from the root node, the screen space error at this time is calculated by the maximum geometric error of the node, compared with rho. This is a recursive process until the lowest requirement for screen space error is met. Generally, to take advantage of GPU depth buffering by accessing child nodes from the front to the back, this is very efficient and easy to implement.

(3) Display method design

Usually, the goal is to render a better scene with the simplest LOD, so it theoretically requires a standard to determine whether a LOD rendering result will make the scene look better. A useful objective quality measure is the difference in pixel units, also called the number of pixels in screen spatial error (Screen Space Error). It is usually difficult to calculate this value accurately, but it can be estimated by simplifying the estimation. In the figure, consider the LOD for simplifying the object, let the observer distance from the object along the viewpoint direction be d, the optic vertebral width be w, the display resolution be x pixels, and the field angle be θ. The geometric error of the simplified version of the object is ε, meaning that each vertex on the full detail model deviates from the nearest corresponding vertex on the low detail model in no more than ε units (the geometric error is calculated when the slice is created. The finest layer geometric error is selected when the slice tree is created, the selected error is 0.5. The next geometric error is 2 times the previous one). The screen space error is ρ, and a simplified formula of ρ can be derived, which shows how much ρ is, the next detailed version of the object will be rendered.

From Fig. 6.16, we can see that ρ is proportional to ε, it follows that:

$$\frac{\epsilon}{\omega} = \frac{\rho}{x}$$
$$\rho = \frac{\epsilon x}{\omega} \tag{6.14}$$

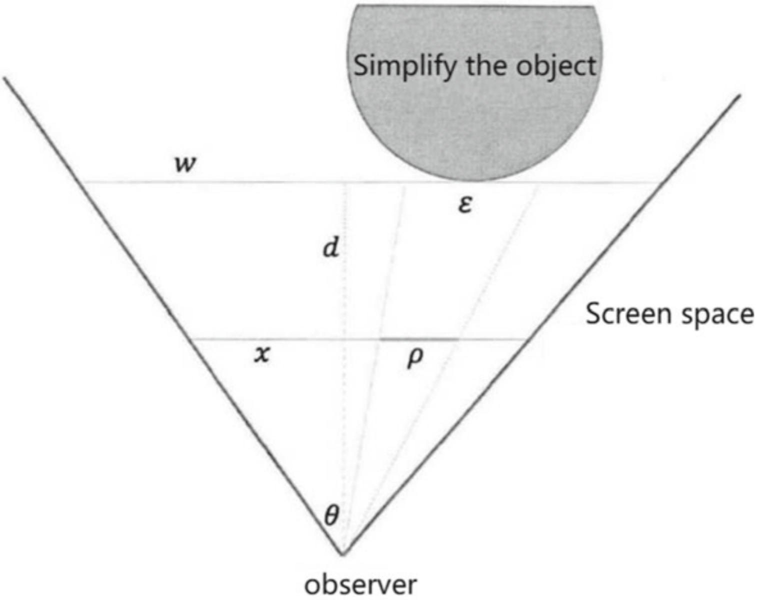


Fig. 6.16 Schematic representation of the spatial error

The optic vertebral width W is easily obtained at distance d, substituting with the upper formula:

$$\begin{aligned} \omega &= 2d\tan\frac{\theta}{2} \\ \rho &= \frac{\varepsilon x}{2d\tan\frac{\theta}{2}} \end{aligned} \tag{6.15}$$

As can be seen from the above equation, the screen spatial error p is estimated by the distance between the observer and the object, the viewpoint parameters and the geometric error ε of the object ε. When the perspective is certain and the distance is certain, the larger the geometric error of the object, the greater the screen spatial error introduced. Therefore, we can judge whether the current LOD is fine enough according to the screen spatial error introduced by the object in the runtime. Otherwise, it can be further refined. Usually during the rendering process, the enclosure box of the object is used together with the geometric error to calculate the screen space error of all pieces of **A**. The general rendering engine will set the maximum screen space error that can be tolerated, and dynamically adjust according to the state of the hardware resource. If the maximum allowable range is exceeded, the child node slices are loaded for further refinement.

The rationale for dynamically selecting slices for rendering with HLOD ideas is described above, and an algorithm will be used to describe this dynamic selection process below. First, set the maximum screen space error that the rendering system can tolerate to rho, and the RHO value can vary. At the same time, enter the instance that needs to have Ḁ slices and the current scene state, including the distance from the slice to the camera, screen size, resolution, viewing angle range, etc. For each slice, the introduced screen space error was calculated based on the maximum geometric error of the slice and then compared with the rho values. If the screen space error of the slice is less than the allowed upper bound, the slice is rendered. Otherwise, its eight child nodes recursively call the function. The process continues until the entire scene can meet the lowest layer of detail of the screen space error requirements.

In a rendering function, subslices are requested for rendering only if the viewpoint parameters change and the scene needs more details. Due to the delay of slice network transmission and rendering, the 3D scene jitter will be caused, and the picture is not smooth enough when the viewpoint is moved. Using the caching mechanism, the prefetch optimization strategy is developed.

Prefetch optimization—After initializing the loading, continue to request the sliced child nodes in the current viewport, and preload the data to the browser cache. Using the browser negotiation cache mechanism, when the viewport is moved, the new slice can be loaded directly from the browser cache, reducing the download time and increasing the efficiency.

Rendering loads the first section that meets the screen space error requirements first, but in the optimized algorithm, the subsection of each rendered section is also requested to be loaded, which is a pre-fetch slice procedure, because the likelihood that the corresponding subsection needs to load increases when the observer moves. In addition, when the subslice of the current slice is not loaded, regardless of the small screen error, the current slice will be stained. Therefore, when a block of cache is lost, the system renders the optimal data currently available.

6.2.2 Visualization Command Technology

(1) Map visualization technology

At present, map visualization has relatively mature technologies, such as state Grid unified GIS platform within the system, WebGIS technology outside the system, Amap, Baidu Map, etc.

1) Unified GIS platform of State Grid

Due to the natural connection between power grid equipment and facilities and geospatial location, GIS has been widely used in the power industry in recent years as an important tool, technology and means to obtain, store, analyze, and manage geospatial data.

The State Grid Unified GIS Platform is a GIS application platform with independent intellectual property rights based on a home-made GIS platform. The design of the platform has made a lot of innovations in architecture and key technologies to meet the characteristics of power applications. The platform is designed with a flexible architecture that can run without relying on specific base GIS platform software;

it makes full use of multi-level caching technology to reduce the network and server pressure caused by centralised spatial data deployment, and achieve the high performance service for the concurrent maintenance of network graphics and topology by a large number of users.

In terms of data scale, the power grid GIS platform integrates and maintains massive basic geographic data, power grid spatial data, and power grid topology data. On the business application scale, the platform has gradually realized the integration with production management, marketing management, distribution automation, power transmission and transformation status monitoring, grid planning system, providing grid resources graphics visualization and space analysis services for the grid production management, disaster prevention and mitigation and emergency command, planning and design, power Internet of things, power communication and other kinds of business applications.

The State Grid Unified GIS Platform API provides a very complete map function, such as distance viewing, search prompts, field of view retrieval, map zoom and a series of practical functions, which are closely related to the visual display of maps in this article.

2) WebGIS technology

WebGIS (Network Geographic Information System) is the release and application of geospatial data through the Internet to realize the sharing and interoperation of spatial data, such as online query and business processing of GIS information. The WebGIS client-side uses a Web browser, such as IE, FireFox. WebGIS is a new technology that uses Internet technology to expand and improve GIS. Its core is the application system of HTTP standard embedded in GIS, so as to realize the management and release of spatial information under Internet environment. WEBGIS can use multi-host, multi-database for distributed deployment, and can be connected through Internet/Intranet. It is a browser/server (B/S) structure. The server-side provides information and services to the client-side, and the browser (client-side) is able to obtain various spatial information and applications.

The information in WebGIS is mainly the spatial data that needs to be expressed in terms of graphics and images. Users can query and analyze the spatial data through interactive operation. Users can easily browse various meteorological data based on WebGIS undermap, and carry out various meteorological information retrieval and spatial analysis. Using WebGIS technology, basic observation, basic products, service products and basic geographic information are displayed in layers, graphics, images and other ways, so as to provide users with a variety of more intuitive data sharing services, including time, space, meteorological data types, observation tools, layers, etc.

3) Leaflet technology

Leaflet is a modern, open source JavaScript library developed for mobile devices. The design of Leaflet adheres to the philosophy of simplicity, high performance and good usability. It operates efficiently on all major desktop and mobile platforms. It can take advantage of HTML5 and CSS 3 in modern browsers, and also supports old browser access. The powerful open source library plug-ins of Leaflet involve all aspects of map application, including map services, data supply, data format, geographic coding, route and route search, map controls and interaction, etc. More than 140 plug-ins of many different types are involved. At the same time, it supports custom controls, with good scalability.

Leaflet is a lightweight and cross-platform, with a compressed library package of 38kB. It is mobile friendly and all effects on the PC are seamlessly rendered on mobile terminals. Leaflet provides an L.Icon interface to set the icon image and shadow image to make the icon more three-dimensional and to set the position of the anchor point to make the icon positioning more accurate; it also supports the implementation of temporal animation, heat map and aggregation point effects.

Leaflet uses html5 to achieve high performance rendering. The map rendering is fine and smooth, and the combination with SuperMap iClient9D for Leaflet can easily render more than 100,000 points of data, while supporting vector chunking layers. The vector chunking is a client-side vector map, and the rendering of the map is all done on the client side. The server provides the map vector data, as well as information on the rendering style attributes of the map. SuperMap also provides various services such as network analysis, spatial analysis, traffic interchange, real-time data services, big data analysis and so on.

GeoJSON is a structural format for web to transfer and encode a variety of geographic data. Leaflet provides the L.geoJSON interface to easily encode GeoJSON and render it on the map; OGC services are also very comprehensive. Based on the L.TileLayer interface, it can be docked on WMS, WMTS and other services. At the same time, L.TileLayer can be extended to build custom layers.

(2) SVG visualization technology

1) Overview of SVG technology

SVG is a language based on XML to describe 2D graphics. It uses the descriptive language of text format to describe the content of images, and it is a vector graphics format, independent of image resolution. SVG is easy to edit and modify, and image files are readable. It can interact with existing technologies, and can control its objects by embedding JavaScript scripts. The SVG graphic format can be easily indexed to search the content of the image. SVG can use three types of graphic objects: images, text, and vector graphic shapes (paths consisting of lines and curves). At the same time, we can transform, marshal, stylize and combine the graphic objects into new objects. SVG can be customized, including nested transformations, paths of clips, template objects and filtering effects. SVG can also be drawn dynamically and interactively. In addition, SVG can define animations, triggered either by script or declaratively (embedding the animated elements of SVG into SVG content). With the addition of the JavaScript language, the SVG text object module (DOM, Document Object Model) provides access to all of its attributes, elements, and features, and can handle very complex and cumbersome functionality. SVG is very rich in event handling and can support various event attributes in HTML, such as mouse events such as onmouseover (mouse movement), onclick (mouse click), and keyboard events such as onkeydown (keyboard down), onkeyup (keyboard up), and can also define these event attributes to any SVG graphics object. Because of its compatibility and leverage of other Web standards, features such as scripting involving HTMLS and SVG elements can be done simultaneously within the same Web page.

a) SVG fully supports the DOM (document element model), so external events can be controlled by scripting languages such as mouse manipulation, keyboard manipulation, and manipulation of various images and elements.
b) SVG images are in a text-based format, so all the text in SVG can be searched and queried through a web search engine, or directly edited and searched through a browser.
c) Command statements in SVG images can interact freely with scripts or programs, such as JavaScript or XML, and can be implemented entirely by code.
d) Since SVG is not restricted by the operating system, SVG can work cross-platform and solve the problems related to color, bandwidth, external output, etc.
e) SVG image files can be easily and dynamically generated by a computer programming language, such as JavaScript, Java, etc. This is a great advantage for some graphs that need to be dynamically displayed, because the images can be displayed in real-time and dynamically according to the data in the database.

2) Introduction to SVG Graphics Objects

SVG provides a rich set of graphic objects including rectangles < rect >, circles < circle >, ellipses < ellipse >, lines < line >, folds < polyline >, polygons < polygon >, and so on. And you can make these graphics objects display different effects by setting different properties and display styles. SVG also provides group management tags (< g > tags), definition defs references, and style definitions for the same attributes of the same class of objects, so that objects of the same type can be set to the same attributes without the unnecessary hassle of multiple definitions.

Objects in SVG files are represented using XML tags as they are in XML. In the visual system, the control of SUG is through traversing the ID of the object in the SUG file, and after finding the object, we can dynamically change its style, whether it is visible or not, to achieve the effect of SUG graphics dynamic display.

3) Research on SVG graphics visualization technology

SVG display method is mainly through the SVG graphics files embedded in the HTML page for display, the method can be achieved mainly through the following ways:

a) < embed >:

Syntax: < embed src = “circlel.svg” type = “image/svg + xml"/ >

Advantage: The < embed > tag supports all major browsers and can be scripted.

Disadvantages: Not recommended in HTML 4 and XHTML, but allowed in HTML.

b) < object >:
   Syntax: < object data = “circlel.svg” type = “image/svg + xml” >
   Advantages:The < object > tag supports all major browsers and supports the HTML4, XHTML, and HTMLS standards.
   Disadvantages: Scripts are not allowed.
c) < iframe >:
   Syntax: < iframe src = “circlel.svg” >
   Advantage: The < iframe > tag supports all major browsers and can be scripted.
   Disadvantages: Not recommended in HTML 4 and XHTML, but allowed in HTML.

The SVG embedding implemented in this project primarily uses the < embed > label. When using the “embed” tag, you can use multiple attributes at the same time to reference an SVG diagram. You can specify the width and height of this SVG diagram in the HTML page by defining the values of the width and height attributes. Type can be used to specify the type of SVG, typically image/svg-xml. Src specifies the specific path address of an SVG data file. Once the “embed” tag is defined, the SVG diagram under that path is displayed in the appropriate position on the HTML page. However, it should be noted that SVG currently does not support GB encoding format, you must use UTF-8 encoding to complete the Chinese font display. A more significant feature of the Src attribute is the ability to dynamically load different SVG graphics without changing the page code by dynamically setting the property values.

The refreshing mechanism of SVG is realized by timing reloading of SVG browsing, so we can directly use the Java Script timer setTimeout or setInterval to get the data in the database in real-time through AJAX data acquisition technology, and change the attribute value of the specified graphics in the SVG image or change the text in a text box through the data acquisition.

(3) Echarts visualization technology

ECharts, a pure Javascript charting library, can run smoothly on PCs and mobile devices, compatible with most current browsers (IE8/9/10/11, Chrome, Firefox, Safari, etc.), and relies on the lightweight Canvas class library ZRender to provide intuitive, vivid, interactive, highly customizable data visualization charts. ZRender (Zlevel Render) is a lightweight Canvas class library, MVC encapsulated, data-driven, and provides a DOM-like event model.

ECharts provides regular line charts, bar charts, scatter charts, pie charts, k line charts, box charts for statistics, maps, thermal charts, line charts for geographic data visualization, diagrams for data relationship visualization, treemap, parallel coordinates for multidimensional data visualization, funnels for BI, dashboards, and mashups between diagrams.

ECharts is driven by data, and changes in data drive the changes represented by the chart. As a result, the implementation of dynamic data becomes much simpler. ECharts will find the difference between the two sets of data and animate the changes only if it obtains the data and fill in the data.

The volume of the chart library should be as small as possible. The refactoring of the ECharts and ZRender code resulted in a reduction in core volume. The refactoring of ECharts and ZRender code brings the ability to shrink core volumes to provide on-demand packaging because ECharts has many components and continues to grow.

ECharts 3 began to enhance support for multidimensional data. In addition to common multidimensional visualization tools such as parallel coordinates, for traditional scatter graphs, the incoming data can be multidimensional. With the visual mapping component VisualMap, it can provide rich visual coding, and map data of different dimensions onto different visual channels of different color, size, transparency, shading, etc.

6.2.3 Electric Power Emergency Visualization

Power emergency visualization mainly refers to map visualization, power emergency data visualization and emergency command visualization. Map visualization refers to the visualization of power facilities by using the unified GIS platform of the national network, and the ability to timely and accurately obtain the affected power grid equipment or power facilities before or in the event of a disaster. Power emergency data visualization refers to the visualization of various data in the process of power emergency response, mainly including the data of power outage caused by a disaster (suspended substation, line, station area and users experiencing power outage), emergency repair data (input personnel, input vehicles, input emergency repair team and input emergency repair resources). Emergency command visualization refers to the visualization of emergency response process in the process of emergency response, so that the emergency personnel participating in the emergency response process have an overall understanding of the overall response process and assist in the emergency response work.

The Unified GIS Platform of China Network is a GIS application platform with independent intellectual property based on the research and development of domestic GIS platform. Multi-level caching technology is fully used to reduce the network and server pressure caused by the centralized deployment of spatial data. Power grid GIS platform integrates and maintains massive basic geographic data, power grid spatial data and power grid topology data. The API of the Unified GIS Platform for State Network provides a series of complete and practical map functions, such as distance viewing, searching and displaying, searching in the field of vision, and map scaling. In the application of electric power emergency visualization, the GIS Platform for State Network is mainly used to forecast and count the affected power facilities in time in combination with the prediction scope and impact scope of natural disasters, and to conduct early warning response and emergency response, as shown in Fig. 6.17.

In the field of electric power emergency response, data visualization mainly includes visualization of spatial information (visualization of emergency response resource distribution, etc.), data visualization (visualization of power grid damage

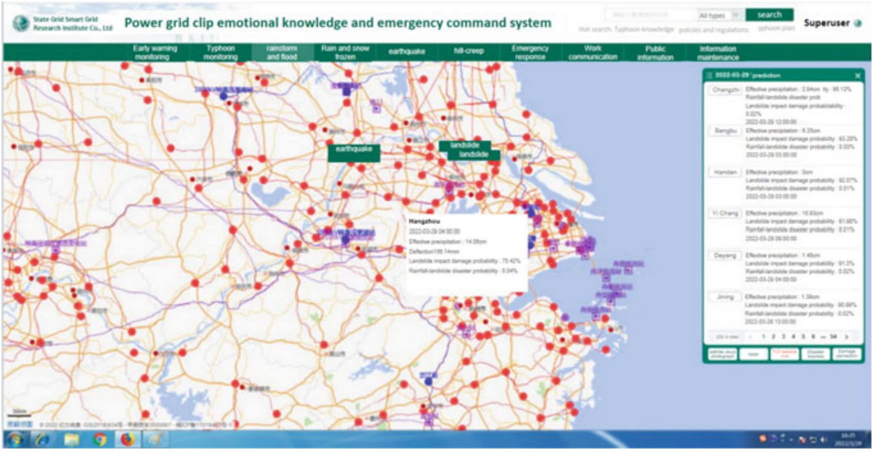


Fig. 6.17 Visualization of natural disaster impact power grid forecast

and recovery, visualization of power grid damage prediction, visualization of emergency response resource demand, visualization of meteorological disasters, etc.), and visualization of on-site images (field video monitoring, field video recording of emergencies, etc.). The visualization technologies in respect of three aspects complement each other and can effectively help the staff members to have a direct understanding of the different regional states of the power grid, distribution of emergency response resources, field, and other information.

Power grid damage and recovery: In the form of a histogram, visualize the situation of lines (damaged, restored), substations (damaged, restored), distribution station area (cumulative power outage, restored), users (cumulative power outage households, restored households), important users (cumulative outage households, restored households) and other situation information. At the same time, combined with the actual power grid business, it provides the configuration function of the column chart template information items, colors and other contents, as shown in Fig. 6.18.

The power grid emergency repair input function is based on Echarts technology, and displays data such as large-scale emergency repair machinery, emergency lighting equipment, emergency repair teams, emergency repair vehicles, power generation vehicles, generators, etc. in the form of pie charts, radar charts, and text, as shown in Fig. 6.19.

Emergency command visualization is mainly based on the emergency handling process and related tasks generated by the special emergency plan in the emergency handling process, so that the emergency response staff has a comprehensive and in-depth understanding of the overall emergency handling process, and they can fully understand the emergency handling process and the tasks of each stage and link, real-time task status feedback, and the emergency command personnel in the emergency command center can fully understand the progress of the emergency handling work and the completion of each work to conduct visual emergency command.

Fig. 6.18 Visualization of grid damage and recovery

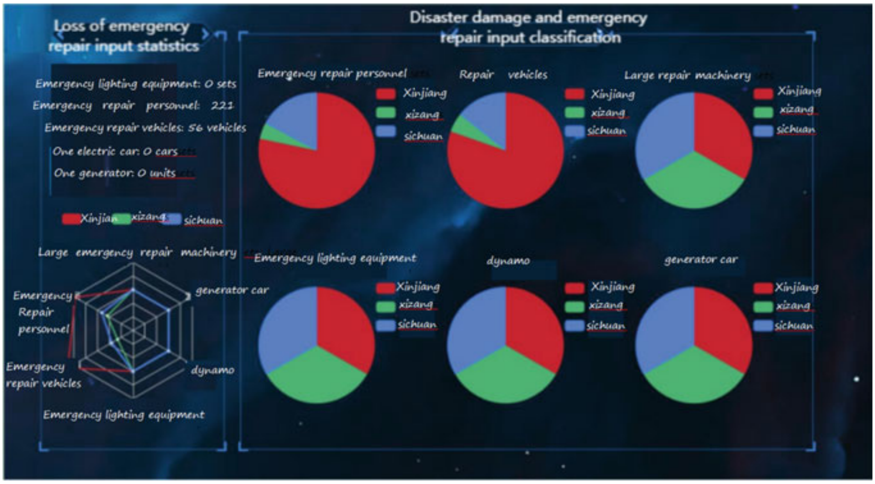


Fig. 6.19 Schematic diagram of grid damage and recovery

According to the special emergency plan, combined with the departmental disposal plan and the on-site disposal plan, the monitoring and early warning stage is divided into several links “risk monitoring, analysis and judgment, early warning suggestions, early warning review, early warning issuance, early warning action, early warning adjustment or lifting”, and then the corresponding tasks (what to do) and related suggestions (how to do) of each department in each link are accurately pushed, so that the tasks can be accurately pushed to the relevant responsible persons, and the relevant status of each task can be tracked in real-time “not viewed, viewed, in progress, completed”. In the tasks of each department in the corresponding link, you can filter and view your own tasks. At the same time, they can be notified of the

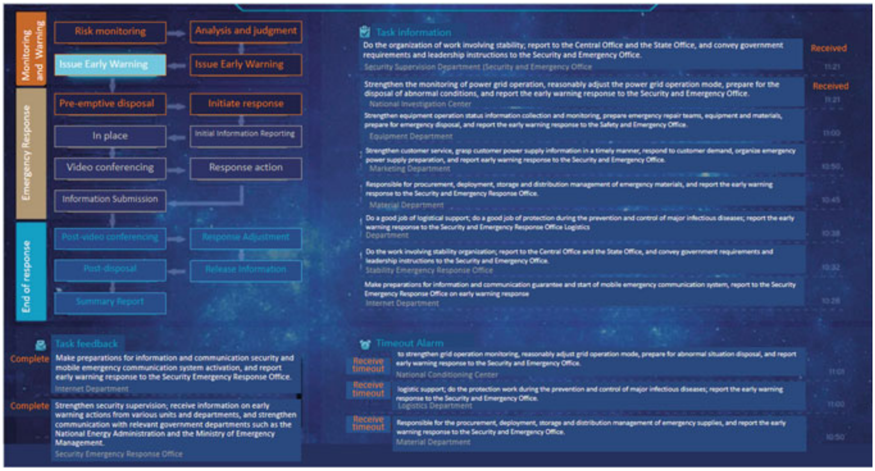


Fig. 6.20 Visualization diagram of emergency response

need to complete relevant tasks through SMS. If all the tasks in a certain link are "viewed" by all personnel, the whole process can be automatically carried out to the next link. One link can be highlighted and flashed when it is its turn to be carried out.

