




Integration of cloud computing with the Internet of things for the treatment and management of the COVID-19 pandemic

Mehdi Darbandi¹ · Adel F. Alrasheedi² · Khalid A. Alnowibet² · Danial Javaheri³ · Abolfazl Mehbodniya⁴ 

Received: 13 February 2022 / Revised: 16 June 2022 / Accepted: 29 June 2022

© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2022

Abstract

The globe is now fighting the COVID-19 epidemic, and a cost-effective method to battle the outbreak is urgently required. In this era, the Internet of Things (IoT) offers healthcare systems or checks and discovers patients in epidemics to prevent the virus from spreading. In order to tackle the current COVID-19 pandemic, intelligent health care based on IoT is becoming increasingly vital in better digital technologies. This technology allows gadgets to link hospitals and other predefined sites to tackle this dilemma. The cognitive Internet of Medical Things (IoMT) is a potential technology for quick analysis, dynamic monitoring and control, improved therapy and management, and prevention of viral transmission. This technology can send a message to the hospital immediately in an emergency. Due to the importance of this subject, the influence of IoT-centered innovations in the management of COVID-19 is examined in this article. The three main areas, including early detection, viral prevention, and patient care, are considered in this paper. The results showed that using IoT, such as drones and robots, has been fruitful in reducing contact with patients and identifying disease symptoms. Also, they showed that the IoT wearable gadgets and the cloud platform to store the patient's information have helped doctors track the patient's condition.

Keywords COVID-19 management · Internet of things · Coronavirus · Cloud computing · Internet of medical things

✉ Danial Javaheri
javaheri@chosun.ac.kr

Extended author information available on the last page of the article

1 Introduction

The current COVID-19 pandemic, which is caused by the coronavirus, causes a severe acute respiratory syndrome, began in Wuhan and has since expanded throughout China and the world, posing significant problems to China's health-care system (Lin and Wu 2020; Vahdat 2020; VAHDAT, Samanian, Shahidi, and Atapour 2021). COVID-19 is now diagnosed mostly by viral nucleic acid testing (Lv, Chen, Feng, Zhu, and Lv 2021; Vahdat 2022). The present precision of nucleic acid testing is from 30 to 50%. Several suspicious or suspected instances may go unnoticed, which is inconvenient for patient quarantine and therapy. The "diagnosis and treatment scheme for COVID-19 pneumonia (Interim Version 5)" was released by the People's Republic of China's National Health Commission, which proposed clinical diagnostic criteria based on chest imaging. Nevertheless, because doctors in multiple areas and hospitals have distinct levels of diagnosis and treatment, some instances are still overlooked, particularly when the nucleic acid test is negative. Furthermore, the interim version has discovered no cases accused of carrying this condition. In some individuals, alterations in Computed Tomography (CT) can predict the identification of nucleic acid tests, according to an investigation done at Mount Sinai Hospital in New York (Bai et al. 2020; Bernheim et al. 2020). Because COVID-19 has no particular therapy and attempts to restrict its spread have failed, there is an immediate need for global surveillance of people infected with COVID-19 (Abbasi et al. 2021; VAHDAT, Shahidi, et al. 2021). The deployment of an incorporated digital sickness surveillance system might be crucial to controlling the condition. The Internet of Things (IoT) is getting worldwide attention and becoming more available for forecasting, preventing, and tracking emerging infectious illnesses (Christaki 2015; Janiesch et al. 2019; Wan et al. 2018).

Cities are confronting abrupt lockdown restrictions as COVID-19 grows at an increasing rate, causing almost 10 billion people to self-quarantine at home. The requirement for essential therapeutic supplies and materials has been enormous, and the capability for quick but urgent replenishment is likely to be exhausted. Individuals and potential sufferers should flee their homes to seek medical help, placing strain on isolation and quarantine procedures and compromising disease control efforts (Zhang et al. 2021a, b). Furthermore, the medical community has advised people with moderate symptoms to stay at home because of a lack of isolation wards and appropriate medical instruments. Obviously, a home-based diagnostic test would be an excellent tool in meeting this critical and ignored demand. The Internet of Medical Things (IoMT) is an expanded version of IoT that focuses on healthcare (Joyia et al. 2017; T. Yang, Gentile, Shen, and Cheng 2020).

IoT is a web of interlinked smart sensors, devices, and persons that allows raw data to be gathered and delivered over the Internet to be examined for trends or developments. Cloud-based remote health testing, wearable health-monitoring devices, and Artificial Intelligence (AI) are all employed in modern IoT-enabled Health Monitoring Systems (HMS) to supply real-time observation (Rahman et al. 2020; Zhang et al. 2020). In China, the outbreak provided a great setting for

field testing of new technological approaches and concepts, notably in IoMT and digital health. Due to the pandemic, many innovative parties, including governments, technology design, the financial community, and regulatory authorities in China and worldwide, have indicated an interest in IoMT and digital health (Lin and Wu 2020).

IoT-based healthcare systems collect relevant data, supply extra perspective via symptoms and activities, enable remote monitoring, and empower individuals to make better decisions about their health (Alam 2020). The fog computing layer, healthcare sensor layer, and cloud computing layer are the three layers that make up the usage of IoT in healthcare systems to combat pandemic scenarios like COVID-19 (Cao, Zhang, Zhao, et al. 2021; Muhasin et al. 2017). The IoT-enabled healthcare equipment includes smart hospitals, wearable gadgets for patients (COVID-19), and doctors (Lv, Yu, Xie, and Alamri 2022). The internal characteristics of smart hospitals, like temperature, may intelligently be monitored (Misra et al. 2020). Health data may be gathered using portable smart devices and transmitted to a clinician employing wearable smart devices. Via a COVID-19 tracking app, physicians employ video chats for remote consultations and diagnosis of patients (Munzert et al. 2021; Roy et al. 2020). Network equipment like routers, gateways, switches, and access points make up the fog computing layer (Abdulsalam and Hossain, 2020; Mukherjee et al. 2017). The healthcare data is sent directly from the healthcare sensor layer over the 5G/6G wireless communication network to the fog computing layer for Machine Learning (ML) algorithms (Lv, Guo, and Lv 2022; Siriwardhana et al. 2020). Conventional cloud servers with adequate processing capacity to deliver storage and end-to-end services make up the cloud computing layer (Ferrag et al. 2021; Yang, Huang, Zhang, and Weinman 2020). The researchers Alhussein et al. (2018) leveraged the convergence of IoT and cloud to monitor the patient's health situation in a Cognitive Healthcare IoT (CHIoT) system. Related information on patient health is gathered from several sources, ranging from IoT sensors to online social networks. The standard information system apparatuses and materials are insufficient to suit the COVID-19 epidemic's requirements. As illustrated in Fig. 1, the medical applications/services sensor system might go through the subsequent general phases.

The IoMT, which gathers, organizes, and analyzes medical data produced by diverse IoT devices, has made significant development in tandem with the design and application of IoT technology in the medical industry (Hanafizadeh, Hatami, Analoui, and Albadvi 2021; Islam, Kwak, Kabir, Hossain, and Kwak 2015). IoMT can increase illness therapy accessibility and effectiveness while also reducing

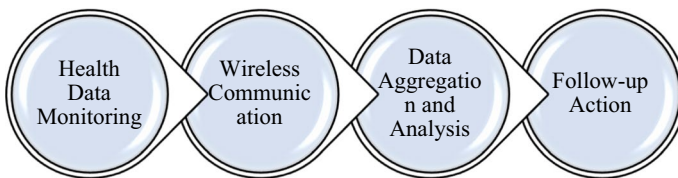


Fig. 1 Sensor device for health tracking and action framework based on the IoT (Udgata and Suryadevara, 2021)

mistakes, improving patient experience, and lowering costs (Baker et al. 2017). The current global large-scale epidemic of COVID-19 has put significant strain and constraints on current medical detection systems and novel demands for medical detection data timeliness, precision, and dependability (Li et al. 2021). IoMT is planned to be employed in this case to gather and evaluate the primary symptoms of COVID-19 sufferers by supplying large-scale real-time detection data and identifying the illness outbreak's source (Lin et al. 2020; Yang et al. 2020a, b).

Since the prevention and management of COVID-19 is one of the most important issues in today's society, the integration of cloud computing and the IoT for the optimal management of COVID-19 was examined. Thus, this paper's significant contribution is:

- Investigating the state-of-the-art regarding the applications of cloud computing and IoT in the prevention, management, and treatment of COVID-19;
- Examining the crucial challenges regarding the applications of cloud computing and IoT in the COVID-19 era;
- Examining the available solutions to the provided challenges regarding cloud computing and IoT applications in the COVID-19 era.

Finally, the organization of the article is presented as follows.

Section 2 analyses the related studies. Section 3 reviews and analyzes the selected articles. Results and discussion are presented in Sect. 4. Finally, Sect. 5 and 6 present challenges, future direction, and conclusion.