The response-end stage is divided into several links "response-end, recommendation review, release of information", and then the corresponding tasks (what to do) and related suggestions (how to do) of each department in each link are accurately pushed, so that the tasks can be accurately pushed to the relevant responsible persons, and the relevant tasks can be tracked in real-time status" Not Viewed, Viewed, In Progress, Completed". In the tasks of each department in the corresponding link, you can filter and view your own tasks. At the same time, they can be notified of the need to complete relevant tasks through SMS. If all the work tasks in a certain link are "viewed", the whole process can be automatically carried out to the next link. The link can be highlighted and flashed when it is its turn to be carried out. The process continues until the end of the response, as shown in Fig. 6.20.

6.3 Integrated Social Information Emergency Command and Decision-Making Technology

6.3.1 Social Information Acquisition and Processing

(1) Access to information from social sources

Information Extraction (IE): Extracts target factual information from unstructured natural language text and then represents it in the form of structured data. Web information extraction is an important part of information extraction, which is the process of extracting subject content information from web pages and presenting it in a structured manner.

Most of the data on the Internet is presented in the form of HTML documents, which is a kind of semi-structured data, the position and layout of its text, images and other contents are arbitrary and unstructured, but the contents of the web pages are organized according to a certain hierarchical structure and meet the DOM standard set by W3C for operation and access. HTML is a markup language document that lacks semantic information. HTML tags are used to present information data in the browser, but they can only express very limited semantic information. Data on the Internet is characterized by huge volume, heterogeneous data sources, lack of semantic information and dynamic variability, which brings many difficulties to web information extraction. Firstly, the hundreds of millions of web sites on the Internet construct a multi-data source environment, as each site is usually independently laid out and designed, resulting in the heterogeneous nature of multiple data sources; Secondly, in addition to the subject content to be extracted, the HTML document also includes noise content such as navigation bar, advertising area and related recommendations, which should be filtered out during web information extraction. Last but not least, it is the dynamic variability of web data. Internet content is updated and changed every day, especially online social media and news data, which are updated frequently and produce a large amount of data anytime and anywhere, and this part of the content is more data-intensive, interactive and more complex in terms of extraction techniques.

In order to solve the above-mentioned problems in web information extraction, many web information extraction methods have been proposed by researchers at home and abroad, and good results have been achieved in general. According to the differences in the principles of web information extraction and extraction objectives, there are four main categories:

1) Rule-based template information extraction method

By observation, although different websites have different design styles and content layouts, for the same web site or a site board, the pages under it have the same or similar structure, which is due to the widespread use of template-population technology in web development, i.e., the front-end pages are often generated by selecting data from the back-end database to populate the same template based on requests. Naturally, if the design template of the web site is somehow obtained and the corresponding information extraction wrapper is generated, then the subject information of the data source can be accurately obtained. As mentioned earlier, because different data sources have different layout structures, a wrapper is only valid for a class of web pages with similar layout structures, so the disadvantage of the method is the high cost of rule maintenance and poor scalability. If you want to handle web pages from different data sources at the same time, you need to design different wrappers for different web sites or web boards, add them to the rule template library and maintain them regularly. The method is implemented with manually written rule templates and (semi-)automated wrapper generation techniques, where automated template generation techniques are used to generate extraction rules from some specific training sets using machine learning techniques. Representative IE systems that use this method are Minerva and WIEN.

2) Information extraction technology based on visual features

HTML document is a collection of web tags and web content, where the tags have two main roles: on the one hand, they are used to organize web content, and on the other hand, they provide page display functions, such as page text style, segmentation control, body text and noise distribution area, etc. So the web page has obvious visual features in the content location, style. These visual features provide important clues for the implementation of page segmentation and information extraction, of which the VIPS algorithm proposed by Microsoft Asia Research Institute is the most classic web information extraction algorithm based on visual features. In the early days, the visual block-based web information extraction technology could segment web pages more accurately based on font size, background and other information, but with the development of web technology, web pages have become more diverse and richer, making it more difficult to extract visual features based on heuristic algorithms, resulting in insufficient accuracy of web information extraction.

3) Statistical-based information extraction techniques

Because web pages are visually divided into different areas, and in fact, the amount of statistical information such as text content and web page tags in different areas is also unevenly distributed, according to the distribution characteristics of these statistical information, the statistical web information extraction technology designs different strategies to achieve the purpose of web information extraction. The number of Chinese characters in the <table> tag in the body of the web page is used as a measure of the web body region, and the ratio of linked text to normal text in each region of the web page is used to set the body extraction threshold to consider the ratio of the number of characters to the number of hyperlinks in different positions of the web page to distinguish the web body region. The advantage of this approach is that it is not limited by data sources and does not require supervised learning methods to train web pages, which is somewhat generalizable.

4) Web information extraction technology based on DOM tree structure

Before extracting information from a web page, a web document can be transformed into a parse tree, also known as a DOM tree, using a web parser. DOM tree can visualize the hierarchical structure of HTML tags, and the hierarchy is closely related to the content of web pages. The web extraction technology based on DOM tree structure is an important technical direction in web information extraction method. Many classical algorithms and mature systems have been developed, such as the MDR algorithm proposed by Liu et al. in the early twenty-first century and the improved algorithm, which mainly extracts data records of <table> table nodes, and the web information extraction method based on tag path clustering was designed by Miao et al. in 2009.

At present, in the design of many web information extraction methods, it is often not limited to a certain extraction technique, such as the web information extraction method based on tag path ratio proposed by Wu Gongqing et al. The algorithm integrates the structure of web pages and statistical information to complete the extraction of web news body.

In the field of information retrieval and statistical classification, accuracy P and recall R are often used to evaluate the quality of results. Similarly, these two metrics can be applied to web information extraction systems to measure the goodness of web information extraction algorithms. Here, the following formula is defined:

$$P = \frac{IE\ Number\ of\ results\ correctly\ extracted\ by\ the\ system}{IE\ Number\ of\ all\ extraction\ results\ in\ the\ system} \times 100\% \qquad (6.16)$$

$$P = \frac{IE\ Number\ of\ results\ correctly\ extracted\ by\ the\ system}{IE\ The\ system\ should\ extract\ the\ correct\ number\ of\ results} \times 100\% \qquad (6.17)$$

According to the definition of the formula, it is obvious that P and R take values from 0 to 1. The higher the value, the higher the accuracy or recall, indicating that the information extraction system performs better. However, for an IE system, these two metrics cannot be obtained at the same time, and the improvement of one metric tends to reduce the other system metric. In order to judge the merits of IE systems more objectively, the F-index has been introduced, which is generally characterized by taking the geometric mean of the accuracy P and the recall R.

(2) Information resource de-duplication

The web pages of the Internet are linked together by hyperlinks, using the web pages as nodes and the hyperlinks as links to form a huge network graph of document resources. The principle of a web crawler is to request the corresponding HTML document on a site through some initial URL, then parse the content of the HTML document, extract the URL link, and start the next round of web crawling. In this way, we achieve a constant stream of information data crawled from the Internet.

The general process of a traditional web crawler roughly goes through several core parts, including initial configuration, web page download and web page parsing, and its flow chart is shown in Fig. 6.21.

Read the web crawler related configuration parameters from the configuration file, such as crawl depth, number of crawler threads, number of failed page retries and URL filtering rules, and then add the manually collected seed URLs to initialize the web crawler URL queue.

The downloading of web pages is done through the downloader in the web crawler, the web downloader usually uses the HTTP protocol and can design the request parameters, the web downloader implementation can be based on the Java's HTTP client tool.

As for the web pages downloaded to the local area, the web crawler will call the web parser to extract the web page information, which mainly includes two parts. The first is to extract the body information from each web document and store it in a local file or database, and the second is to lift the URL links in the web document and put them into the front URL queue after URL de-duplication.

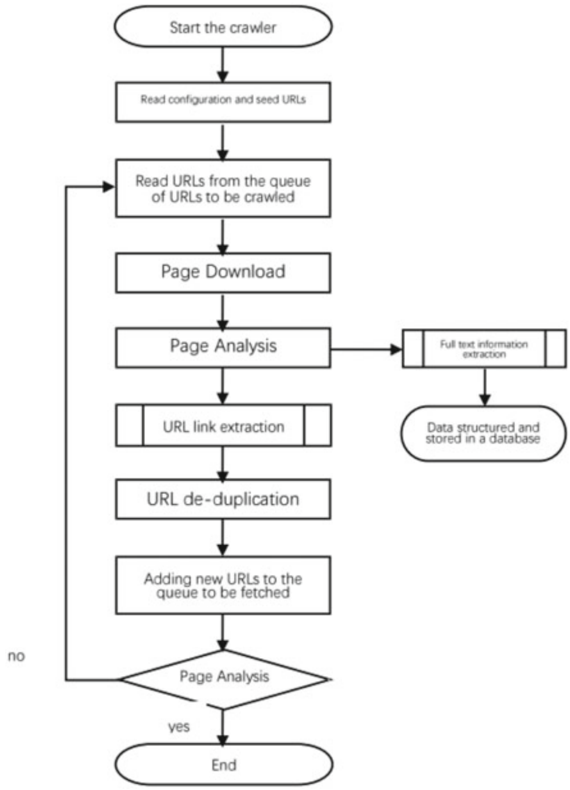


Fig. 6.21 Workflow diagram

The web downloader again takes a new URL link from the URL queue and starts the next round of web crawlers until some manual end condition is reached.

In this way, after certain initial conditions are manually set, the web crawler program can independently and continuously complete the collection of web data until the crawler program meets the stopping conditions set by the system.

The traditional web process described above is a batch-type crawler, where the web data collection task is opened with a limited crawl target and crawl range, and stops crawling when the stopping condition is reached. In addition, there are incremental crawlers and vertical crawlers by crawler function. Incremental crawlers are widely used in general search engines to accomplish the task of continuous web collection and regular updates, while vertical crawlers focus only on web information of a specific topic or industry. For the task of collecting web data to be carried out for a long period of time, you should choose the incremental crawler method to continuously collect new web information data and update the old information data.

Due to the link relationship between Internet web pages, the URL extracted from the current web page link may have been downloaded and resolved in the previous web crawler, so it is not desired that the same web page be downloaded multiple times in the subsequent web crawling process, because repeated downloads will not only waste system resources, but also activate the corresponding anti-crawler rules of the site due to the excessive access load to the data collection site, resulting in the subsequent inability to collect web data from the site. So web page de-duplication is an important element in the web data collection process, and there are many related techniques to solve this repetitive downloading problem, such as URL de-duplication techniques from the link perspective, Sim Hash and other algorithms from the web page content. The URL de-duplication technique starts from the hyperlinks of the web pages and selects the links that have not yet been downloaded to the queue of URLs to be crawled, which basically ensures that the same web page will not be repeatedly crawled; The Sim Hash algorithm generates the information fingerprint of a web page through the Hash function, and determines the similarity of the web page by comparing the similarity of the two information fingerprints, thus realizing the purpose of web page de-duplication. Here, we only introduce and analyze the URL de-duplication technique.

It is easy to think that in the crawler system, by creating a global URL library to store the links that have been collected in the historical crawler, and then comparing the URLs of the web pages to be downloaded, we can determine whether this URL corresponds to a web page that has been crawled. The simplest way is to use disk files to store each historical URL link sequentially, and then perform a search to match the new URL link to achieve the purpose of URL de-duplication, but this will become a performance bottleneck for large-scale web crawlers, both in terms of storage space and search efficiency. Considering the efficiency of web crawlers and memory storage space, URL de-duplication technology nowadays is mainly about how to store the URL library and find the URL, and currently the main idea of Hash mapping is used.

1) Storage based on MD5 compression mapping

MD5 is an encryption algorithm that uses the Hash Hash idea. It is applied to URL de-duplication by first compressing the link string to get a 128-bit integer information fingerprint, then Hash mapping the information fingerprint to get the physical address of the storage, and by comparing the two URL information fingerprints to see if they are the same, we can determine the duplication of the URL. In addition, it is good that the chance of Hash mapping collision using MD5 is very small. However, since it takes 16 bytes of storage space to store one URL, it requires a lot of memory space when storing billions of URL information.

2) In-memory database based storage

To store a huge number of URL libraries, the method of in-memory storage faces the problem of memory overflow. In fact, we can use external memory to assist in storage. In-memory databases based on Key-Value storage model Berkeley DB and Redis are both famous No SQL databases, which are very suitable for URL repositories in web crawlers because of their simple data storage model and support for high concurrency and random storage. The problem of URL de-duplication can be easily solved by using the compressed URL byte array as the key and the corresponding value with a Boolean value to identify the crawl state.

3) Bloom Filter-based storage

Bloom Filter is a space-efficient and fast random data structure that maps each string to an n-bit binary vector using k Hash functions. The Bloom filter can quickly determine whether an element is already in the set and only uses the storage space of an n-dimensional array, which is the optimal choice for URL de-duplication methods in large-scale web crawlers.

6.3.2 Data Acquisition in the State of Missing Field Information

(1) Specific system interface data collection methods

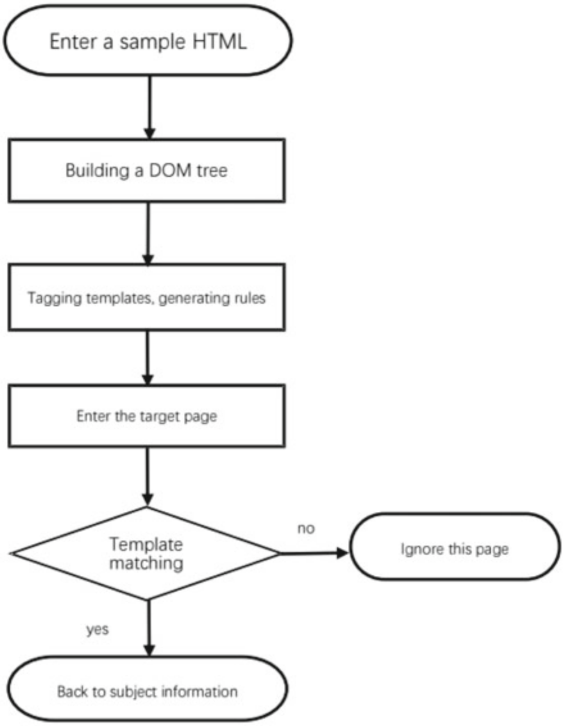
As for a specific data source website, the web pages of the website often have a similar structure, and by discovering templates and generating data wrappers, accurate opinion information extraction can be achieved. As for microblog and forum data sources, on the one hand, the number of such data sites to be collected in this paper is small but the layout of each other's pages is very different; on the other hand, the data of these data sources are organized in a fixed format and the data are related to each other, such as the data of the index page of the main post of the forum and the data of the content page of the main post, and the data of the blog posts and comments of microblog, which require accurate data extraction to ensure the correct operation of the collection program and thus extract the correct and formatted data of public opinion information. Therefore, the rule template design method is used here, and the data layout templates are manually marked for different microblogging and forum data sources and added to the rule template library for subsequent information extraction. The general flow of web information extraction based on rule template design is shown in Fig. 6.22.

Specific operating instructions are as follows:

1) As for a specific data source, first open the web page source code through Google chrome browser's developer tools, locate the specific topic information area, such as microblog user information, then record the CSS path of the topic information and add it to the specific topic rule template for that data source;
2) When parsing the downloaded pages, we will look for the corresponding rule templates from the rule template library and then match the corresponding theme information CSS paths one by one;
3) If the rule matches successfully, use the JSoup tool to extract the corresponding topic information;

Nowadays, HTML web pages are generally designed by the DIV+CCS layout method. CSS is short for Cascading Style Sheets, a technique used to express the style of documents such as HTML or XML. JSoup is a simple, fast and efficient java web parsing tool that provides a very easy API to extract and manipulate data

Fig. 6.22 Rule-based template approach to web information extraction



through DOM, CSS and j Query-like operations. In practical engineering practice, JSoup+CSSPath technology is used to build microblog and BBS forum web information extraction rule templates.

(2) Other data collection methods on the external network

Distributed crawlers are further divided into master–slave distributed and peer-to-peer distributed crawlers according to the crawling model. Master–slave distributed crawler has a dedicated Master node to maintain the queue of URLs to be crawled and is responsible for distributing URLs to different Slave nodes each time, while the Slave nodes are responsible for the actual data collection and sending the extracted URL links to the Master node, where URL de-duplication is done. In addition to maintaining the queue of URLs to be crawled, the Master node also balances the load of each Slave by distributing URLs. The shortcoming of this model is the performance bottleneck of the Master node. Today's fairly mature distributed crawler architecture is the Python-based Scrapy-Redis crawler architecture, where the Scrapy framework loads web page downloading and parsing, and the distributed key-value memory database Redis builds URL queues, which solves the performance bottleneck of the Master node. In peer-to-peer distributed web crawler mode, all nodes of the cluster share the same work, and each crawler server can get URLs from the queue of URLs to be crawled, and then the URL host name or domain name is hash-processed and distributed to the corresponding crawler nodes after the hash value is modulo the number of machine nodes. The early shortcoming of this model is its scalability, as a machine downtime leads to redistribution of crawler tasks, resulting in a waste of resources.

Here we use the first distributed data collection method and build a URL queue using a Redis database. The architecture of the distributed web news page collection design is shown in Fig. 6.23. The Master node acts as the control node and uses the Redis in-memory database to manage the URL crawler queue, including the storage of URL links and the de-duplication of URLs. Here we use the same number of URL queues in Redis based on the number of Slave nodes to store the URL links of the corresponding web news sites, so that each Slave node can retrieve the URL links from the corresponding URL queue in Redis. Here the URL de-duplication is done with the help of a global Bloom filter, that is, before the Spider parser on the Slave node extracts a new URL link and puts it into the Redis crawler queue, it is checked by the Bloom filter first, if the URL is not in the Bloom filter, then it is added to the Bloom filter and inserted into the corresponding URL queue, otherwise, the URL link is discarded.

The Slave node runs a web crawler program that obtains URL links from the Master node URL repository, downloads web pages, parses web news content and

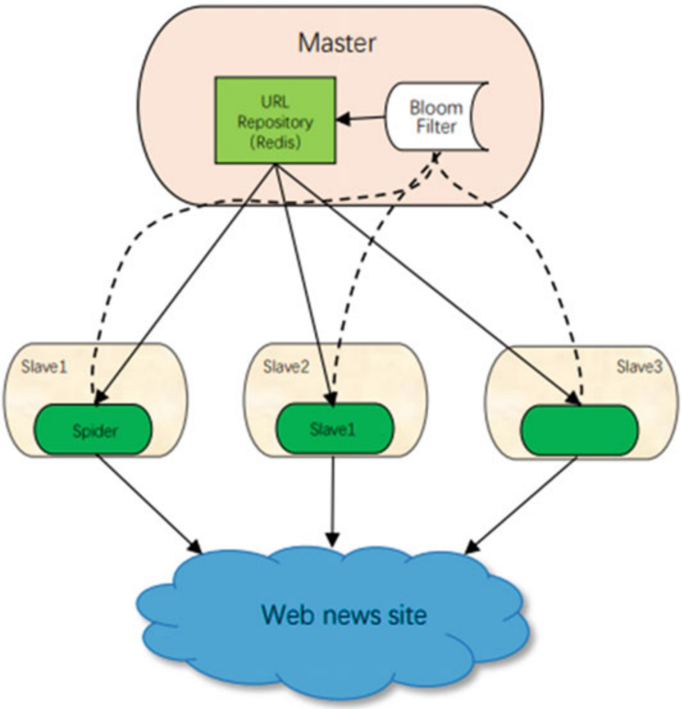


Fig. 6.23 Distributed web page collection architecture design

stores it in the HBase database, then extracts the URL links and returns them to the Master node. The workflow of the Spider program run by the Slave node is shown in Fig. 6.24.

1) start, initializing configuration parameters, including connection to the master node URL repository;
2) Based on the manually assigned set of news gathering sites, Spider's task scheduler fetches the URL links with crawling from the corresponding Redis queue on the Master node
3) Web page downloader to download web news pages;

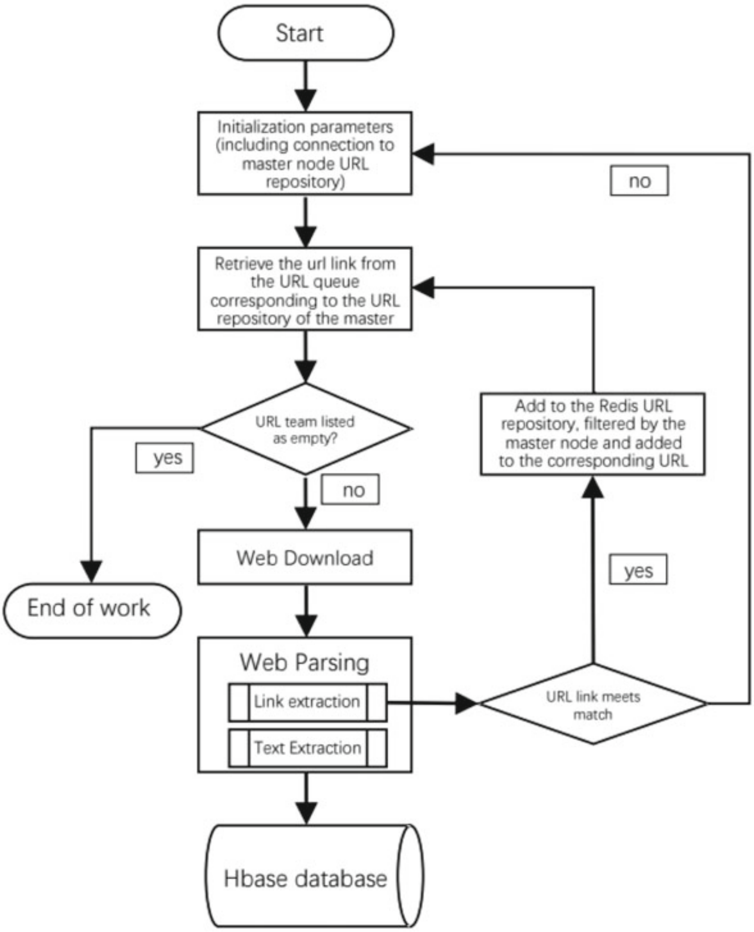


Fig. 6.24 Workflow diagram of Spider on Slave node

4) The web page parser on the one hand retrieves information such as web news body, title and release time, and stores it in HBase database after formatting, and on the other hand extracts news external links from the web page;
5) regular matching of the extracted URL link to ensure that the link is a page from the assigned site collection and then returned to the master node via the scheduler;
6) The URL links returned to the master node are first de-duplicated by the global Bloom Filter and then added to the corresponding Redis queue.

Considering that web news sites will update a large number of messages every day, in order to achieve the function of incremental collection of web news data, we need to regularly inject artificial seed URLs, which are to collect links to the home pages of certain sections of news sites, because these home page information will be dynamically updated every day. Based on these seed URLs, you can constantly extract the newly updated web news links every day to achieve the function of incremental collection of web news data.

(3) Satellite transmission mode information acquisition

Some power disaster data is not available from existing systems or internal data, and first-hand data needs to be obtained from power disaster sites. However, sometimes geological disasters or floods occur on site, which can destroy the real-time communication on site and make the primary data collected on site unable to be transmitted back to the system in time. At this time, it is necessary to consider using on-site information acquisition satellite communication module for satellite communication, transmitting the first-hand data collected in the field, back to the system in a timely manner through satellite transmission. As shown in Fig. 6.25.

The on-site information collection module based on satellite communication has 2G, 3G and 4G communication functions at the same time. In the areas with good ground public network or wireless network, the on-site information collection module can transmit the collected information back to the system in real-time through the public network or wireless network, and because it involves intranet data security,

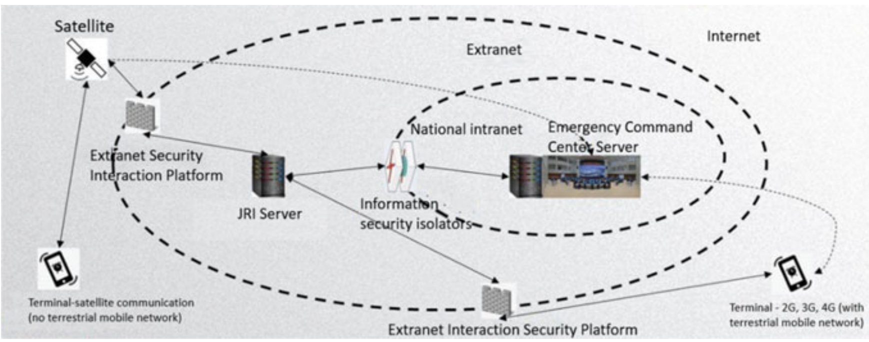


Fig. 6.25 Field information acquisition module communication system

a security interaction platform is specially set up. When the information collection site is hit by serious natural disasters, such as mudslides, earthquakes, floods, etc., the natural disasters will cause destruction to the ground public network, and then the information collected through the site information collection module cannot be transmitted back to the emergency command center in time, which requires the satellite communication function of the emergency terminal to be activated to transmit the collected site first-hand power disaster data back to the emergency command center through satellite in time for reference by emergency commanders.

6.3.3 Data Fusion Processing of Comprehensive Social Source Information

(1) Principle of multi-source information fusion

Multi-source information fusion is a fundamental function prevalent in human or other biological systems. Humans understand their surroundings and ongoing events by applying this ability to combine information (external objects, sounds, smells, touch) from various sensors (eyes, ears, nose, limbs) of the human body and use a priori knowledge to count them. The basic principle of multi-sensor information fusion technology is like the human brain integrated processing information, making full use of multiple sensor resources and combining the redundant or complementary information of multiple sensors in time and space according to some criteria through the rational domination and use of these sensors and their observation information, so as to obtain a consistent interpretation or description of the observed object.

Data fusion system also means that various real-time, non-real-time, accurate, fuzzy, fast-varying, gradual-varying, similar or contradictory data from various data sources are rationally allocated and used, and the redundant or complementary information is synthesized and analyzed according to some specific rules, so as to obtain a comprehensive description of the measured object.

Specifically, the principle of multi-source data fusion is as follows:

1) Multiple types of data collection on the target;
2) Feature extraction of the collected data and extraction of the feature vector representing the target measurement data
3) Effective pattern recognition processing of feature vectors using artificial intelligence or other methods such as pattern recognition that can convert feature vectors of targets into attribute judgments to complete the description of each sensor data about the target under test;
4) Grouping of the description data of the objectives in association with the same objective, based on the results of the previous step;
5) The grouped data by each target is synthesized using an appropriate fusion algorithm to obtain a more accurate and consistent interpretation and description of the target under test.

(2) Data fusion scheme for integrated social source information in the absence of on-site information

The characteristics of power disaster data make it necessary for data fusion to calculate each row and column of the data, completing both the correspondence of each column parameter of different data sources and the matching between different data sources for each row, using an attribute-based matching method. The main idea of the designed algorithm is to discover the columns and rows with high similarity in the data and use them as the seed data, and then use them as the starting point to learn to discover other new matching columns and rows until the matching of the whole data is completed. This has the advantage of locking the column matching to the most probable columns, reducing the computational effort of matching all columns and finding the global optimal solution through the local optimal solution. The specific algorithm design block diagram is shown in Fig. 6.26.

The block diagram of the improved data fusion method is shown above. By analyzing the data, setting the seed features → finding matches from the seed features → calculating the similarity and updating the similarity table → getting a new match table → …… This cycle is carried out, and finally the matching of all data is completed to get the result of data fusion. The improved algorithm has the following advantages by matching the potentially better matches in the data: 1) Being rewindable with high accuracy; 2) no need to annotate data, which can be applied to multi-source data fusion; 3) Fast convergence and small number of iterations;

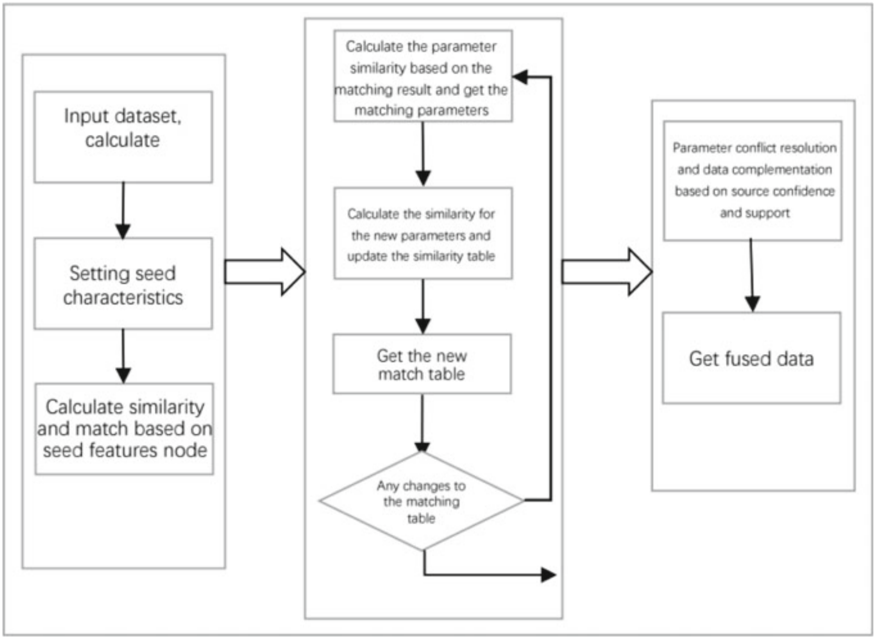


Fig. 6.26 Block diagram of data fusion method

4) Data fusion of the matched parameters to complement the data and improve the confidence level; 5) Low complexity of calculation; 6) All kinds of parameters are adjustable and highly flexible.

The seed feature columns, i.e., the columns selected at the outset to best represent the data characteristics, need to have low overlap in this data source and use a fairly homogeneous description specification across data sources. Since it serves as the beginning of the matching process and affects the subsequent matching process, the selection of a good seed feature column can speed up the subsequent matching process while helping to find a globally optimal solution, so the selection of the seed feature column is crucial. Two parameters are proposed to measure and select the seed feature columns. One is the degree of repetition of the parameter columns and the other is the degree of descriptive uniformity of the parameter columns from different data sources. Repetition is used to measure the degree of repetition of the data description of a parameter column of a single data source, i.e., the degree of difference between parameters using that parameter column, with a greater degree of difference indicating a greater likelihood that it can be used as a unique distinguishing identifier. The higher the degree of uniformity, the higher the standard of description of the same thing in both data sources, and thus the higher the usability of using it as a matching criterion. Feature columns require low repetition and high descriptive uniformity, and also need to be selected as seed features by considering the actual characteristics of the commodity data.

After determining the seed feature columns, it is necessary to calculate the matching degree between different data sources, which is obtained by weighting the similarity of each attribute and is calculated using the attribute based similarity measure method. The attribute-based similarity measure is a measure of similarity using the weighted sum of similarity between individual attribute values.

Definition of similarity: Suppose a message has multiple attributes. As for a single attribute, let it be able to represent its similarity to another message with a number from 0 to 1, the higher the value means, the higher the similarity. For the similarity measure of attributes, different similarity calculation methods can be selected according to the specific data types of attributes, and then different weights can be assigned to different attribute values according to the a priori knowledge and the actual situation of the data to characterize their different importance in entity unification, and finally the similarity of each attribute is weighted and summed to obtain the similarity between entities, and two entities with similarity greater than a certain threshold are considered to be similar.

Specific calculations: Calculation of the similarity of genus between c_i, d_j, marked as $sim_{attr}(c_i, d_j)$. $sim_{attr}(c_i, d_j) = \sum_k sim_{attr}(c_i(k), d_j(k)) * P_k$, where $sim_{attr}(c_i(k), d_j(k))$ denotes the similarity between c_i, d_j matching attributes k, P_k represents the weight of attribute K.

Similarity calculation: There are several methods for calculating the similarity of character type data based on semantic similarity, statistical association and literal similarity. The semantic similarity method is achieved by understanding the semantic meaning of character strings, and strings with the same semantic meaning are considered the same; The statistical correlation party method calculates the similarity of strings based on their statistically similar data; the literal similarity method is mainly based on the edit distance and synonym (word) methods. Among them, the edit distance is widely used because of its fairly mature calculation method and fairly good results.

The edit distance is used to measure the similarity between the attributes of the character type, and the multiple of deviation from the standard deviation is used to measure the similarity between the attributes of numeric type. The edit distance is the number of times two strings become the same character by the least number of edit operations (insert, replace, delete) between them. The edit distance mainly measures the errors that may occur in the string input transmission on a character-by-character basis. The larger edit distance indicates the greater difference between two strings, so the smaller the similarity, and the smaller the edit distance, the greater the similarity. As for data-valued data, the edit distance method does not apply to measuring the similarity because its values have specific meanings. In this chapter, the standard deviation of the attribute column of the value type is calculated in advance, and the difference between two attribute values is measured by the multiple of the standard deviation. In general, the larger the value, the smaller the similarity, and if the value is 0, the two are equal.

Standardization of similarity: Since the edit distance and the multiple of standard deviation are both unrestricted in the data range, and since different attributes need to be weighted to get a total similarity, the edit distance of individual attributes cannot be too large to affect the similarity of the whole entity too much, while the edit distances of different attributes also need to be standardized to make all the data have the same range. Both the edit distance and the difference standard deviation multiplier take values in the range $(0, +\infty)$, and in practice, they are generally finite. In order to facilitate understanding, we need to map them into a uniform fixed finite interval, and the commonly used normalization methods are min–max normalization and z-score (standard score) normalization. The min–max normalization is more influenced by the max–min values, but can ensure that all values are within a certain range. Z-score is not sensitive to the max–min values and can reflect the characteristics of the overall values, but the range of values is uncertain. In order to avoid the large influence of the maximum and minimum values on the data, the z-score normalization is used here to normalize the above distances. The specific steps are as follows:

Step 1: Find the initial matching row based on the seed feature column. By having set the seed feature column A_{k1} of data source A, seed feature column B_{k1} of data source B (can be other columns, specified here for illustrative purposes), calculate the similarity $sim_{attr}\left(a_{i1}, b_{j1}\right)$ of each entity of data sources A and B with respect to the seed column (i takes 0–n, j takes 0–m), entities whose similarity reaches a set threshold are considered similar at this stage. Here it is assumed that the similar entities obtained are A_{c1} and B_{c1}, A_{c2} andB_{c2}.

Step 2: Find a new matching column based on the initial matching row. Based on the similarity pairs obtained, the similarity between individual attributes is calculated, and the average similarity of known pairs of attributes in each column is calculated. When the similarity of an attribute column is higher than a set threshold, the column is considered similar. Therefore, calculate A_{c1} and B_{c1}, each of the attributes $sim_{attr}(a_{1i}, b_{1j})$ and $sim_{attr}(a_{2i}, b_{2j})$ of A_{c2} and B_{c2}(i takes 0–n, j takes 0–m), and calculate the average similarity between each column pair $sim_{attr}(A_{ki}, B_{kj}) = avg(sim_{attr}(a_{vi}, b_{wj}))$ (where v, w are paired entity pairs), as $sim_{attr}(A_{ki}, B_{kj}) = avg(sim_{attr}(a_{1i}, b_{1j}) + sim_{attr}(a_{2i}, b_{2j}))$. Assuming that here we get similar attribute column pairs as A_{k2}, B_{k2}.

Step 3: Find new matching rows based on the new matching columns. Based on the newly obtained feature column pairs, calculate the similarity of each entity of each data source on these attributes, get the new similarity between each entity, and update the similar entity pairs table according to the threshold value. This process involves both new entity pairs being judged as new matching entity pairs and entity pairs that have already been judged as matches being judged as non-matching entity pairs. This allows backtracking results to ensure that the matching results find a locally optimal solution based on the added evidence, and use this locally optimal solution to approximate the global optimal solution.

Step 4: Based on the newly obtained matched entity pairs, calculate the similarity between the attributes of each entity pair, and calculate the similarity of each attribute column to the matched entity pair to get the new matched attribute column. The overall process is similar to step 3, but with a different entry angle. The difference is that when matching rows by columns, each attribute has a different weight, while when matching columns by rows, each row has the same weight, and when matching columns, column names (parameter names) are also involved in the matching process. If any matching rows change, proceed to step 3; if not, proceed to step 5.

Step 5: Data conflict resolution for the matched data. The matched rows (entities) are obtained from step 4, where the attribute values of the matched attributes will have the possibility of data conflict, and data conflict resolution is needed to get more credible and complete data, which is one of the purposes of data fusion.

6.3.4 Power Emergency Warning and Response Process Command Decision

(1) Electricity emergency warning assisted decision-making

Comprehensive social source information, early warning for power facilities, auxiliary power emergency warning, early access to affected power facilities, early warning response.

The power emergency warning assisted decision-making process is as follows, and the flow chart is shown in Fig. 6.27.

Step 1: Obtaining information from social sources and processing the information to get disaster warning information;

Step 2: Combining the disaster warning information with the grid GIS data information to obtain the affected grid facilities through data analysis and processing;

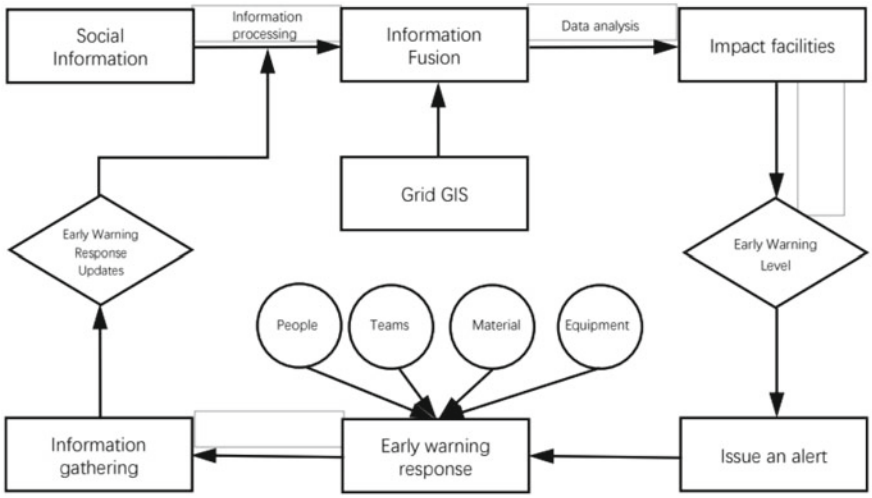


Fig. 6.27 Schematic diagram of the power emergency warning aid decision model

Step 3: Conducting disaster warning analysis and research based on the affected grid facilities, further analyzing the degree of impact of the disaster on the grid, and thus deriving recommendations for warning issuance;

Step 4: Issuing an internal warning for early warning response after analysis and discussion are confirmed;

Step 5: Obtaining personnel, team, material, and equipment data information to aid in the deployment of early warning response;

Step 6: Real-time follow-up and update of disaster warning information, re-analysis and research, and real-time update of early warning response decisions based on personnel, team, material, and equipment data information to assist in power emergency warning work.

(2) Electricity emergency disaster damage prediction model

The prediction model of power event development trend (loss of power equipment and facilities) is shown in Fig. 6.28.

The execution process of power emergency trend prediction is shown in the figure.

Step 1: Based on the underlying and current data, the forecast data can be used for damage prediction based on the proposed power emergency scenario projection;

Step 2: Obtaining scenario extrapolation of disaster development through basic data and other data, and obtaining specific predicted data on damage to electrical equipment and facilities through scenario extrapolation;

Step 3: The content of the scenario extrapolation is mainly based on historical damage records, and the specific data are corrected by the macro disaster loss prediction results in order to obtain more accurate trend prediction results;

Step 4: The event development prediction data is influenced by the emergency disposal command decision, so it is necessary to continuously track the emergency

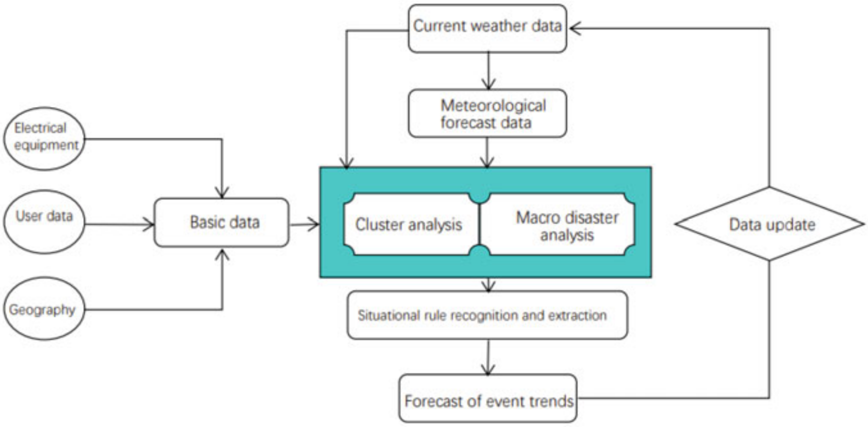


Fig. 6.28 Schematic diagram of the event trend prediction model

disposal process, and update the results of the event development prediction in a timely manner while constantly updating the internal data and external data to ensure the real-time nature of the prediction results.

The prediction process is shown in Fig. 6.29.

Step 1: Based on the relevant basic data, current damage data can be obtained for the current state of the outage range and the results of the prediction of the event trend;

Step 2: Based on the results of the event development trend prediction, the results of the outage scope prediction can be obtained by analyzing the impact capacity of the damage status of the power facilities in the results. It is necessary to realize the results of determining the depth of the analysis and gradually analyzing the secondary impact and tertiary impact of power facility damage.

Step 3: The number of outage areas and outage users in the forecast results can assist in the prediction of outage scope in two ways. The number of outage users and the number of station areas can provide more powerful prediction data for speculating

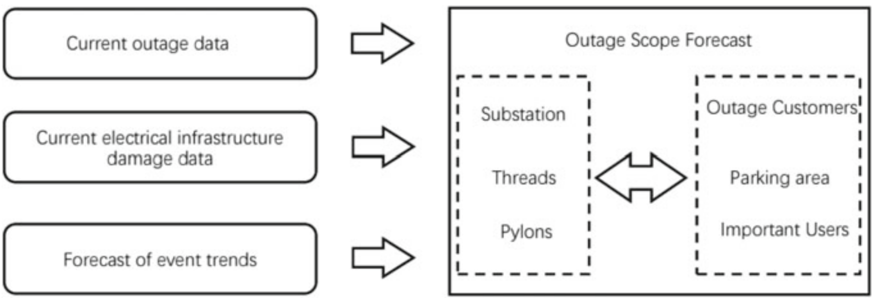


Fig. 6.29 Outage range prediction model

the size of the outage range. At the same time, the prediction results of outage users, outage station areas, and outage important users can be used to reverse the prediction of which power equipment is more likely to be damaged.

Step 4: As the event develops, the outage scope prediction results are continuously updated based on the changes in the data.

(3) Command center and field information interaction model

In the absence of information at the emergency site, the interaction model between the command center and the information on site is established to realize the transmission of information at the disaster site and the communication of command center instructions, as shown in Fig. 6.30.

The command center interacts with the field information model in the following steps:

Step 1: In-depth survey and information gathering through a base team;

Step 2: The base team transmits the collected on-site information, including on-site video, on-site pictures, text descriptions, voice information, etc., through the mobile public network or satellite communication;

Step 3: After receiving the relevant information, the on-site command will analyze and judge the situation, mobilize the repair team nearby to carry out repairs, and at the same time make applications for material allocation to ensure the supply of emergency materials;

Step 4: The on-site command reports the relevant information to the emergency command center, or the base team reports the information directly to the emergency command center by means of mobile public network communication or satellite communication;

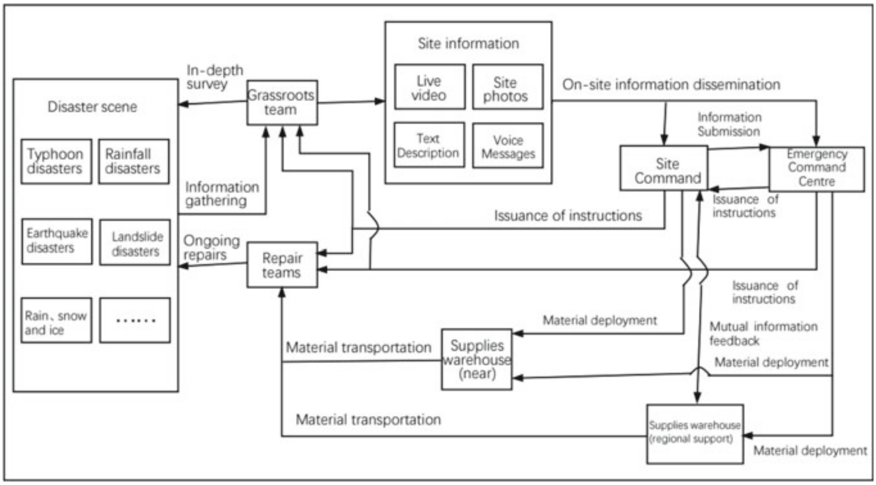


Fig. 6.30 Command center and field information interaction model

Step 5: After receiving the information, the emergency command center will analyze and research, and can transmit the instructions to the field command, or directly to the nearest material deployment;

Step 6: The emergency command center can also conduct cross-region material deployment for cross-region material support;

Step 7: The emergency command center can directly convey instructions to the repair team, which carries out continuous repair work at the disaster site.