2 Related works

In this part, we'll look at some cloud computing and IoT overviews for managing the COVID-19 outbreak.

To determine the possibilities of this technology, Javaid and Khan (2021) looked at academic publications on IoT in healthcare and the COVID-19 epidemic. With the use of a workflow chart, they examined the important accomplishments of IoT. Afterward, in 2021, they highlighted seven significant IoT technologies that appear to be useful for healthcare throughout the COVID-19 epidemic. Ultimately, throughout the COVID-19 outbreak, they found sixteen basic IoT applications for the medical area, each with a brief explanation. They discovered that this information-based service offers novel healthcare prospects by moving toward the ideal manner for an information system to adapt to world-class outcomes while also enhancing hospital treatment systems.

The goal of Chakraborty and Abougren (2021) was to deliver an overview of the role of ML and the IoT in combating the pandemic. They discovered that ML was an effective and strong AI technique that could reliably recognize and diagnose COVID-19 from X-ray and CT (Computed Tomography) images. It might be a useful diagnostic tool in the radiology department. Besides, ML might be utilized for COVID-19 segmentation and prediction. Additionally, ML could help in medication discovery and minimize clinical errors.

Kumar et al. (2020) performed a thorough literature analysis of the prevalence of previous epidemics and COVID-19. Numerous problems were discovered throughout the literature review that limited the operation of health care personnel and posed a risk to their safety. Their goal was to undertake a comprehensive analysis of the literature to discover the medical sectors' problems in dealing with the pandemic and to provide viable solutions based on cutting-edge technology like AI and IoT. They helped by detecting problems and categorized them as physical, resource-based, operational, technical, organizational, and external healthcare difficulties.

Manavi, Nekkanti, Choudhary, and Jayapandian (2020) looked at and assessed a variety of IoT-enabled screening, contact tracing, and surveillance technologies and apps. Throughout COVID-19, the goal was to provide a comprehensive understanding of the current and planned innovations of IoT-based alternatives in order to improve the situation. They investigated ongoing IoT initiatives and potential situations for tackling numerous COVID-19 difficulties like pre-screening, tracing quarantined/infected persons, etc. They also looked into the study prospects that emerged due to the utilization of IoT to address the COVID-19 problem. They also noted a number of obstacles and concerns that must be tackled while adopting IoT throughout the COVID-19 outbreak.

Although these articles have examined the influence of the IoT on helping the COVID-19 epidemic, none of them have taken our approach. It can be said that the approach has tried to classify and analyze a large part of the existing literature in three important sections in a new grouping. Finally, Table 1 provides a comparison of existing review articles. As can be seen, the existing articles have some shortcomings, including the fact that some lack classification, future work, or open topics. The goal of this post is to go through each of these points.

3 How the cloud and IoT prevent COVID-19 outbreaks

The healthcare industry has been a rapid adopter of IoT. The whole healthcare industry faced significant obstacles, particularly during the COVID-19 epidemic. Numerous IoT application possibilities have been suggested in this regard. It involves limiting disease transmission, remote patient surveillance, and intelligent diagnosis. In this article, to provide solutions in the literature by examining the effect of cloud computing and IoT on the COVID-19 epidemic were tried. Therefore, the primary goal is to answer the following questions:

Table 1 The related survey in the field of cloud computing and IoT for the management of the COVID-19

Author	Year	Technique	Classification	Open issue	Future works
Javaid and Khan	2021	IoT	No	Yes	No
Chakraborty and Abougreen	2021	ML and IoT	No	No	Yes
Kumar et al.	2020	AI and IoT	Yes	Yes	No
Manavi et al.	2020	IoT	No	No	Yes

- What are the state-of-the-art technologies related to the applications of cloud computing and the IoT for the prevention, management, and treatment of Covid-19?
- What are the crucial challenges related to cloud computing and IoT applications in the COVID-19 era?
- What are the solutions for the provided challenges concerning cloud computing and IoT applications in the COVID-19 era?

For this purpose, the articles entitled were found “Cloud Computing” AND “Internet of Things” OR “IoT” AND “COVID-19” OR “coronavirus” using Google Scholar, Dimension, and Scopus Database. There was a total of 28 articles with these titles until 11 May 2022. The titles and abstracts of the articles were reviewed. There was one duplicate article, and there was 1 article that did not have access to the full text. One article was also non-English, so the remaining 25 articles were analyzed. Selected articles are shown in Table 2. The results of the systematic review showed that the number of existing articles has increased since 2021, and Springer publications has had the largest number of printed articles. Hindawi, IEEE and Wiley publications have also been active in the field of research related to the IoT in the cloud platform for the management of the COVID-19virus. In 2021, there is an increase in the publication process of their articles. And other publications have also presented methods to prevent and control this disease with the help of the IoT to prevent contact with the patient from 2022.