Realize real-time interaction between emergency command center and field information through information transmission from base team, repair team and field command.

(4) Interaction model between resource deployment auxiliary decision-making command center and on-site information

The generation of resource deployment-assisted decision scenarios can be refined on the basis of the forecast results:

Input resource reassessment: An important issue is that the results of input application at that time may not be optimal, which means that more maintenance resources can be dispatched from other areas that are not affected to improve maintenance efficiency in order to achieve the best maintenance results. At this level the data on the amount of resource input needs to be increased appropriately according to the actual analysis results.

Resource statistics based on emergency capability pool instances: Based on the specific work content of emergency capability pool instances, the actual amount of resources required during the execution of each capability is counted. At this stage, the specific level of implementation of each competency in the competency pool is derived, that is, how many times each competency can be implemented or how long it can be sustained.

Task Bank-Capability Bank Correspondence Calculation: Based on the results of disaster damage prediction and disaster development trend prediction, correspondence adjustment calculation is performed with the emergency capability bank instance, and each task in the task bank instance is determined to determine whether it has the ability to execute the response plan in the capability bank.

Specific redeployment program design: Based on the number of emergency resources and the time required for maintenance, a specific resource redeployment program is developed. Various factors need to be considered such as the distance of emergency resources from the failure site, continuous working time, consumables management, and energy management. Also consider the change in the scope of the area where the outage occurs and develop a final and reasonable emergency resource dispatch plan.

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Chapter 7
Intelligent Sensing and Emergency Command System for Power Grid Disasters

7.1 General Architecture

7.1.1 Technical Route

Based on the multiple information collection technology for power grid disaster losses, remote real-time information interaction technology, and disaster information analysis and prediction technology, a prototype system for intelligent perception and emergency command of power grid disaster situations is developed. The system is divided into terminal and main station service functions yes, the functional framework diagram is shown in Fig. 7.1.

Key features include: (1) Intelligent equipment identification function, using the "UAV-based line disaster survey and identification technology" in Chap. 3, to achieve the use of deep learning technology to build a model identification library of power grid equipment, the use of UAV automatic detection system to identify the site of power disasters, to achieve automatic identification and survey of the disaster damage site. (2) on-site data collection function, using "Chapter 3 of the Internet of Things based on the typical electrical equipment disaster damage multiple information fast collection, automatic collection technology", based on three-dimensional point cloud, two-dimensional images and radio frequency RFID-assisted comprehensive on-site power equipment intelligent identification collection, through integration with the back-end intranet PMS system, monitoring systems, etc., to achieve real-time pushing of data such as on-site equipment ledger, equipment drawings, historical maintenance and operation records, real-time load operation status, to assist field operators in the emergency site to carry out diagnostic analysis of damaged equipment. (3) Disaster loss information fusion analysis and prediction function, using "Chapter 4 of the power grid disaster loss information fusion analysis and prediction technology" to realize the information fusion and fuzzy dynamic power grid loss prediction of the comprehensive database of power grid emergency command

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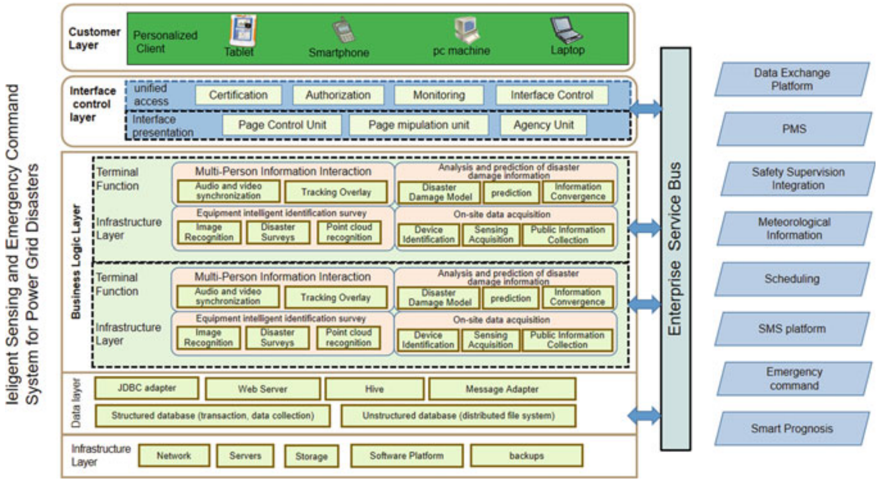


Fig. 7.1 Functional framework diagram of power grid disaster intelligent perception and emergency command prototype system

and the disaster loss model database. (4) real-time multi-person information interaction technology, using the "Chapter 5 real-time information interaction technology between the emergency site and the command center" to achieve real-time interaction between the disaster damage site terminals and real-time multi-person interaction between the site and the remote command center, to build an efficient multi-type information reporting method, and to improve the ability to interact with information between various departments and locations for emergency response.

The technical route of the prototype system of intelligent perception of power grid disaster situation and emergency command is as follows:

Smart mobile devices use the Eclipse development platform, and the development uses HTML5, Java and other development languages for function can be developed. Use JSON structured data format to communicate with the background server for web service interface.

The main station system function adopts the eclipse development platform, and the development adopts C, Java and other development languages for the master server for the development of services, the external service interface adopts tomcat for unified service distribution, and the database adopts open source MySQL database technology, unstructured data using cstor distributed storage.

According to the needs of business functions, the architecture of the power grid disaster intelligent perception and emergency command prototype system is divided into four levels: data resource layer, business logic layer, presentation layer, and channel client, and each layer is interdependent.

The data resource layer includes the database, enterprise information system, file system, and directory service of the emergency command system to provide data support.

The business logic layer includes multiple information collection, power equipment identification, disaster information analysis, disaster information prediction, real-time information interaction, and public information display.

The presentation layer is the display and interactive operation layer of business functions, and the system adopts standard HTML/JS, Flex, artificial intelligence reasoning, workflow engine and other technologies to realize the rich client interaction capability of the presentation layer.

Channel clients include PC clients, tablets, phones, PDAs, smart terminals, and so on.

The research and development of power grid disaster intelligent perception and emergency command prototype system can be logically divided into user layer, application layer, service interface layer, and database service. (1) The user layer mainly includes hardware devices such as intelligent mobile devices, networking equipment, and intranet servers. (2) The application layer mainly includes business pages and platform presentation frameworks. Platform presentation layer used by various page modules to compose a business page. The business application module combines the business characteristics to customize the business logic at this layer. (3) The service interface layer includes the communication client running in the browser and the service access point running on the server side. The service interaction layer provides functions such as formatting, transmission, packet and unpacket, URL processing and distribution of user request data. The platform supports RESTful, BlazeDS, and the platform provides Web service support for integration between systems. Platform internal service call data is serialized in JSON format. The server uses the Dispatch Servlet in Spring MVC for request distribution. The business logic module of the business application system, the standard logic module provided by the platform, and the public service agent constitute the business logic layer. Platform services expose public service interfaces in the business system operating environment, which can be referenced by business logic or exposed to client calls through the service interaction layer (solving the cross domain problem of browser HTTP requests). (4) The database service layer adopts MySQL database to analyze and backup structured and unstructured data in a unified manner, and adopts CSTOR distributed storage for data management to ensure data efficiency and security.

7.1.2 Overall Architecture Design

(1) Technical architecture
 1) Technical requirements

The construction of the power grid disaster intelligent perception and emergency command system should adopt international advanced and mature IT achievements to ensure that the system has a leading technical level in the corresponding fields in China. During system implementation, the following technical requirements should be observed:

a) Progressiveness: the realization of the system should refer to the international benchmark and combine the current situation, adopt advanced and reliable equipment and technology, ensure the advanced and mature of the system, and ensure the effectiveness and continuity of investment.
b) Safety and reliability: the system must meet enterprise-level security standards, provide good security and reliability strategies, support a variety of safety and reliability technical means, and formulate strict safety and reliability management measures.
c) Openness: the system should be based on the open standards of the industry at home and abroad, carry out unified national planning, and lay the foundation for future business development.
d) Scalability: the system should have flexible scalability, with the ability to easily adapt to changes in business needs and quickly support new services.
e) Scalability: the system should have good scalability, and the system performance and concurrent processing capabilities should have smooth expansion capabilities for the host device to support the rapid development of business volume.
f) Usability: the system should be easy to use and maintain, with a good user interface, userfriendly management tools and complete help information.

Under the guidance and constraints of the overall technical requirements, the core technology of system design and implementation is realized by component technology, considering the comprehensive balance between quality elements such as performance, reliability and ease of use to ensure the smooth realization of technical objectives.

2) Technical architecture design

The system technical architecture defines the core technology roadmap of the target system, defines the hierarchical model used in the system, defines the role and bearing relationship of each level in the application system, and the correspondence between each level and the normative system.

a) Service-oriented business component design

In the system standardization design, the specific functional applications of the power grid disaster intelligent perception and emergency command system business are divided into interface control components and business logic components for business logic encapsulation, and all business application functions are decomposed into basic processing units according to the degree of business coupling, and adapt to the dynamic changes and business expansion needs of the power grid disaster intelligent perception and emergency command system business through the combination and assembly of components.

Specific business components can provide standard service interfaces for other applications in the method of web services. Others the application system can obtain related component service information through standard services, including service call information and data the rules, etc., and the corresponding functions are implemented through the web service according to specific needs, and integrated into its applications.

b) J2EE based technical implementation

According to the design of the application architecture and data architecture of the system, the business application of the power grid disaster intelligent perception and emergency command system adopts a J2EEbased multilayer technology architecture that meets the combination of technological advancement and maturity to improve the flexibility, scalability, security and concurrent processing capability of the system.

The multilayer architecture of power grid disaster intelligent perception and emergency command system business application technical support system adopts component technology to separate interface control, business logic and data mapping, realize loose coupling within the system, and respond flexibly and quickly to the requirements of the system for business changes. The system hierarchy is generally divided into presentation layer, integration service layer, business logic layer, data resource layer (including data mapping layer and data source layer), and infrastructure layer the bearer relationship of services between hierarchical system components to realize system functions as shown in Fig. 7.2.

① Presentation layer: it is the view layer of the platform, and all human–computer interaction activities will be implemented based on this layer. The entire presentation layer will be implemented based on the B/S pattern. Leaflet, Echart and other chart technologies are used to visualize meteorological information, typhoon information, heavy rain and flood, rain, snow and freezing, earthquake disasters, landslide disasters, emergency response, public information, etc.; It adopts the MVC application framework, which consists of interface controller components, interface operation components, JSP page components and service proxy units to realize data information maintenance and monitoring management functions.

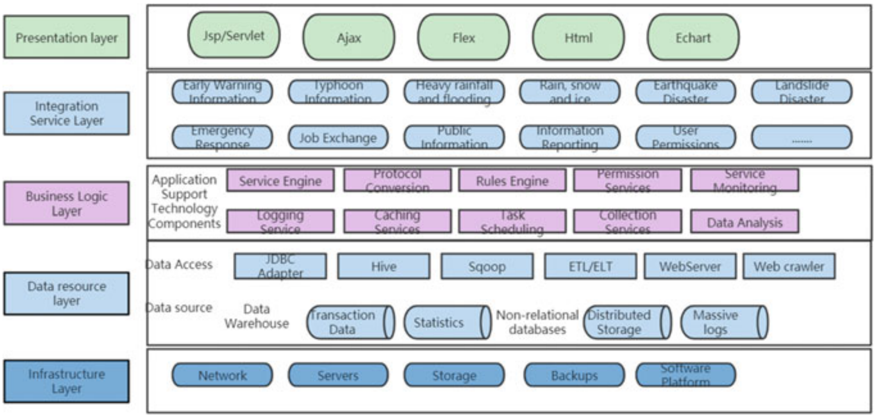


Fig. 7.2 System technical architecture

② Integrated service layer: integrate internal and external system business data information, configure and maintain business system users, permissions, etc., timely obtain meteorological information and disaster information such as typhoons, heavy rain, rain, snow and freezing, earthquakes, landslides, etc., and display data fusion with internal station system information to realize the integration and display of multiple data sources of business systems in the emergency command center.

③ Business logic layer: used to deploy business logic components, including application support technology components, service engines, protocol conversion, rule engines, big data analysis, permission services, service monitoring, log services, cache services, task scheduling, collection services, etc.

④ Data resource layer: composed of data sources and data access, data sources mainly include relational databases, nonrelational databases, etc., of which transaction data and statistical data are selected relational databases, meteorology, power grids, logs and other data are selected nonrelational databases, data sources specify the access and storage methods of platform data, and data access methods include JDBC adapter, ETL, WebService, sqoop, hive, etc.

⑤ Infrastructure layer: the basic software and hardware environment on which the platform design, development and operation depend. The whole platform will be compiled and deployed based on Windows operating system, data acquisition and data service part will be based on J2EE architecture technology development system, Java language development and implementation, data processing and product processing based on Java language, meteorological service product display based on Leaflet technology, power business data display based on Echart technology, mainly including network, server, storage, backup, software platform, etc.

(2) Data Architecture

From the perspective of enterprise data asset management, we formulate strategies, models and processes for data collection, storage, movement and access in the whole data life cycle, adopt data sharing and exchange methods such as data replication, intermediate library/ETL, WebService service, external network data capture and resource penetration call based on service bus technology, realize integration with internal and external systems to complete the centralization of professional basic data and business data as the main data support in the process of emergency command, and improve the efficiency of data storage and sharing. This is shown in Fig. 7.3.

1) Data architecture planning

The data architecture is designed based on the data model from two aspects, namely data technology classification, data deployment design, each of which addresses a key issue in one area, while supporting and complementing each other to form a unified and organic overall data architecture.

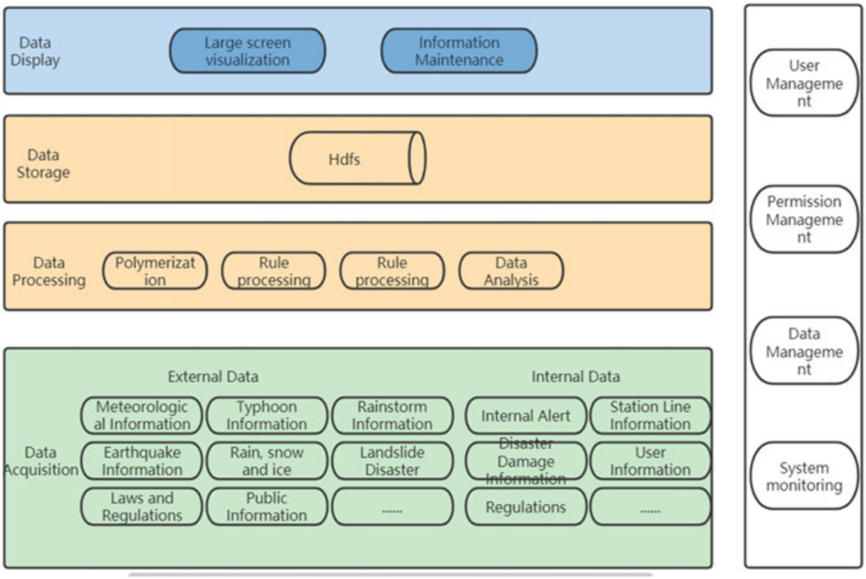


Fig. 7.3 System data architecture

2) Data model design

The data model of power grid disaster intelligence sensing and emergency command system is guided by the enterprise data model by analyzing and sorting out the important business concepts and data involved in emergency management, and considering the undertaking relationship with the enterprise data model. The data model of grid disaster awareness and emergency command system is established by analyzing and sorting out important business concepts and data involved in emergency management, and considering the undertaking relationship with enterprise data model.

The data model consists of two parts: the conceptual data model and the logical data model. The main goal of the conceptual data model is to define and present the core business concepts and relationships as a bridge between business personnel and technical personnel, and is the basis of the logical data model, whose inputs are business requirements and business specifications. The main goal of the logical data model is to further refine each business entity based on the framework designed by the conceptual data model and combined with business requirements, which mainly consists of entities, attributes and relationships.

The top-level conceptual model is first designed to delineate the data topic domains and define the relationships between them. Then the top-down design is carried out separately for each data subject area, and the design content is gradually refined to complete the conceptual model and detailed logical model design for each data subject area. The top-level conceptual model is the conceptual model of the data domain and the detailed logical model design. The top-level conceptual model is the highest guidance for the design of data domain conceptual model and data domain logical model. The top-level conceptual model is the highest guideline for the design of data domain conceptual model and data domain logical model.

(3) Business architecture
1) Business analysis

The grid disaster intelligence perception and emergency command system integrates early warning monitoring, typhoon monitoring, heavy rain and flood disaster warning, rain and snow freeze disaster warning, earthquake disaster warning, landslide disaster warning, emergency disposal function module, work exchange function module, public information function module, etc. to provide unified data interaction services, improve the accuracy and perception of various disaster warnings, take the power grid GIS platform as the basis, take Based on the grid GIS platform, with emergency command as the purpose and grid GIS as the data display carrier, it integrates grid environment, disaster prediction, disaster analysis and other resources with multiple calibers to complete real-time intelligent perception of grid disasters and emergency command of emergency repair.

The system integrates basic information such as power grid load, substations, transmission and distribution lines, distribution substations, towers, power users, early warning information, disaster express, disaster damage perception, weather, typhoon, earthquake, cloud map, radar, rainfall, landslide, etc., into GIS maps through data conversion and data analysis import. Through the integration of basic information of power grid with external environment information and emergency command information, it provides basic display data for real-time disaster awareness and emergency disposal.

The grid disaster intelligence perception and emergency command system includes two business scenarios: information maintenance and frontend display; different scenarios, providing different system interfaces and addressing the core issues of concern for different application scenarios. System Business Architecture The architecture of the system is shown in Fig. 7.4.

Information maintenance: this scenario is applicable to system maintenance personnel for basic information maintenance. The characteristic of this scenario is that it requires an accurate, timely and detailed understanding of the basic information of the power grid, early warning and monitoring information, equipment and facilities outage and recovery, and emergency repair force input. For this scenario, the design is intended to be realized by means of tabular display.

Frontend display: This scenario is applicable to the disaster damage perception and emergency disposal work. The characteristics of this scenario is that it requires a holistic, accurate, and intuitive understanding of the basic information of the power grid, disaster damage prediction and real-time disaster damage perception, and emergency disposal. In response to this scenario, this design proposes to use various charts

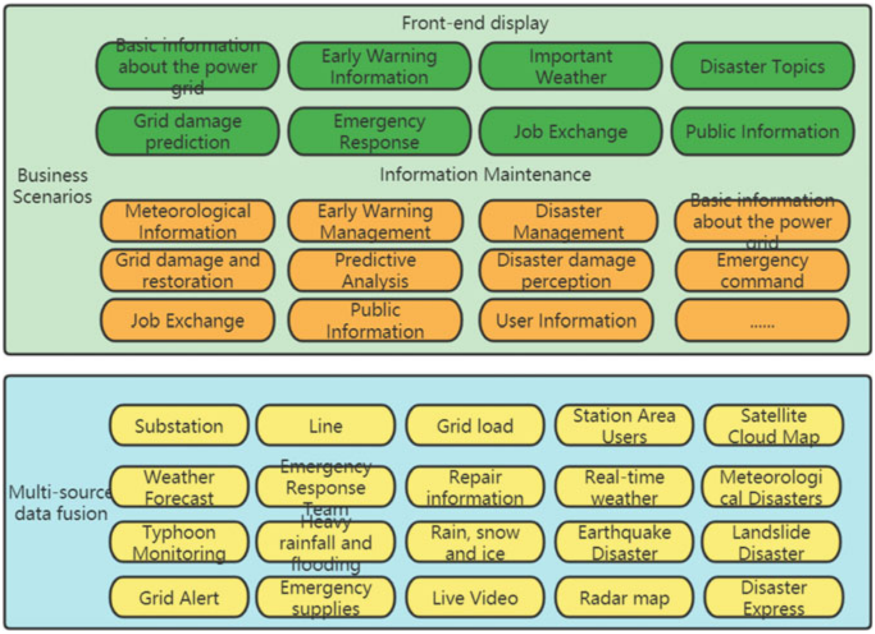


Fig. 7.4 System business architecture diagram

organically combined with the large screen of the emergency command center for comprehensive display.

2) Business Model

By integrating various disaster prediction models, the power grid disaster perception and disaster damage prediction system provides support for emergency command and emergency disposal. Through the system, you can view early warning monitoring information, typhoon monitoring information, heavy rainfall and flooding information, snow and ice information, earthquake information, landslide information, emergency disposal, work exchange, public information and other modules. The system business model is shown in Fig. 7.5.

7.1.3 System Non-functional Design

(1) Performance

System response time: transaction processing business, simple business response time ≦5 s, complex business response time ≦8 s; query business, simple query response time ≦3 s, comprehensive query response time ≦5 s; statistical analysis business, the average response time of real-time statistical business shall not exceed

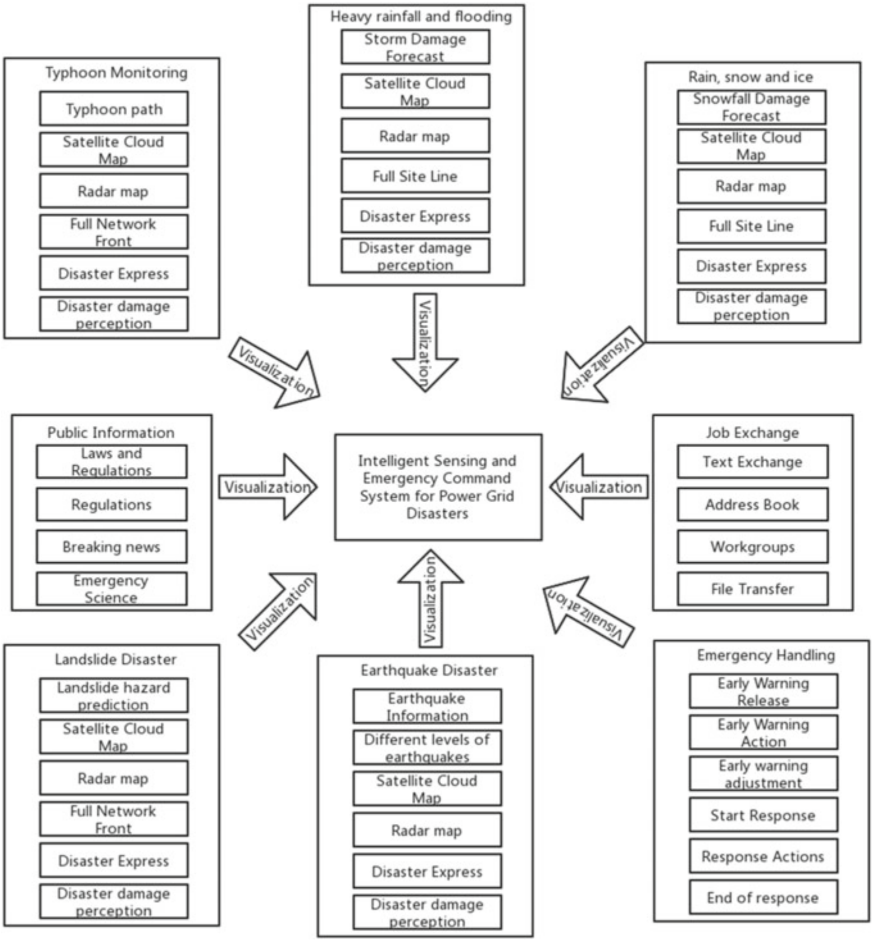


Fig. 7.5 System business model diagram

20 s; system business, 90% of the interface switching response time ≤3 s, the rest ≤5 s, receiving abnormal events, external process information response time The response time of receiving abnormal events and external process information is ≤5 s.