After reviewing the full text of 25 articles, the some were presented as reports and some journals were invalid were found. Therefore, 15 articles were deleted. Since the number of articles obtained from this survey was less, we searched for articles that had the title either cloud computing and COVID-19 or the title included COVID-19. However, the text used both cloud computing and the Internet. As a result, 18 articles were analyzed. Articles are classified into 3 groups (see Fig. 2). In the following, 18 articles are reviewed on the role of IoT and cloud in preventing disease transmission, patient care, and early diagnosis. Figure 2 shows this fact.

Finally, the countries that have done the most research on cloud computing and the IoT are shown in Table 2 and Fig. 3. As illustrated, India is at the top of the list with 89 articles. Then the United States with 27 articles and Saudi Arabia with 21 articles are ranked 2nd and 3rd.

3.1 The role of IoT and cloud computing in reducing transmission of the disease

COVID-19’s rapid global spread has increased the amount of data collected from multiple sources. Cloud computing solutions are frequently used by workers who work from home to assist them in completing their tasks swiftly. Home hospitalization is one of the finest feasible methods for reducing the spread of the virus and maintaining the health of people who require hospitalization (Alashhab et al. 2021). In the COVID-19 outbreak catastrophe, the cloud computing and IoT ecosystem is an unsung hero (Azam et al. 2019). Cloud computing and the IoT are two essential technologies that have meaningfully aided the growth of the

Table 2 Comparing the countries with the most articles

Id	Country	Documents	Citations	Total link strength	Id	Country	Documents	Citations	Total link strength
1	Ukraine	2	0	0	29	Singapore	4	25	3
2	Algeria	1	0	0	30	Cyprus	3	2	4
3	Colombia	1	1	0	31	Greece	4	3	4
4	Estonia	1	1	0	32	Kuwait	3	5	4
5	France	2	0	0	33	Bangladesh	11	10	4
6	Indonesia	6	1	0	34	Poland	2	1	4
7	Sri Lanka	3	0	0	35	Vietnam	2	72	4
8	Sweden	1	2	0	36	Norway	1	0	5
9	Thailand	4	2	0	37	Taiwan	1	0	5
10	Papua New Guinea	1	0	0	38	Lithuania	1	0	5
11	Morocco	3	7	0	39	Denmark	2	9	6
12	Ecuador	1	4	1	40	Egypt	7	7	6
13	Mauritius	1	0	1	41	Nigeria	7	18	6
14	Turkey	2	0	1	42	Jordan	6	142	8
15	Oman	1	21	1	43	Brazil	4	58	9
16	Serbia	1	0	1	44	United Arab Emirates	6	80	9
17	Romania	4	6	1	45	South Korea	10	23	9
18	Namibia	1	12	1	46	Canada	8	130	11
19	Spain	6	12	2	47	Italy	8	58	12
20	Tunisia	5	61	2	48	United Kingdom	8	74	12
21	Chile	1	1	2	49	Portugal	6	65	14
22	Finland	1	12	2	50	China	11	53	14
23	Ghana	1	0	2	51	Australia	11	18	18
24	Iran	3	27	2	52	Pakistan	8	17	18

Table 2 (continued)

Id	Country	Documents	Citations	Total link strength	Id	Country	Documents	Citations	Total link strength
25	Iraq	10	16	3	53	United states	27	187	19
26	Ireland	3	1	3	54	India	89	211	28
27	Malaysia	6	7	3	55	Saudi Arabia	21	123	30
28	Mexico	3	8	3					

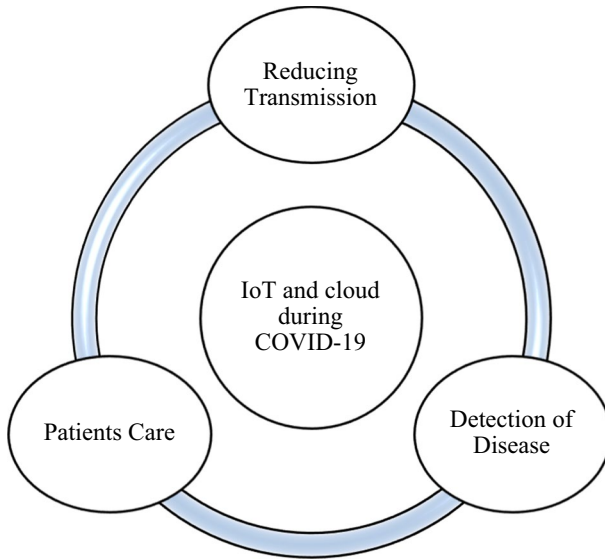


Fig. 2 Aspects of IoT assistance during the COVID-19 epidemic

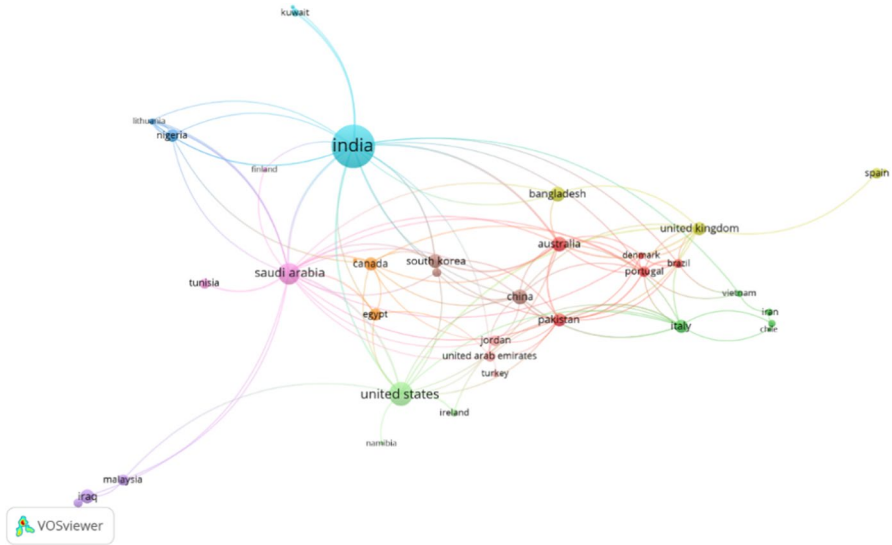


Fig. 3 Mapping of nations where the most articles

healthcare industry (Qasem, Abdullah, Atan, and Jusoh 2018). These advancements allow patients to recover and get treatment in the privacy of their own homes, surrounded by their loved ones. Patients' health and the surroundings in the hospitalization room are tracked to allow doctors to track the procedure and

provide suggestions to patients and managers. 2020 (Hassen et al. 2020). Below are some relevant papers to consider.

In Angurala et al. (2020), DBCMS (Drone Based COVID-19 Medical Service) is a recommended system for the protection of medical staff who are susceptible to COVID-19 infection. The recommended approach could significantly enhance COVID-19 patients' treatment outcomes. They developed a drone service strategy to lower the risk of infection among physicians and other medical personnel, hence avoiding disease transmission. They similarly anticipated that the first step would be segregating individuals at home rather than admitting them to hospitals, a condition known as a lockdown or curfew. The transmission of illness may be efficiently managed throughout various nations worldwide.

Chaudhari, Mene, Bora, and Somavanshi (2020) discussed the influence of COVID-19 and the significance of HIoT apps in combating the technology epidemic. According to their results, IoT applications in healthcare can assist keep real-time data on the cloud. Various statistical analyses may be performed on this data to anticipate COVID-19's future situations. You may also create a happier workplace with the correct use of IoT apps.

Besides, to identify absconding, Singh et al. (2020a, b) created an IoT-based wearable quarantine band. They designed it with the expense, global supply chain interruption, and COVID-19 quarantine length in mind, as recommended by the WHO. The wearable prototype and the accompanying mobile app provide real-time reporting and tracking of absconding quarantine victims. IoT-Q-Band is a cost-effective approach for preventing the spread of COVID-19 in low-income areas.

Alrashidi (2020) suggested an intelligent technique relying on two optimizers (Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO)) to find the ideal relocation of a group of individuals connected with IoT devices to regulate their positions and motions inside an interior area. An amphitheater containing pupils was employed as a real-world test, and the algorithms steered pupils to appropriate safe postures. ACO and PSO are two evolutionary techniques developed to tackle the challenge. Afterward, utilizing several assessment criteria to examine the behavior of the suggested system, he conducted a comparative analysis among these algorithms and the Genetic Algorithm (GA).