System throughput: transaction processing business, fast response class 1000 pcs/min, ordinary response class 600 pcs/min, batch processing class 200 pcs/min; query business, simple query class 1000 pcs/min, comprehensive query class 500 pcs/min; statistical analysis business, simple statistical analysis class 500 pcs/min, complex statistical analysis class 100 pcs/min; system class business, meet 300 pcs/min.

(2) Reliability

The whole system should be able to work continuously for 7 × 24 h without interruption, and if there is a fault, it should be able to alarm in a timely manner; Under the condition of running continuously for 2 h with the maximum number of concurrent users, the system runs smoothly and the business failure rate does not exceed 0.1%. The average CPU occupancy rate is less than 60%, and the memory occupancy rate does not increase significantly and the memory recovers its initial value after one hour. The system runs smoothly and the business failure rate does not exceed 0.1% when the maximum number of concurrent users is 40 percent for 8 h. The system runs smoothly, the business failure rate does not exceed 0.1%, the average CPU occupancy rate is less than 60%, the memory occupancy rate does not increase significantly and the initial value is restored after 1 h. The system has the ability to compensate for transactions.

The system should have automatic or manual recovery measures so that it can quickly resume normal operation in case of errors. When the software system fails, the automatic recovery time is <10 min and the manual recovery time is <1 h; the user concurrency is too large When the number of concurrent users is too large, the system should be prevented from crashing by consuming too many system resources; the average failure free rate of the system is >99.96%; the success rate of automatic data processing of the system is >99.96%.

(3) Scalability

The system adopts a modular design to achieve seamless integration of newly developed functional modules with existing functions and facilitate functional expansion. The system defines a unified process data interface, which facilitates access to existing information systems and information systems that may be accessed in the future. The system supports the scalability of data storage and can be extended with server clusters to achieve large scale data storage, query and analysis. The system supports scalability of data storage and can be extended with server clusters to realize largescale data storage, query and analysis.

7.2 Main Functions

7.2.1 System Function Development

Develop an intelligent perception and emergency command system for power grid disasters, to achieve grid disaster intelligence perception and emergency site information and visualization command in the absence of information, and effectively improve emergency command efficiency in disaster judgment and operation command. Realize intelligent mobile equipment, background equipment monitoring system, power emergency command system software and hardware integration, with onsite information collection, disaster management, and emergency command. It has the functions of onsite information collection, fusion analysis and prediction of disaster damage information, rapid information reporting, feature identification, remote real-time interactive command and so on. It provides technical support for emergency exercises, training and rescue operations.

The system allows you to view early warning and monitoring information, typhoon monitoring information, heavy rain and flooding information, rain and snow freezing information, earthquake information, landslide information, emergency disposal, work exchange, public information and other modules.

The weather warning information includes weather warning and internal warning, weather warning can be viewed by filtering conditions for 24, 48 and 72 h, and can also be viewed by filtering conditions for different levels of red warning, orange warning, yellow warning and blue warning, and can view the weather warning information of central weather station, provincial weather station, local city weather station and county weather station according to different issuance levels. You can view the weather warning information of central weather station, provincial weather station, local city weather station and county weather station according to different issuance levels; internal warning can view the warning information issued by different company levels, you can view the company headquarters warning, branch warning, provincial company warning, local city company warning and county company warning, you can also statistically display the number of different warning levels of all kinds of warnings, view the number of red warning, orange warning, yellow warning and blue warning of different levels of warnings.

Typhoon monitoring includes typhoon path, satellite cloud map, radar map, sitewide line, disaster express, disaster damage perception, where the typhoon path can view the current typhoon's real-time path, predicted path, typhoon wind speed, pressure, moving speed and other information, satellite cloud map can view the current satellite cloud map information, superimposed display satellite cloud map to help judge the current typhoon development trend, radar map can view the current situation. The whole site line can display the GIS station line information of the power grid, and the affected situation of substations, lines and users in the station area can be analyzed through the typhoon path and the predicted path, and the disaster damage situation of the typhoon development path can be predicted. The disaster damage perception is divided into disaster damage perception statistics and disaster damage perception details, and the current equipment disaster damage situation is judged intelligently through the images taken by drones.

Storm flooding includes storm damage prediction, satellite cloud map, radar map, sitewide line, disaster express and disaster damage perception, among which storm damage prediction can view the current rainfall area, effective rainfall amount, rainfall disaster probability and other information, satellite cloud map can view the current situation of satellite cloud map information, superimposed display satellite cloud map to help judge the current rainfall development trend, radar map can view the current situation of radar. The whole site line can display the GIS station line information, and the rainfall range and predicted rainfall can analyze the affected situation of substations, lines and station area users. The disaster damage perception is divided into disaster damage perception statistics and disaster damage perception details, and the current equipment damage situation is judged intelligently through the images taken by drones.

Snow and ice includes snowfall damage prediction, satellite cloud map, radar map, full site line, disaster express, disaster damage The snowfall damage forecast can view the current snowfall area, ice thickness, total load rate per unit length The satellite cloud map can view the current situation of satellite cloud information, superimposed display satellite cloud map to assist in judging the current snowfall development trend, radar map. You can view the current snowfall development trend, radar map can view the current situation of the radar map information, superimposed display radar map The whole site line can display the grid GIS station line information, through the snowfall range and predicted snowfall can analyze the impact of substations, lines and station users, and the disaster damage express is divided into information express and danger express. The information report is mainly through the fixed information template to report the current disaster damage information, and the danger. The disaster damage perception is divided into disaster damage perception statistics and disaster damage perception details. The disaster damage perception is divided into disaster damage perception statistics and disaster damage perception details, through the images taken by drones, to intelligently determine the current equipment damage situation.

Earthquake information can be filtered to view the information of 3, 7 and 15 days, and can also be filtered to view the information of earthquakes below 4.0, 4.0 6.0 and above 6.0, and the earthquake express can view the current earthquake area (including latitude and longitude information), forecast equipment damage information (including substation and tower information), satellite cloud map can view the current satellite cloud map information and superimposed satellite cloud map to assist in judging the current weather conditions, and radar map can view the current satellite cloud map information and superimposed radar map to assist in judging the current weather conditions. Satellite cloud map can view the current satellite cloud map information, superimposed on the satellite cloud map to help determine the current weather conditions, radar map can view the current radar map information, superimposed on the radar map to help determine the current weather development trend, the whole site line can display the grid GIS station line information, through the earthquake information can The disaster damage express is divided into information express and danger express, information express is mainly through the fixed information template to report the current disaster damage information, danger express is mainly through the mobile terminal to achieve rapid reporting of onsite danger, disaster damage perception is divided into disaster damage perception statistics and disaster damage perception details, through the disaster damage perception is divided into disaster damage perception statistics and disaster damage perception details, and the current disaster damage of the equipment is judged intelligently by the images taken by the drone.

Landslide disaster includes landslide damage prediction, satellite cloud map, radar map, full site line, disaster express, disaster damage. The landslide damage prediction can view the current rainfall landslide area, landslide disaster probability and other information, and satellite cloud map can view the current satellite cloud map information. Satellite cloud map can view the current satellite cloud map information, superimpose the satellite cloud map to assist in judging the current rainfall development trend and analyze the possibility of landslide, radar map can view the radar map information under the current situation, and superimpose the radar map to help judge the current rainfall. The radar map can view the radar map information under the current situation, superimpose the radar map to assist in judging the current rainfall development trend, and assist in analyzing the landslide situation. The GIS station line information of the power grid can be displayed, and the landslide caused by rainfall can analyze the affected situation of substations, lines and station area users. The disaster damage express is divided into information express and danger express, information express is mainly through the fixed information template to report the current disaster damage information, danger express is divided into information express and danger express. The information report is mainly through the fixed information template to report the current disaster damage information, and the danger express is mainly through the mobile terminal to realize the rapid report of onsite danger. The disaster damage perception is divided into disaster damage perception statistics and disaster damage perception details, and through the images taken by drones, we can intelligently judge the current damage The damage perception is divided into damage perception statistics and damage perception details.

Emergency disposal starts emergency response, carries out emergency disposal, and the system pushes out the division of work of each department to clarify the responsibilities of each department, and be able to view the progress of emergency response, real-time tracking and display of information at various stages such as issuing warning, warning adjustment, starting response, response adjustment, etc. The system combines the "Emergency Response Work Rules for Electricity Emergencies" with the event scenario topic, and automatically pushes the emergency event command system and response flow chart. It makes the staff involved in emergency response have clear knowledge of the command system and response process to ensure that the emergency disposal work is carried out smoothly. For the disposal of emergency events, the system automatically generates the disposal process by combining the emergency plan and departmental disposal plan, automatically pushes the emergency disposal work tasks, and automatically marks the task status according to the completion situation to view the overall progress of the event and the completion of individual tasks.

Emergency communication list for work communication: Automatically create a special event emergency team working group based on the emergency plan, and view contact information. Work communication: Communicate with emergency response personnel at all levels in terms of graphics, text, audio and video work.

The public information module contains public information data sources, public information data classification preview, laws, regulations and rules, emergency related situations, emergency science related knowledge, etc.

Fig. 7.6 UAV background system operation interface

7.2.2 System Function Display

Through the business composition of the power grid disaster intelligence perception and emergency command system, and the visualization model to understand the information of all aspects of the system, we design and develop the power grid disaster intelligence perception and emergency command system. Through the visualization model of the information, we design and develop the grid disaster awareness and emergency command system:

(1) Unmanned Aerial Systems

An overview of the operating interface of the UAV backend system is shown in Fig. 7.6.

The functional architecture of the system is illustrated in Fig. 7.7.

A schematic of the system data architecture is shown in Fig. 7.8.

1) Main head view

It performs real-time monitoring of the current situation in the execution of the flight mission or handheld mobile terminal in the execution of line inspection, and the relevant coordinate positioning and view analysis of the relevant information.

The module realizes the functions of real-time collection of site information, monitoring the status of the UAV body and the site environment. Including flight data such as the altitude of the flight.

2) Map view

The map application module supports distance and area calculation; the profile tool is set up to facilitate users to view the terrain in the field to facilitate the user to view the terrain in the field; to set the photo evidence function to record the latitude and longitude of the photo for the user to take photos in the field to facilitate users to record the walking route in the field and share it with others, we have set up a tool to record the walking track and draw a sketch with the map as the background.

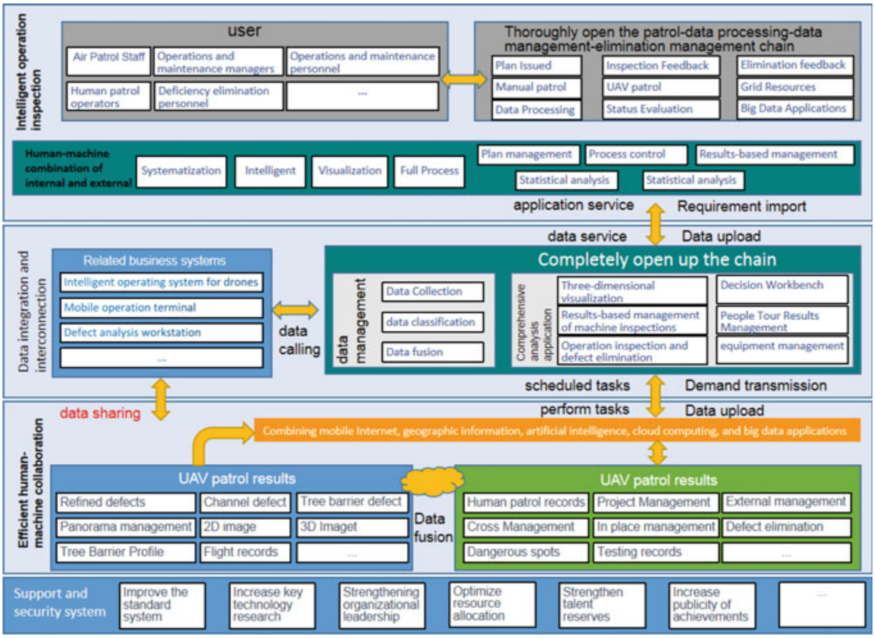


Fig. 7.7 Overall system architecture

The GPS and GIS geographic technology of transmission line intelligent inspection system includes space, ground and receiving end, with functions of omnipotence, global and all weather positioning, which can accurately locate towers and personnel, record the trajectory of inspection and provide accurate navigation information, while the differential data can also realize the spatial GIS geographic information display. It also provides accurate high-level data calculation and high precision differential data for UAV autonomous cruise. Mainly combined with GIS map data, the 3D location of the transmission line's towers, ground attachments, and alignment can be edited by means of layers. The topography of the corridor, including the location information and direction of the power grid, as well as the location data such as personnel patrol trajectory and crossover, can be overlaid and presented in the It can also be used for measuring, editing and pointing on the GIS map. The platform monitors in real time the current flight task or handheld mobile terminal in the execution of. The platform can monitor the current flight task or handheld mobile terminal performing line inspection in real time, and perform coordinate positioning and view analysis on the relevant information.

3) HUD control

Dashboard for drone control. Displays the flight parameters, attitude information, and navigation information of the UAV, projected onto the on the perspective mirror directly in front of the operator's field of view, so that when the pilot maintains a

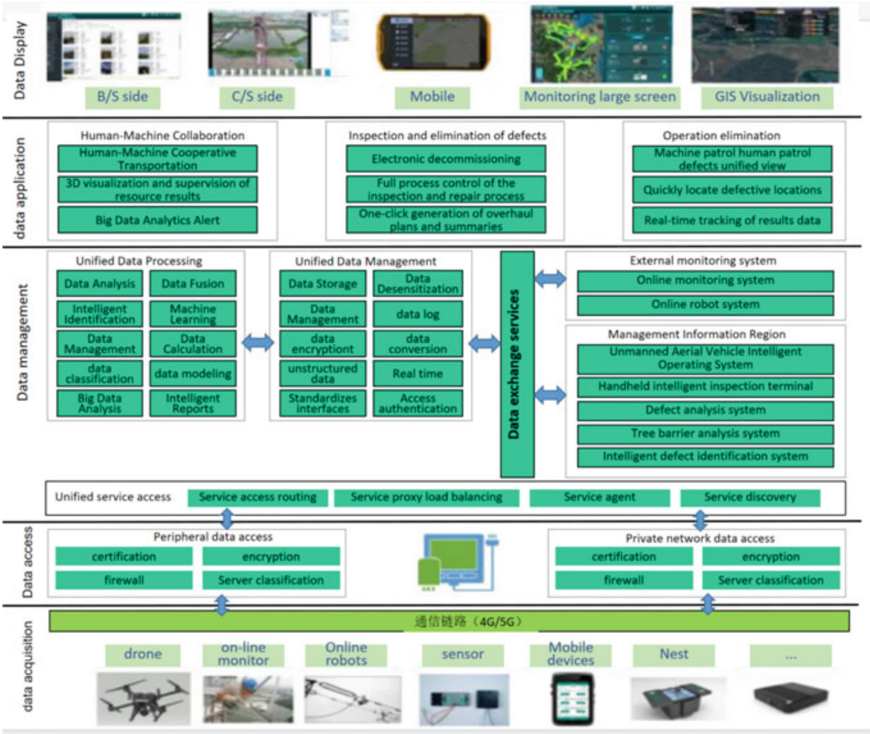


Fig. 7.8 Data Architecture

level view, he can take into account the instrumentation in the same field of view parameters and the external visual reference in the same field of view.

4) Flight control

The Fine Patrol module has three patrol types: manual mode, learning mode, and patrol mode. Select manual mode, the UAV is manually controlled by the aviator to shoot the inspection point.

When manual mode is selected, the aviator manually controls the drone to shoot the inspection point; when learning mode is selected, the system will automatically record the latitude and longitude of the shooting point and the gimbal angle after the aviator manually controls the drone to shoot the inspection, which will provide data support for the next automated inspection by the drone.

When selecting the learning mode, import the tower file onto the map, long press any tower icon, click on one button navigation, enter the altitude, and the drone will automatically take off above the selected tower. Click on Start Learning, and the system will start recording the drone's photo position. After the learning is completed, click End Learning in the lower right corner, after successful learning, the icon of the tower will turn green.

When selecting the inspection mode, click on the one key navigation or automatic inspection after inputting the height, so that the drone automatically flies to the pole tower overhead, or by manually controlling the drone to fly over the tower after the automated inspection. In addition to single base tower automatic inspection, you can also select multiple towers that have been studied together for inspection.

By clicking on "Execute Mission", the UAV will begin automated inspection operations, which are used in conjunction with RTK.

5) UAV rudder volume information

Show the control information of specific drone rudder amount, including the rudder angle of front and back, left and right, and up and down, left and right rotation.

6) UAV data

This includes information on the GEO safety system for the drone and the apron, as well as monitoring the power usage of the drone and showing the number of nearby satellites and magnetic field strength. Traditional drone inspection is limited by battery life, usually only about 20 min of flight, the drone's flyer needs to follow the drone synchronized movement, affecting the flight efficiency. For this reason, we have conducted research in two directions, one is to modify the aircraft, mainly in the direction of battery life, and the other is to solve the limitations of relying on personnel. To this end, the "station-station" UAV operation mode was born. The so-called "station-station" refers to connecting the channels between two substations, allowing the drone to fly the entire route, recording the pause points in each route, that is, the GPS position of each tower, issuing instructions for the drone to automatically take photos, and then placing machine nests in the two substations, allowing the drone to automatically return to the nest for charging after flying, and the entire process is automatically completed. Through "station to station" automatic inspection, the constraints of operation and maintenance personnel on site have been liberated, greatly improving the flight efficiency of unmanned aerial vehicles.

7) Background function module division

See Table 7.1 for a list of backend functional modules.

a) Decision Analysis Desk

It display core basic and business data in the form of charts, statistics, summaries, icons, etc., real-time statistics of the number of aerial flights on the day, the number of handheld logins, the length of aerial flight lines, the number of registered towers in place, the mileage of special patrols, the machine patrol operations for the month including operators, the number of aerial flights, the length of lines, the mileage of aerial flights, as well as the number of tree barriers, channels, the number of defects found by fine patrols and the number of treatment; it shows the execution status of tree barriers, channels, human patrols City, human patrol three span, human patrol no-fly zone, temporary refinement patrol and other cycle patrol plan, and you can click to view the implementation of specific lines to complete the degree; it also

Table 7.1 Backend function module division

Secondary function module	Tertiary menu
Decision analysis desk	Decision analysis desk
Three-dimensional visualization	Layer management
	Adding layers
	Flight replay
	Real-time monitoring
	Other functions
Scheduled task management	Weekly inspection plan
	Cycle execution management
	Work order management
Results-based management of machine inspections	Channel defect management
	Fine-tuned defect management
	Tree barrier defect management
	Panorama management
	Two-dimensional image management
	Three-dimensional image management
	Tree barrier profile management
Results-based management of machine inspections	Flight history
People tour results management	Temporary notice
	Human patrol defect management
	Project management
	Special file management
	Cross information management
	Cross audit management
	Infrared temperature measurement management
	Cross information change management
	Hazardous point management
	Grounding resistance management
	Ice thickness management
	Zero value detection management
	Attendance management
	Transmission manual management
	Patrol history management

(continued)

Table 7.1 (continued)

Secondary function module	Tertiary menu
	Online personnel list
Defect management	Undistributed defect management
	Distributed defect management
	Defect-free management
	Return defect management
	Eliminated defect management
Grid resource management	Line management
	Tower management
	Tower picture management
	Tower change management
	Special area management
	Common tower management
	Tower model management
	Tower height change management
	Line wire type management
	Transmission line channel property management
	Pole learning data
Grid resource management	Inventory management
	Maintenance management
	End-of-life management
Equipment management	Drone management
	Terminal management
	UAV type management
Statistical reports	Line defect statistics report
	Defects and hazards statistics
	Equipment defects
	Inspection operation list
	Attendance statistics report
	Crossover statistics
	External breakage statistics
	Work content statistics
	Machine patrol operation statistics
	Weekly schedule summary report
Permission management and system administration	Permission management
	System administration

includes different annual summary analysis of defects, special file statistics, bird's nest thematic map.

b) 3D visualization

Mainly combined with GIS map data, can be edited by way of layers, the transmission line tower 3D location, ground attachment, corridor topography, including power grid location information, direction, and personnel inspection track, crossover and other location data overlay presentation, and can be measured on the GIS map, editing, point selection function, but also can open the flight monitoring and human patrol monitoring, platform real-time The platform monitors the current situation of executing flight tasks or handheld mobile terminals in executing line inspection, and performs coordinate positioning and view analysis of relevant information.

c) Plan task management

Plan management is the source of promoting the whole operation and maintenance work, and the difference of the line condition determines the need to develop different plan strategies for the line. Plan task management requires flexible customization of various plan tasks, including periodic inspection tasks, detection tasks, special operation mode inspection tasks, and operation tasks during the power supply period. It can also track the execution of the entire plan, provide timely warnings and reminders, and manage the completion of inspection in detail, supervise the operation and maintenance control work of each team.

d) Machine patrol results management

Management of all UAV data generated a series of results, including channel defects, refinement defects, tree barrier defects; panoramic map, 2D images, 3D images, tower gear distance profile and flight history browsing and other functional modules; uploaded 2D images and 3D images can be displayed in the 3D visualization, and the specific results can be converted into report data functions, as well as 2D and 3D image management and defect data sources formed.

e) Man patrol result management

Collect all daily frontend data sources, including temporary notification, human patrol defect records, project data management, special file management of external breakage, crossover information update, inspection data management, personnel in place records, track management, online terminal situation and other information, and can facilitate managers to instantly view real-time data, statistical analysis of personnel work, results export and other functions.

f) Defect management

Summarize all defect hidden danger records, confirm and grade defects based on defect standards. The defect level is classified into three categories: general, serious, and critical. The defect system support to achieve the front-end defects verification, modification, deletion, and other operations. At the same time, the defect library is available to satisfy the requirement of filtering, exportation, analyzation, and statistics according to certain filtering conditions.

g) Grid resource management

Management of all line towers, conductors, insulators, fixtures, ancillary facilities, cables, crossover accounts, places of ownership, district power supply office, tower location, parameters, photos, history, grid resources should be easy to manage, timely synchronization, accurate visual characteristics. The grid resources should be easy to manage, timely synchronization, accurate visualization and other characteristics.

h) Equipment management

Manage all drones and patrol terminals, intelligent devices, etc. in the transmission center, including the model, acquisition time, equipment management personnel, management team, positioning of the device, maintenance records, etc.

i) Statistical Management

Customized export of various results and table data, allowing for free selection of filtering conditions and customized output of results, facilitating management personnel to view statistical analysis.

j) Permission Management and System Management

This module is the configuration portal for all users, permissions, departments and roles, and also manages data dictionaries, system parameters, wire types, defect libraries, hidden danger libraries and cross libraries. system parameters, conductor type, defect library, hidden danger library, cross library, also can view login log, operation log, system exceptions, and monitor server resources.

(2) UAV intelligent inspection system architecture

The UAV can carry specific equipment according to the different inspection tasks, and can also carry visible light, infrared thermal imager, ultraviolet imager, laser and electromagnetic detection equipment at the same time to conduct a comprehensive inspection of the substation. In the inspection process of the tower, you can choose to carry only video and photo equipment, and the drone with autonomous flight capability flies according to the automatically generated road force, during which it takes photos and records videos to obtain information about the surrounding environment and the power tower, and transmits pictures back to the ground station in real time, and then analyzes the pictures through manual recognition or machine learning methods to determine which components have safety hazards and dispatches and the staff will be dispatched in time to eliminate them. Multirotor drones are used in the inspection of towers and substations because of their flexible mobility and hovering. Among them, the schematic diagram of the intelligent inspection system of substation drones is shown in Fig. 7.9.

With the deeper application of robotics in substations, more robots of different functional types will be involved in various tasks of substations. Multirobot collaboration can not only cope with complex and changing application scenarios, but also efficiently integrate existing resources, give full play to the advantages of various robots, reduce development costs, and shorten the time from R&D to application. In

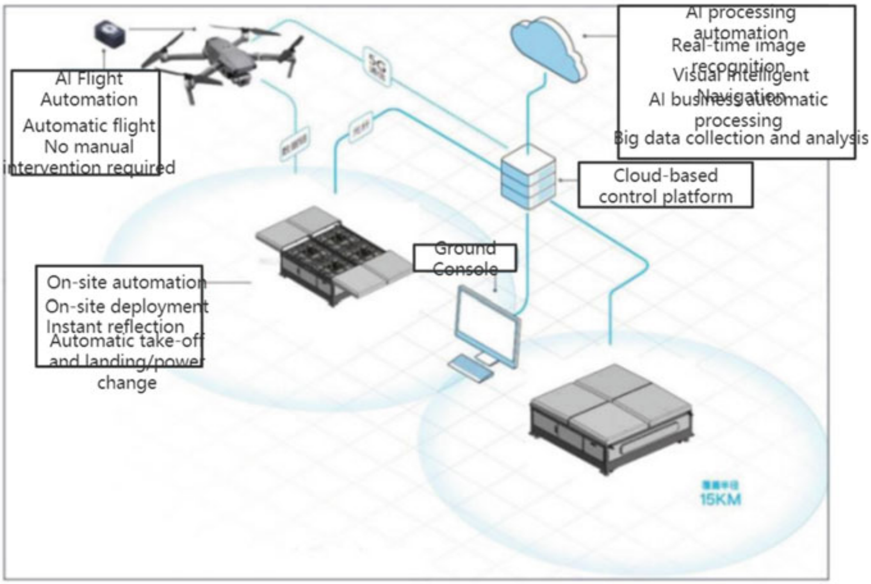


Fig. 7.9 Substation UAV intelligent inspection system schematic diagram

order to ensure that each robot can complete its own division of labor in an accurate and orderly manner, a unified multirobot joint management platform needs to be established. All robots are managed and data interacted with one statistical platform, so that robots involved in the same task use completely centralized motion planning, i.e., a centralized planner plans the motions of all robots so that the motions between them do not interfere with each other, and thus a deep learning-based architecture for intelligent inspection systems for drones can be established, as shown in Fig. 7.10.

At present, the automatic inspection function of the drone has been completed, and the flight route waypoints can be marked on the GIS map. The UAV can carry out automatic inspection of transmission lines according to the preset routes and carry out rapid disaster damage identification, and has now achieved real-time image, video

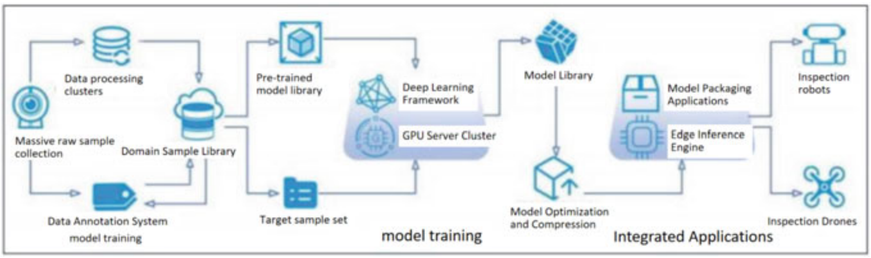


Fig. 7.10 Deep learning based UAV intelligent inspection system architecture

and drone parameters are transmitted back to the frontend page, and the drone can remotely carry out line inspection tasks. The gimbal control and visible light/infrared light lens switching can be carried out remotely for the drone carrying out inspection tasks, as shown in Fig. 7.11.

(3) UAV disaster damage detection intelligent analysis system architecture

The UAV inspection + AI intelligent processing program is a fully automated solution, providing one-stop service from the frontend UAV flying patrol to the backend AI identification. This solution combines artificial intelligence technology with power patrol business through conceptual innovation, and empowers traditional industry through AI to enhance new industrial dynamics; followed by technological innovation, which introduces migration learning into the algorithm framework and target identification framework for fault determination to improve accuracy, and

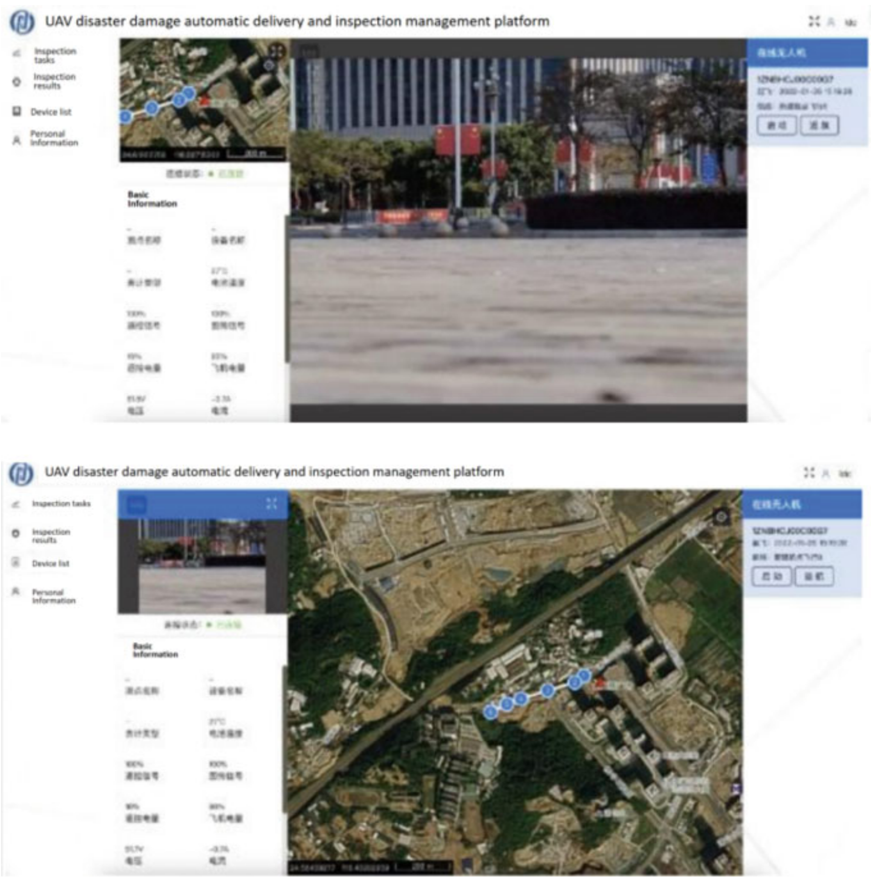


Fig. 7.11 Automatic inspection by drone

through continuous implementation on the ground, the accumulation of image data from flying patrol, after cleaning and processing, forms effective data assets.

As the name suggests, transfer learning is to transfer the model parameters that have been learned and trained to the new model to help train the new model. Considering that most of the data or tasks are correlated, transfer learning can share the learned model parameters (which can also be interpreted as the knowledge learned by the model) to the new model in Å a way to speed up and optimize the learning efficiency of the model without starting from scratch, as most networks do. (starting from scratch, tabula rasa).

Adopting B/S architecture to integrate the monitoring backend of spring cloud microservice system, which is in line with the development trend of information construction of national network and can be easily extended to the system. It is easy to expand the system to cope with the demand of big data and concurrency. The project is simple and lightweight to deploy, and can collect and analyze the disaster damage data of each provincial network quickly. It can provide powerful data support for disaster relief and anti-disaster Support.

In the field of UAV grid patrol, it can make full use of the massive data accumulated in other fields and the models already built to reduce the preliminary workload and difficulty. Firstly, AI modeling is carried out through massive source data (e.g., pictures of wire extraction on power lines), and the faster RCNN network is used to generate the original data model. The original data model is combined with the wire extraction characteristics of the power grid, and the target data model is generated by migration learning algorithm.as shown in Fig. 7.12.

(4) Early warning monitoring includes weather warning and internal warning
1) Weather warning can view various kinds of weather warning information in different time periods of 24, 48, and 72 h by filtering conditions, and can also view different levels of red warning, orange warning, yellow warning, and blue

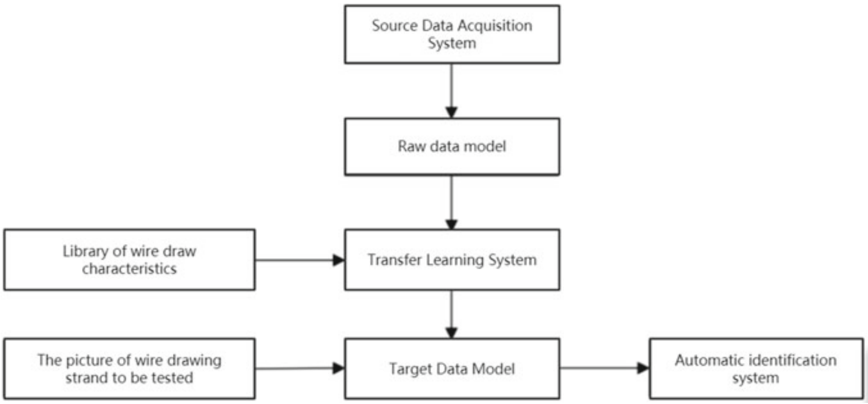


Fig. 7.12 Objective data model for automatic identification and detection of the drawing image of the wire to be detected

Fig. 7.13 Systematic weather warning

warning by filtering conditions, and can view weather warning information of central weather station, provincial weather station, local city weather station, and county weather station according to different issuance levels. As shown in Fig. 7.13.

2) Internal warning can view the warning information issued by different company levels, and can view the company headquarters warning, branch warning, provincial company warning, municipal company warning, county company warning, etc. You can view the warning information issued by different company levels, including headquarters warning, branch warning, provincial company warning, local and municipal company warning, county company warning, and also can statistically display the number of different warning levels. The number of warnings of different levels can be displayed statistically, and the number of warnings of different levels of red, orange, yellow and blue warnings can be viewed. The number of warnings of different levels can be displayed. As shown in Fig. 7.14.

(5) Typhoon monitoring includes typhoon path, satellite cloud map, radar map, full site line, disaster express, disaster damage perception.

1) Typhoon path can view the real-time path and forecast path of the current typhoon, typhoon wind speed, pressure, moving speed and other information, satellite cloud map can view the current satellite cloud map information, radar map can view the current radar map information; as shown in Fig. 7.15.
2) The whole website can display the GIS station line information of the power grid, and through the typhoon passing path and the predicted path can analyze the affected situation of substations, lines and station users, and can predict the disaster damage in the path of typhoon development; This is shown in Fig. 7.16.
3) Disaster Express is divided into Information Express and Danger Express, with Information Express mainly reporting current disaster information through fixed

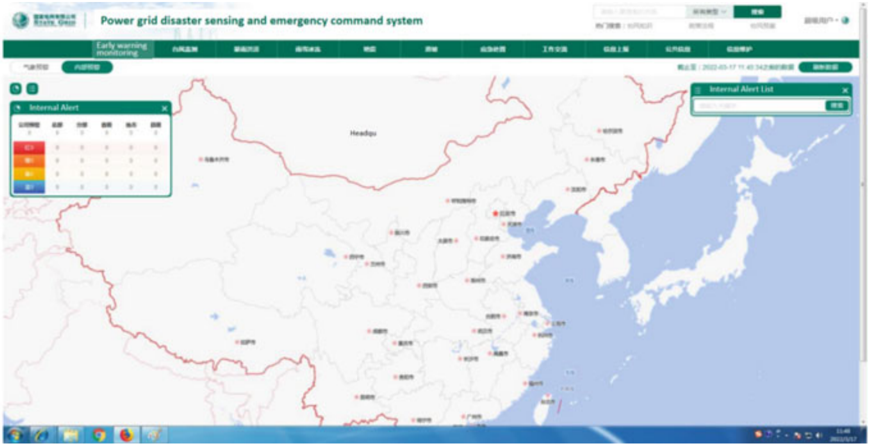


Fig. 7.14 System internal warning

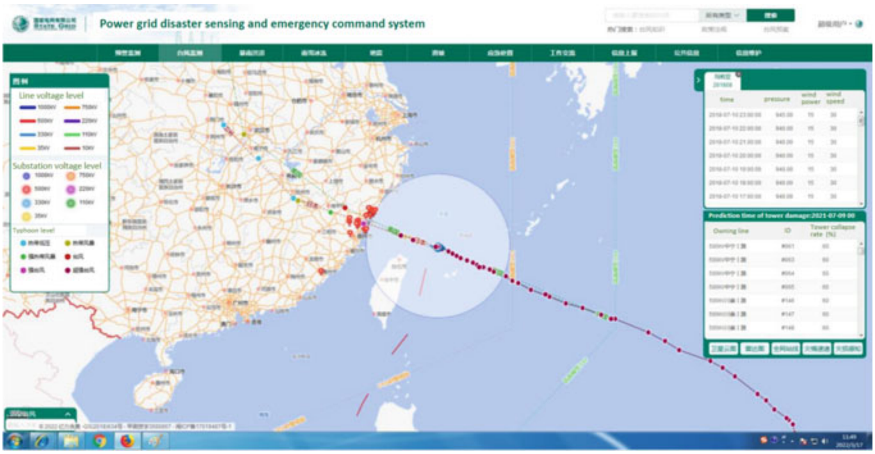


Fig. 7.15 Systematic typhoon path

information templates and Danger Express mainly realizing rapid reporting of onsite danger through mobile terminal; as shown in Fig. 7.17.

4) Disaster damage perception is divided into disaster damage perception statistics and disaster damage perception details, and through the images captured by drones, the current equipment's disaster damage situation is intelligently judged. As shown in Fig. 7.18.

(6) Storm flooding includes storm damage prediction, satellite cloud map, radar map, full site line, disaster express, and Disaster damage perception.

1) Storm damage prediction can view the current rainfall area, effective rainfall amount, rainfall disaster probability and other information, satellite cloud map

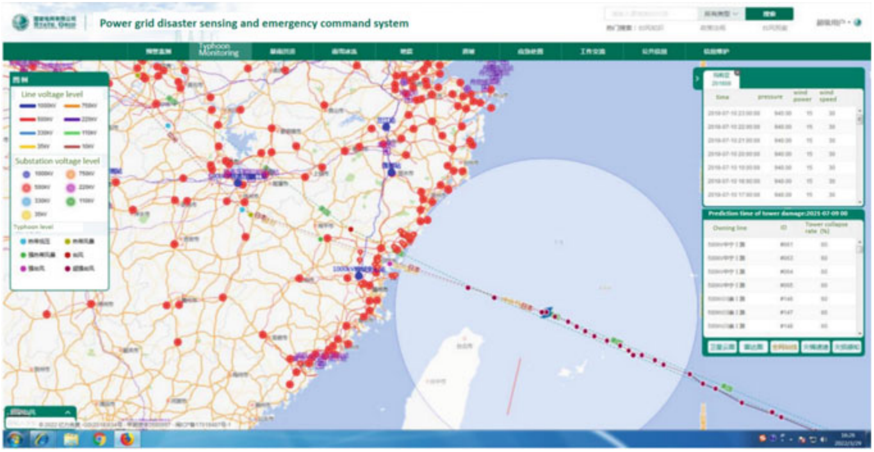


Fig. 7.16 Typhoon disaster full site line map

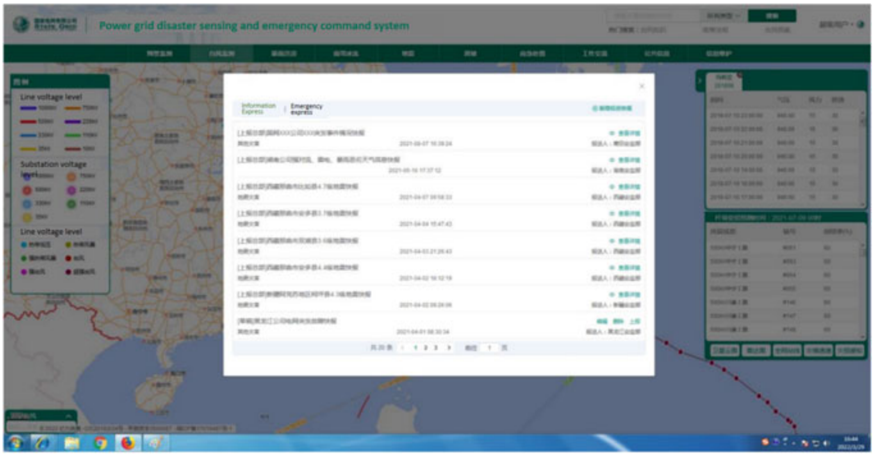


Fig. 7.17 Typhoon damage express simulation

can view the satellite cloud map information in the current situation, and radar map can view the radar map information in the current situation; as shown in Fig. 7.19.

2) The whole site line can display the information of the grid GIS station line, and the affected situation of substations, lines and station area users can be analyzed by the rainfall range and predicted rainfall; as shown in Fig. 7.20.
3) Information Express mainly reports current disaster damage information through a fixed information template, and Danger Express mainly through the mobile terminal to achieve rapid reporting of onsite danger, and disaster damage perception through the images taken by drones. The damage perception uses the

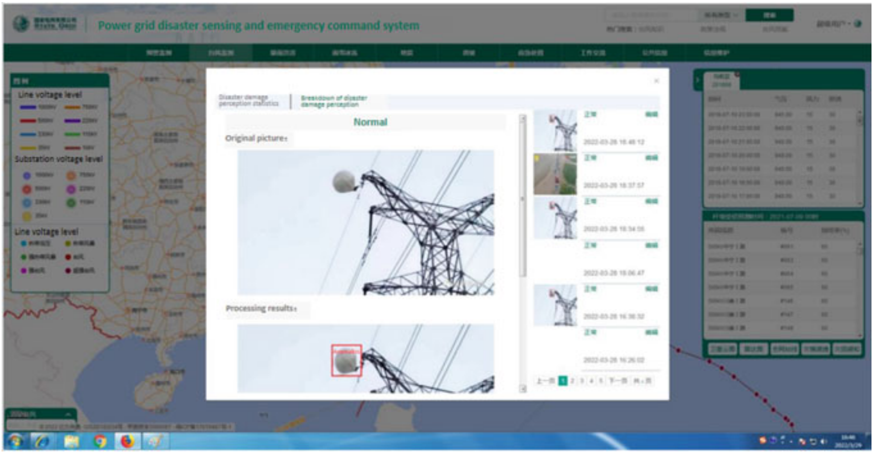


Fig. 7.18 Typhoon damage perception

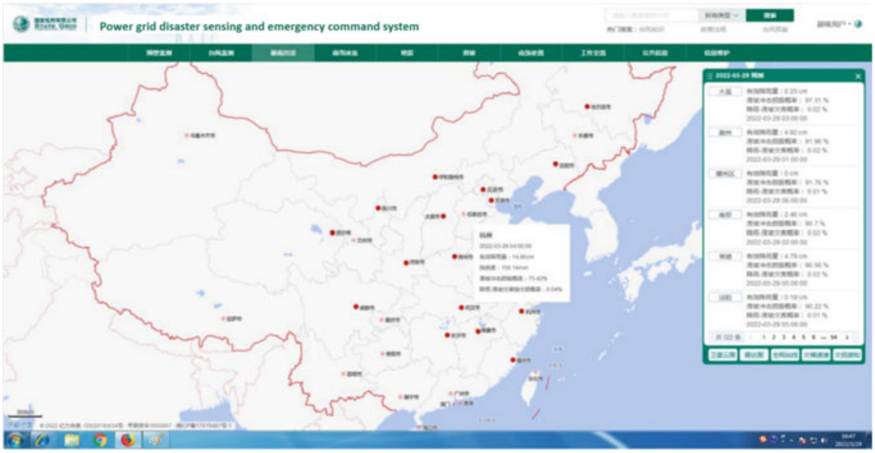


Fig. 7.19 Systematic storm flooding map

images taken by the UAV to intelligently determine the current damage situation of the equipment. As shown in Fig. 7.21.

(7) Rain, snow and ice includes snowfall damage prediction, satellite cloud map, radar map, full site line, disaster express, and disaster damage perception.

1) Snowfall damage prediction can view the current snowfall area, ice thickness, total load rate per unit length and other information. The satellite cloud map can view the current satellite cloud map information, and the radar map can view the current radar map information. The satellite cloud map can view the current situation of the satellite cloud map information, radar map can view the current situation of the radar map information; as shown in Fig. 7.22.

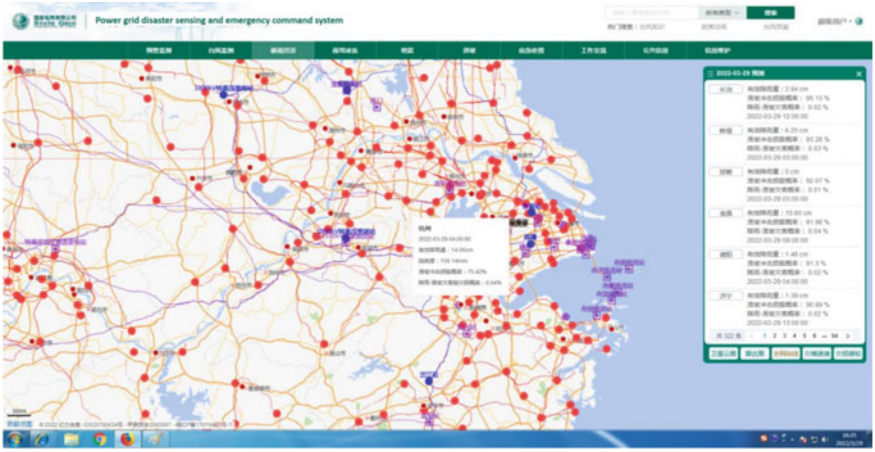


Fig. 7.20 Stormwater full site line map

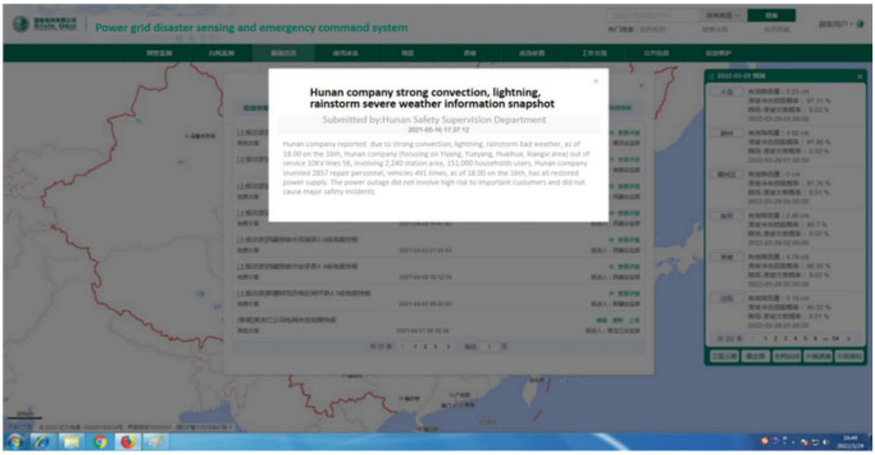


Fig. 7.21 Stormwater information snapshot

2) The entire site line can display GIS station line information of the power grid, and analyze the impact of substations, lines, and users in the substation area through the snowfall range and predicted snowfall conditions;; as shown in Fig. 7.23.
3) Disaster Express is divided into Information Express and Danger Express. Information express mainly reports the current disaster damage information through fixed information templates. Dangerous situation express mainly realizes the rapid submission of on-site dangerous situations through mobile devices. Disaster damage perception is divided into disaster loss perception statistics and disaster loss perception details. Through the images captured by drones, the

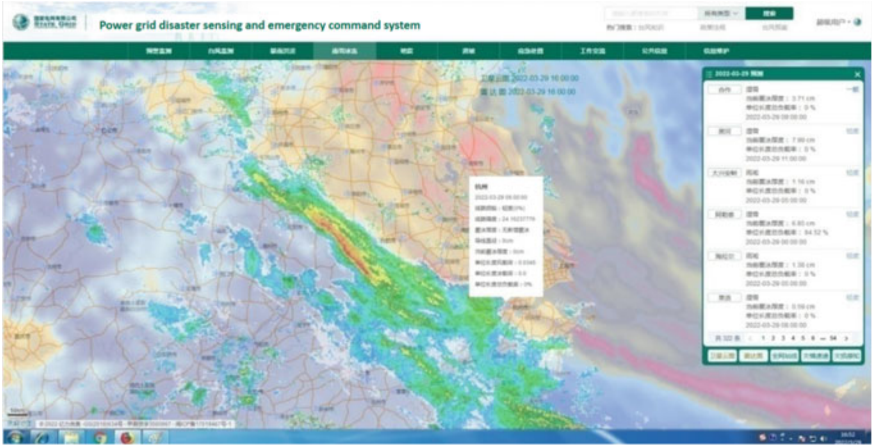


Fig. 7.22 System rain, snow and ice map

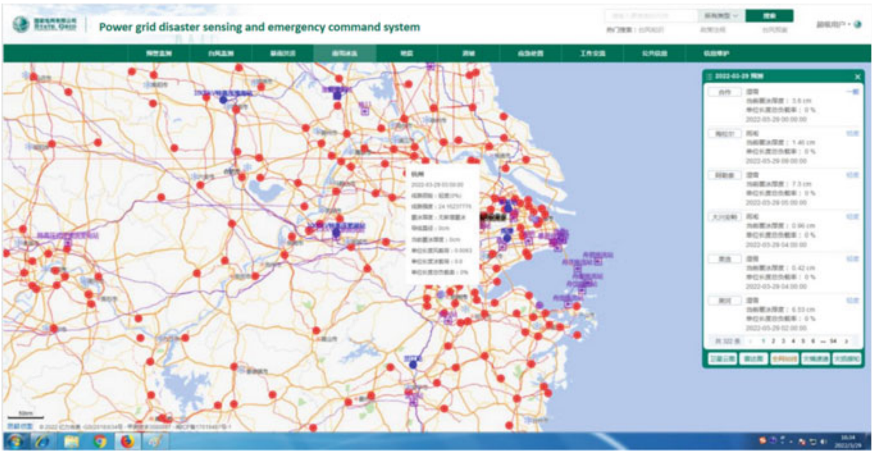


Fig. 7.23 Rain and snow freeze full site line map

current equipment's disaster damage situation is intelligently judged. As shown in Fig. 7.24.

(8) Earthquake information can be viewed by filtering conditions for 3 days, 7 days, 15 days, and 4.0, 4.0 6.0, 6.0 or above. The radar map can view the radar map information under the current situation, and overlay the radar map to assist in judging the current weather trend. The development trend is shown in Fig. 7.25.

The whole website line can display the information of the power grid GIS station line, and the earthquake information can analyze the substation, line, and the disaster damage express is divided into information express and danger express. Information

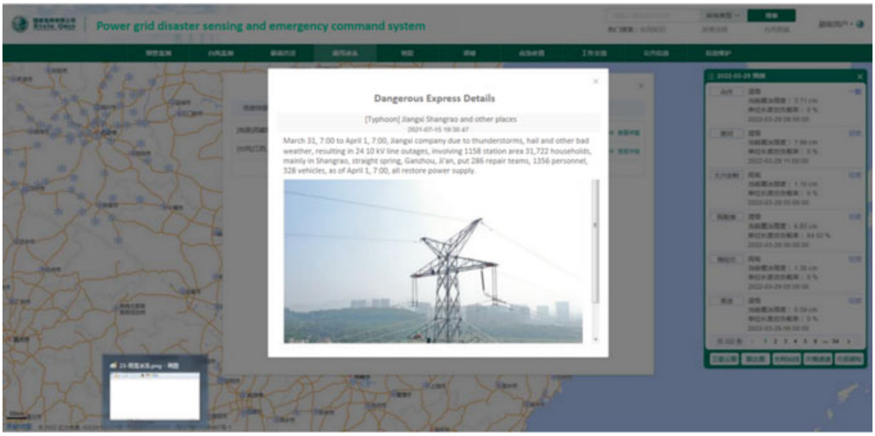


Fig. 7.24 Rain, snow and ice danger express

Fig. 7.25 System seismic information diagram

express mainly reports current disaster loss information through fixed information templates, and danger express mainly achieves rapid reporting of on-site danger through mobile devices. Disaster loss perception is divided into disaster loss perception statistics and disaster loss perception details, intelligent judgment of current equipment damage through drone captured images. As shown in Fig. 7.26.

(9) Landslide hazards include landslide damage prediction, satellite cloud map, radar map, full site line, disaster situation express delivery, and disaster perception.

1) Landslide damage prediction can view the current rainfall landslide area, landslide disaster probability and other information. Satellite cloud satellite cloud

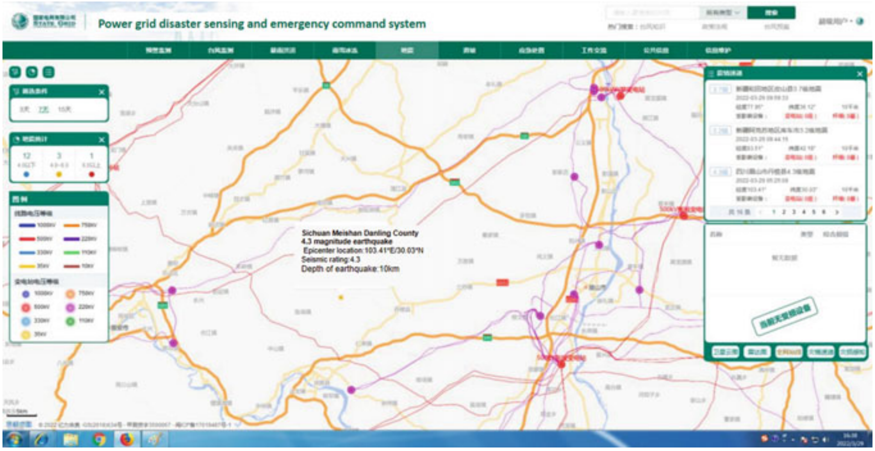


Fig. 7.26 Seismic hazard full site line map

map can view the current satellite cloud map information, superimpose the satellite cloud map to help judge the current rainfall development. The satellite cloud map can view the information of satellite cloud map under the current situation, and superimpose the satellite cloud map to help judge the current rainfall development trend and analyze the possibility of landslide. The radar map can view the radar map information under the current situation, superimpose the radar map to assist in judging the current rainfall development trend, and assist in analyzing the landslide situation; as shown in Fig. 7.27.

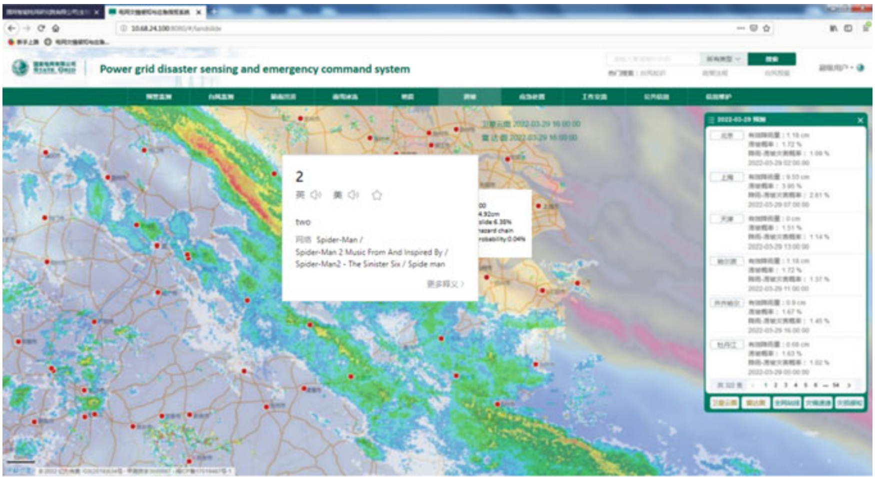


Fig. 7.27 Systematic landslide hazard map

2) The whole site line can display the information of the GIS station line of the power grid, and analyze the impact of landslides caused by rainfall on substations, lines, and users in the substation area. Disaster loss delivery is divided into information express and dangerous situation express. Information express mainly submits current disaster loss information through fixed information templates, and dangerous situation express mainly achieves rapid on-site reporting of dangerous situations through mobile devices. The disaster damage perception is divided into disaster damage perception statistics and disaster damage perception details, and the current disaster damage of the equipment is judged intelligently by the images taken by the UAV. As shown in Fig. 7.28.

(10) Emergency response is initiated, emergency response is carried out, and the system pushes the work division of each department to clarify their responsibilities.
1) View the progress of the emergency response, the release of early warning, warning adjustment, start response, response adjustment and other stages. The information is tracked in real time. As shown in Fig. 7.29.
2) By combining map display, it is possible to view the emergency response situation of relevant key units and areas, as well as real-time information on personnel positions, to ensure the smooth progress of emergency response work. As shown in Fig. 7.30.
3) By combining map display, you can view the location and affiliated unit information of the emergency warehouse, and view various emergency resource related information through the emergency warehouse. As shown in Fig. 7.31.
4) Through the emergency team data access, you can view the location information, personnel and professional information of the emergency team in real time through the system. information, professional information, etc., to conduct

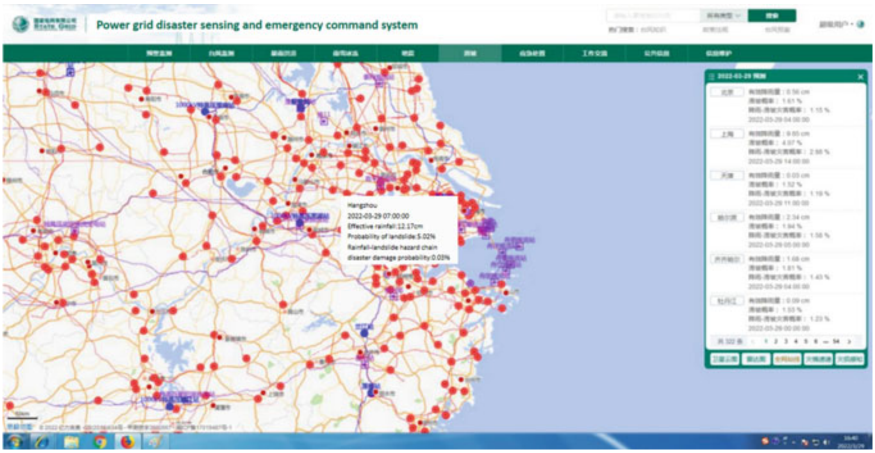


Fig. 7.28 Landslide hazard sitewide map simulation

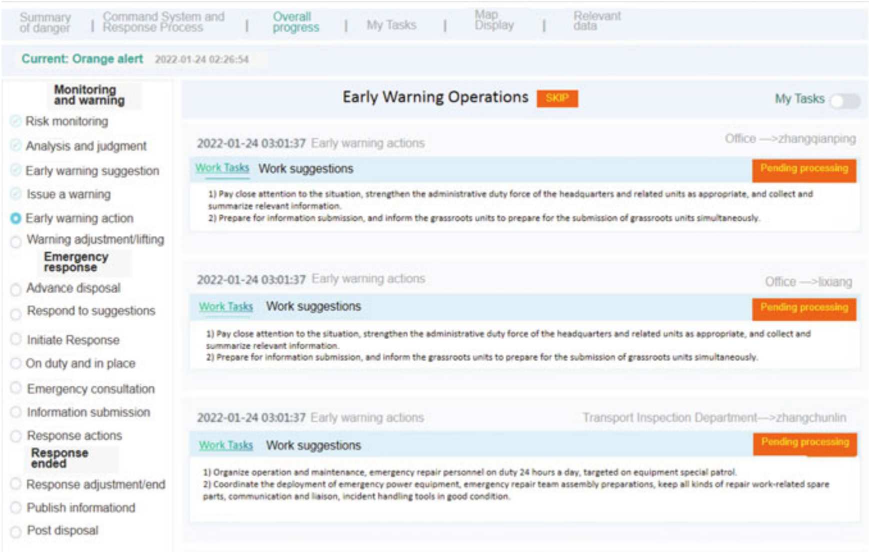


Fig. 7.29 System emergency response diagram

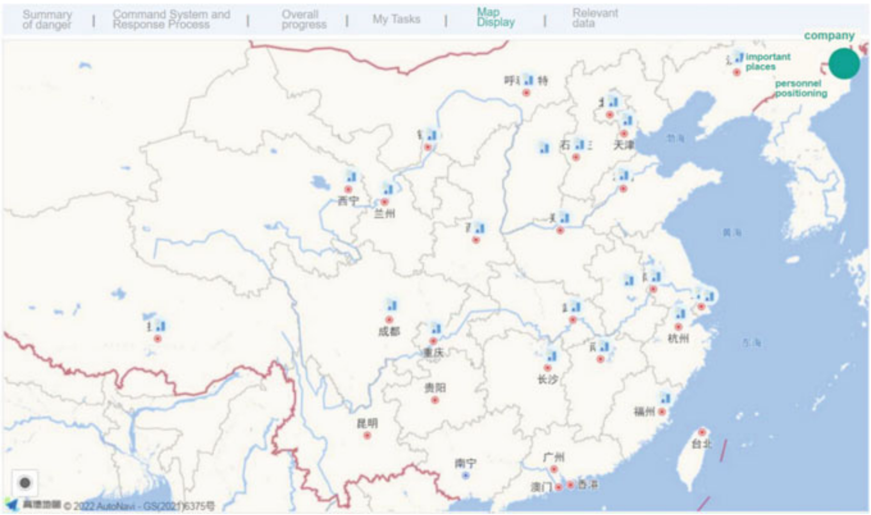


Fig. 7.30 Emergency response map display

the deployment and command of emergency teams and assist in emergency disposal work. As shown in Fig. 7.32.

5) Through the emergency vehicle data access, you can view the location information, license plate number information, vehicle type information and unit information of the emergency vehicles in real time through the system, and

Fig. 7.31 Emergency warehouse map display

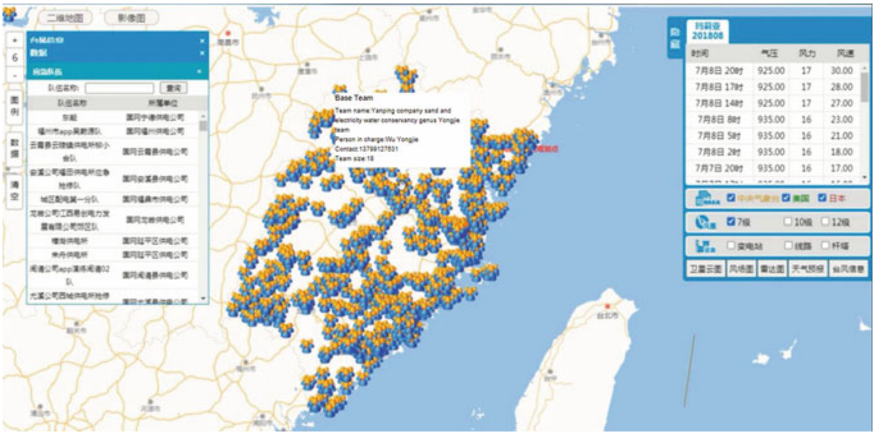


Fig. 7.32 Emergency team map display

conduct the deployment command of the emergency vehicles to assist the emergency response. As shown in Fig. 7.33.

6) Through the system's disaster damage statistics function, you can view the disaster damage situation of each unit of the power grid facilities. The system's disaster damage statistics function allows you to view the disaster damage situation of each unit, either by unit or by category, in the form of pie charts or bar charts for visual display. The pie chart or bar chart can be used to visualize the damage situation. This is shown in Fig. 7.34.
7) Disposal measures are recommended, and the system combines the loss of equipment and facilities caused by current disasters and future disasters development trend, predict disaster loss, and give suggestions on response plans,

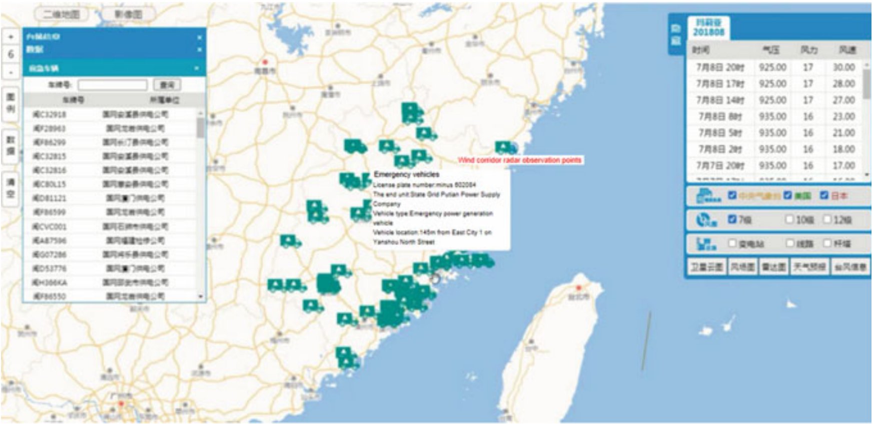


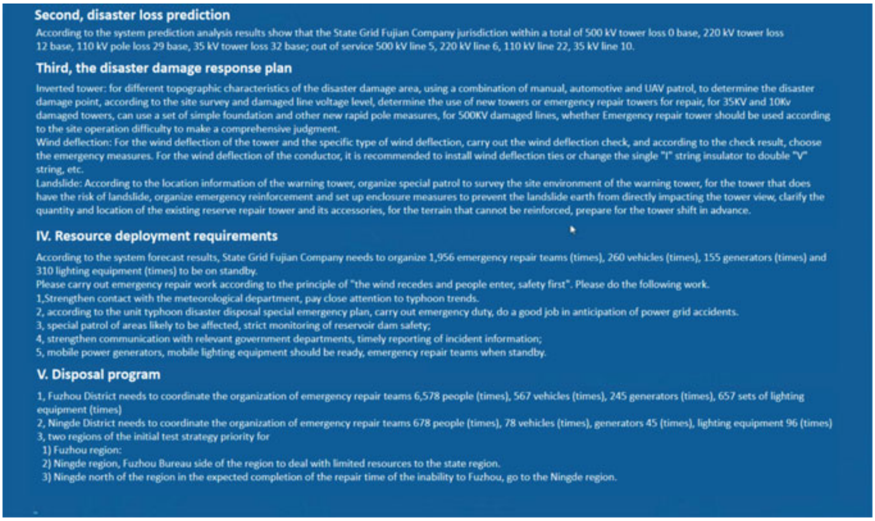
Fig. 7.33 Emergency vehicle map display

Fig. 7.34 Disaster damage statistics chart display

and demand for emergency resource allocation and preset the disposal plan to assist the emergency command work. This is shown in Fig. 7.35.

(11) Work exchange emergency communication: automatically create special event emergency team work groups according to the emergency plan and view contact information. Work communication: communicate with relevant personnel at all levels of emergency response with graphic work. As shown in Fig. 7.36.

(12) Internal and external information collection and integration. The system integrates GIS data information of power grid, completes data and information



Second, disaster loss prediction

According to the system prediction analysis results show that the State Grid Fujian Company jurisdiction within a total of 500 kV tower loss 0 base, 220 kV tower loss 12 base, 110 kV pole loss 29 base, 35 kV tower loss 32 base; out of service 500 kV line 5, 220 kV line 6, 110 kV line 22, 35 kV line 10.

Third, the disaster damage response plan

Inverted tower: for different topographic characteristics of the disaster damage area, using a combination of manual, automotive and UAV patrol, to determine the disaster damage point, according to the site survey and damaged line voltage level, determine the use of new towers or emergency repair towers for repair, for 35KV and 10Kv damaged towers, can use a set of simple foundation and other new rapid pole measures, for 500KV damaged lines, whether Emergency repair tower should be used according to the site operation difficulty to make a comprehensive judgment.
Wind deflection: For the wind deflection of the tower and the specific type of wind deflection, carry out the wind deflection check, and according to the check result, choose the emergency measures. For the wind deflection of the conductor, it is recommended to install wind deflection ties or change the single "I" string insulator to double "V" string, etc.
Landslide: According to the location information of the warning tower, organize special patrol to survey the site environment of the warning tower, for the tower that does have the risk of landslide, organize emergency reinforcement and set up enclosure measures to prevent the landslide earth from directly impacting the tower view, clarify the quantity and location of the existing reserve repair tower and its accessories, for the terrain that cannot be reinforced, prepare for the tower shift in advance.

IV. Resource deployment requirements

According to the system forecast results, State Grid Fujian Company needs to organize 1,956 emergency repair teams (times), 260 vehicles (times), 155 generators (times) and 310 lighting equipment (times) to be on standby.
Please carry out emergency repair work according to the principle of "the wind recedes and people enter, safety first". Please do the following work.
1,Strengthen contact with the meteorological department, pay close attention to typhoon trends.
2, according to the unit typhoon disaster disposal special emergency plan, carry out emergency duty, do a good job in anticipation of power grid accidents.
3, special patrol of areas likely to be affected, strict monitoring of reservoir dam safety;
4, strengthen communication with relevant government departments, timely reporting of incident information;
5, mobile power generators, mobile lighting equipment should be ready, emergency repair teams when standby.

V. Disposal program

1, Fuzhou District needs to coordinate the organization of emergency repair teams 6,578 people (times), 567 vehicles (times), 245 generators (times), 657 sets of lighting equipment (times)
2, Ningde District needs to coordinate the organization of emergency repair teams 678 people (times), 78 vehicles (times), generators 45 (times), lighting equipment 96 (times)
3, two regions of the initial test strategy priority for
1) Fuzhou region:
2) Ningde region, Fuzhou Bureau side of the region to deal with limited resources to the state region.
3) Ningde north of the region in the expected completion of the repair time of the inability to Fuzhou, go to the Ningde region.

Fig. 7.35 Disposal measures proposed display

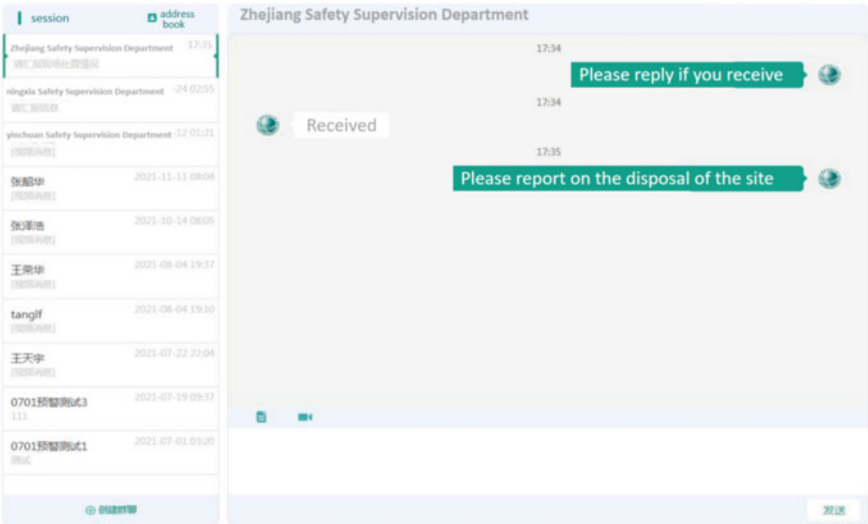


Fig. 7.36 System working communication diagram

collection through mobile terminals such as drones, uses special data interface to import public warning information, and obtains laws, regulations and rules, emergencies and emergency science related knowledge from public network information, collects and integrates internal and external information, and completes disaster damage prediction and auxiliary plan generation of power grid facilities.

1) Integrate internal grid GIS data information to view substation and line information of each voltage level to lay the foundation for disaster loss prediction of power grid facilities, as shown in Fig. 7.37.
2) UAV collection data access, the use of drones for disaster damage data collection, the collection of data into the system. Through the footage captured by the drone, the current disaster damage of the equipment is intelligently determined. As shown in Fig. 7.38.

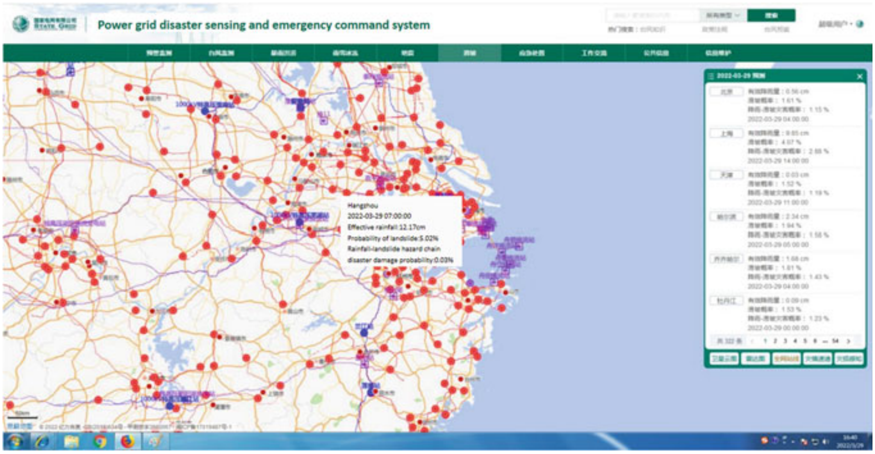


Fig. 7.37 Grid GIS sitewide map

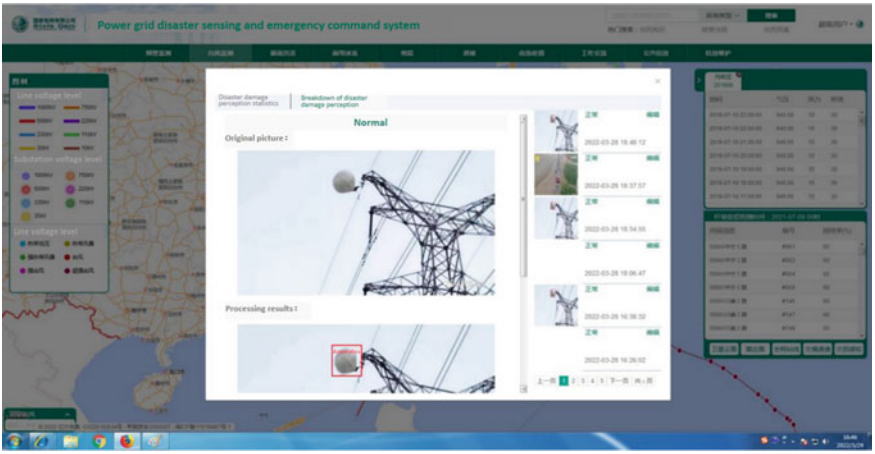


Fig. 7.38 UAV acquisition data access

Fig. 7.39 System public information diagram

3) Public information access, public information module contains public information data sources, public information data classification preview, laws, regulations and rules, emergency related situations and emergency science and technology related knowledge, etc. Through public information access, the auxiliary decision-making function is realized. As shown in Fig. 7.39.

7.3 System Application Examples

After the development of the basic functions of the system is completed, various types of data are accessed and the pilot application of the system functions is carried out in the trial environment. A typical typhoon disaster is selected for the pilot application of the system functions, taking Typhoon No. 6 of 2021, the fireworks, as an example, for the trial example of the grid disaster intelligence sensing and emergency command system. Firstly, it is the preliminary preparation stage, which mainly involves the follow-up and early warning release of typhoon disasters by the system during the period from typhoon generation to typhoon landing. The second stage is the disaster damage perception stage, which uses drones to quickly collect and analyze the damage caused by typhoon disasters, achieving rapid and intelligent perception of power grid disasters, and preparing for emergency command. The third stage is the emergency command stage, where various disaster damage information collected and analyzed by drones is combined with the special emergency plan and on-site disposal plan for typhoon disasters to carry out emergency response work, providing auxiliary support for the emergency response of the power grid against typhoon.

(1) Preliminary preparation stage

A tropical cyclone was generated in the Pacific Ocean on July 18, 2021, and was named "Fireworks" after it intensified into a tropical storm, with the number 202106. The information of the current active typhoon, satellite cloud map, radar map and weather forecast are monitored in real time. The results are shown in Figs. 7.40 and 7.41.

The system continuously tracks typhoon information and issues internal warnings according to the warning issuance rules. After the internal warnings are issued, it will combine with the typhoon special emergency plan to guide the warning action, and the system effect is shown in Figs. 7.42 and 7.43.

(2) Damage perception stage

Fig. 7.40 Typhoon information display

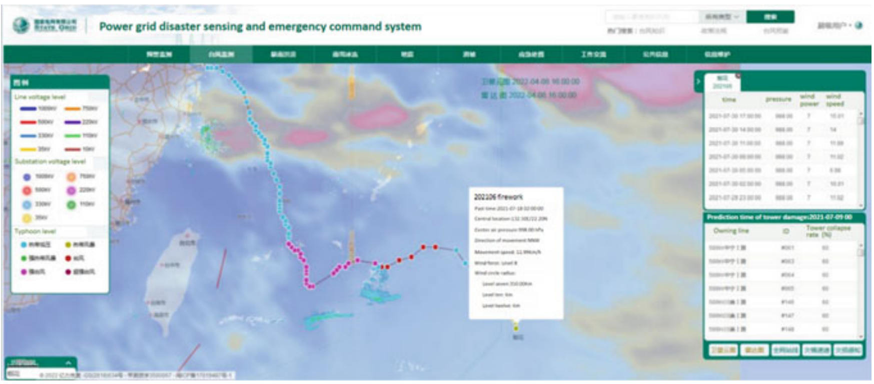


Fig. 7.41 Typhoon satellite cloud map

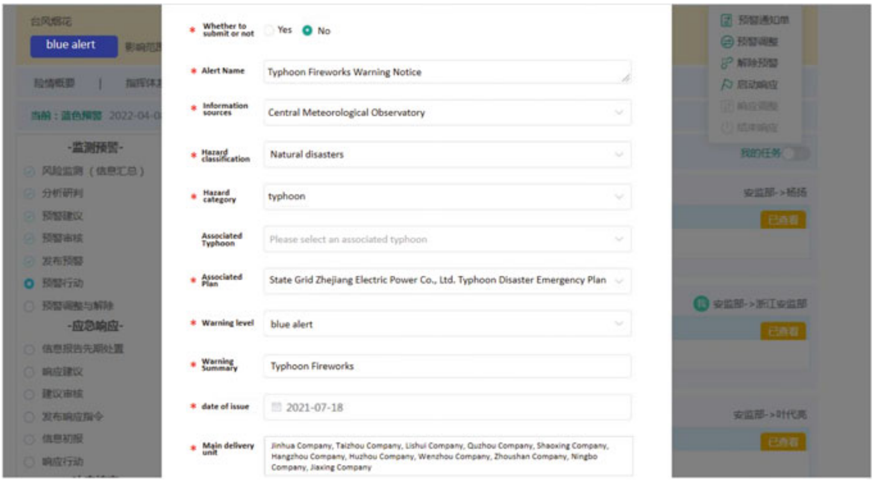


Fig. 7.42 Internal alert release

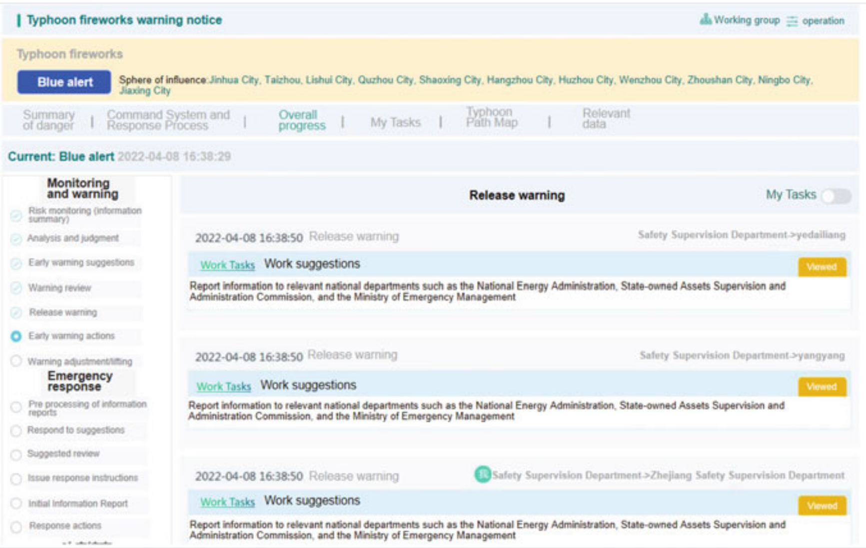


Fig. 7.43 Early warning action guidance

According to the predicted path of typhoon and the real path, by docking the GIS station line information, the disaster damage of typhoon passing through the path can be predicted, as well as the real disaster damage information can quickly realize the intelligent perception of the disaster situation of the power grid. The analysis of the impact of typhoon fireworks on the station line is shown in Fig. 7.44.

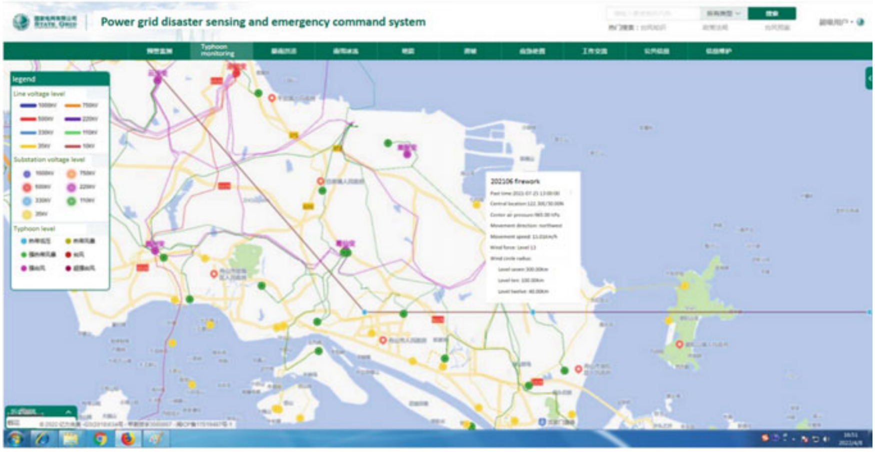


Fig. 7.44 Typhoon impact station line map

When the disaster occurs, the rapid reporting of onsite disaster damage information can be carried out through the disaster damage express function of the system, and the rapid collection and online analysis of disaster damage can also be carried out through UAV, the information express report submits the current disaster damage information through the fixed information template, and the rapid reporting of the onsite danger through the mobile terminal. This is shown in Fig. 7.45.

The system's disaster awareness analysis is mainly disaster awareness statistics and disaster awareness details, and the current equipment's disaster damage is intelligently judged by the images taken by the UAV. As shown in Fig. 7.46.

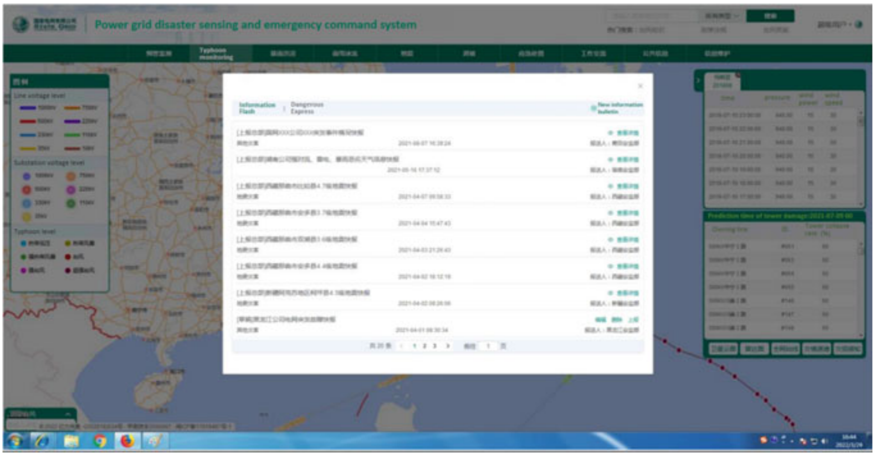


Fig. 7.45 Typhoon damage express application

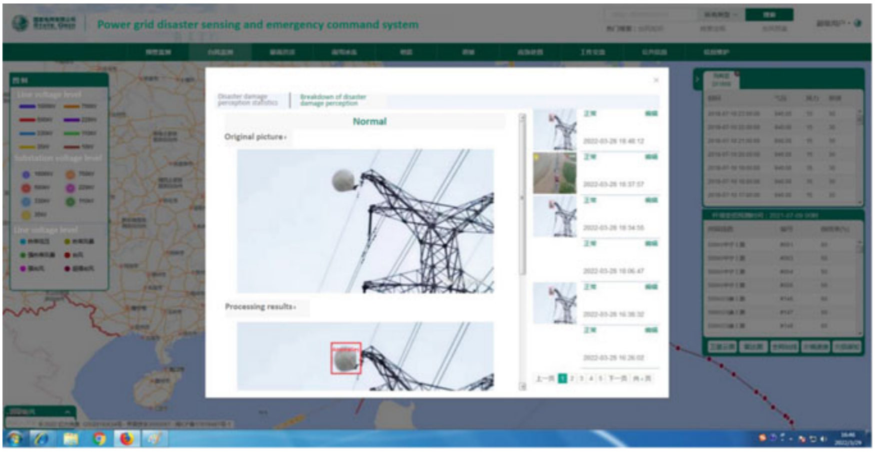


Fig. 7.46 Typhoon damage perception analysis

(3) Emergency command stage

After completing the disaster prediction analysis and real-time perception of disaster damage through the system, the work related to emergency disposal needs to be carried out. In the emergency response stage, according to the company's response initiation rules, the system can automatically generate the command system and response flow chart related to typhoon disaster emergency disposal, and the work responsibilities of each process of each department in the command system can be clearly viewed according to the relevant regulations, and the system functions are shown in Fig. 7.47.

In the emergency command stage, combined with the typhoon disaster special emergency plan and onsite disposal plan, the work tasks related to the digital plan can be generated, in different stages of different links, according to the special emergency plan and onsite disposal plan, the relevant emergency disposal measures can be accurately pushed to the relevant personnel in real time, and the staff of each department can carry out emergency disposal related work according to the action instructions, the system effect The effect of the system is shown in Fig. 7.48.

In the process of emergency response, it is necessary to continuously gather all kinds of public information and professional information, and make work communication and work adjustment through analysis and judgment. The public information mainly includes laws, regulations and rules, emergency situation and knowledge about emergency science and technology as shown in Fig. 7.49; the system interface of each staff for work communication is shown in Fig. 7.50.

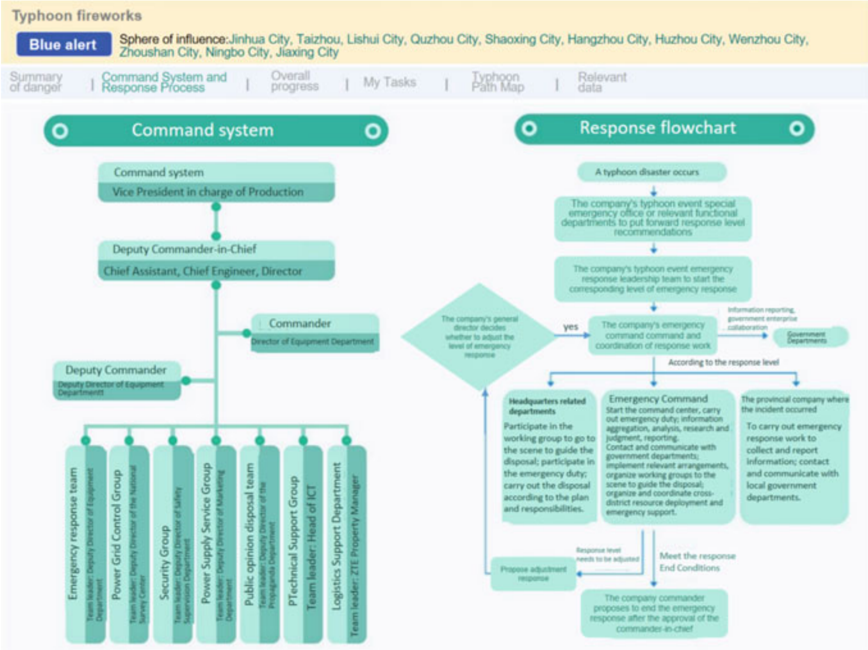


Fig. 7.47 Typhoon emergency command system diagram

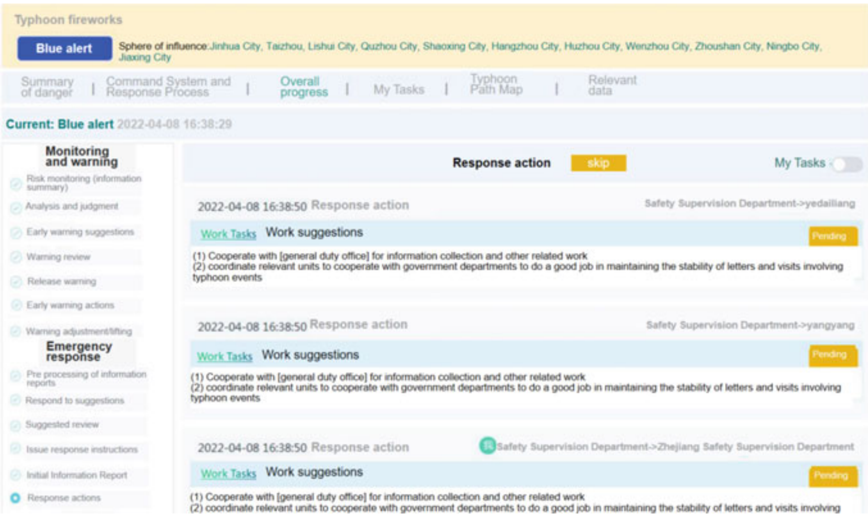


Fig. 7.48 Typhoon emergency response

Fig. 7.49 Comprehensive information display for emergency response

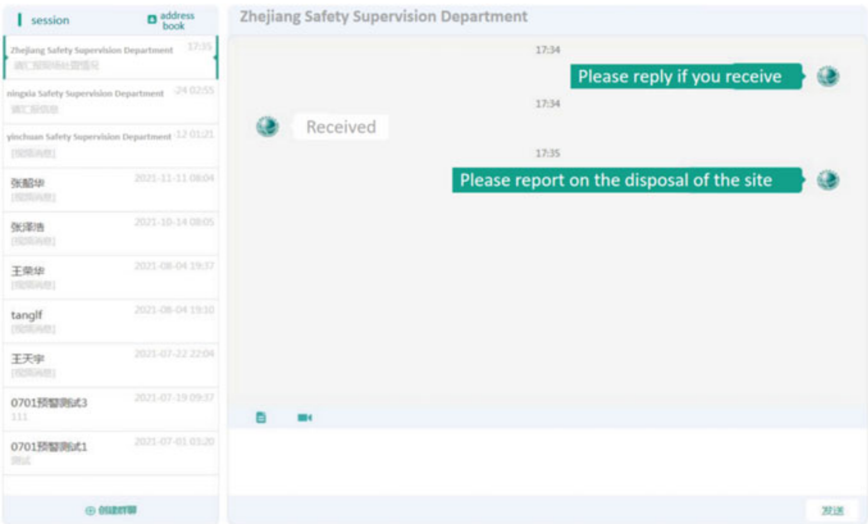


Fig. 7.50 Emergency response work communication

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