Leila, Othman, and Sakli (2020) suggested an IoRT system addressing the COVID-19 epidemic. It captures values of quantifiable medical parameters at any time. It sends them to the cloud, where they are preserved and analyzed by a doctor as part of the hospital's healthcare service. In hospitals, the robot acts as a link across the physical parts of the hospital and information cloud, which records patient-specific values and makes them available on-demand through an Internet connection.

Eventually, the results of this section are summarized in Table 3. The aim, techniques, and results of each article are summarized in the table.

3.2 Role of IoT and cloud computing in the detection of disease

Because there is no preventative therapy for COVID-19 illness, early detection is critical in allowing the patient to be effectively isolated. It lowers the chance

Table 3 Details of articles on the role of the IoT in reducing disease transmission

Work	Aim	Proposed technique	Result
Angurala et al. (2020)	Helping to mitigate the virus spread	DBCMS architecture using Global Positioning System (GPS)	If the DBCMS technique is deployed at the cluster level, the dispersion can be greatly decreased over the world
Chaudhari et al. (2020)	Monitoring the condition of self-quarantine patients without visiting their place	GPS and introducing some IoT applications that are useful in this COVID-19 epidemic	The IoT application will efficiently limit person-to-person interaction, hence limiting the transmission of the COVID-19
Singh et al. (2020a, b)	Mitigating the growth of infections	Designing a wearable band bundled with a mobile application	With its associated cloud-centered monitoring system and mobile application, the IoT-Q-Band presents a cheap, scalable solution for detecting and tracking COVID-19 victims in real-time
Alrashidi (2020)	Maintaining the acceptable social distance among individuals, and if needed, limiting relocation of persons already in the area	Utilizing evolutionary optimization and metaheuristics methods like PSO and ACO to approximate resolution	The effectiveness of ACO and PSO regarding various metrics and measurements and the operational use of such strategies for maintaining social distance throughout the COVID-19 epidemic and other future health emergencies
Leila et al. (2020)	A solution to prevent virus transmission	Introduction of medical robotics	The design is built on medical sensors identifying and communicating clinical parameters of patients via a robot that receives and sends these values to the cloud, i.e., to a collecting server The doctor can examine the COVID-19 patient's condition from a service unit

of infection in healthy people (Nasser et al. 2021). These advancements allow patients to recover and get treatment in the privacy of their own homes, surrounded by their loved ones. Nevertheless, in a smart city context, it creates issues like limited processing capability and poor storage capacity (Lv, Chen, and Lv 2022). Cloud computing, in the meantime, supplies storage and quick processing. To cope with very complex intelligent health care, IoT-cloud integration is essential (Yuehong et al. 2016). Patient observation and real-time communication were always at the heart of intelligent healthcare systems. Nevertheless, the necessity for a cognitive system that uses IoT-cloud technologies to provide patient-centered, low-cost, high-quality smart health care is growing (Sun et al. 2022). Below are some relevant papers to consider.

Oyenyi et al. (2020) looked into and emphasized the potential of IoT while also providing a road plan for combating the COVID-19 epidemic. They concluded that patients, physicians, medical workers, and health management systems would benefit from adopting IoT to identify infectious illness symptoms and treat affected individuals of COVID-19 on a global scale. It will also help to simplify and shorten the time necessary for effective epidemic monitoring.

Barnawi, Chhikara, Tekchandani, Kumar, and Alzahrani (2021) developed an IoTUAV-based approach to capture raw data utilizing onboard heat sensors to limit the influence of COVID-19. Depending on the temperature observed, the thermal picture acquired from the thermal camera was utilized to identify the prospective persons in the image that may have COVID-19. An effective hybrid solution for a face recognition system was presented to recognize humans in infrared photos collected in real-time situations with high body temperature. Besides, they devised a face Mutual Authentication and Secret Key (MASK) recognition technique that identifies if a person is wearing a MASK. The performance of the strategies was assessed utilizing a variety of ML and Deep Learning (DL) classifiers. They leveraged edge computing infrastructure for data processing to minimize reaction time for real-time analytics and forecasting. Employing multiple performance assessment parameters, the suggested technique has an average accuracy of 99.5%, suggesting its practical application in real-time settings.

Elagan et al. (2021) presented a unique technique for identifying COVID-19 illness from a distance. Its goal was to assist clinicians in detecting COVID-19 remotely, reducing direct patient interaction. The suggested system had three smart sensors: a thermal monitoring sensor, a pulse sensor, and a blood sensor. The system's major element is described in depth. The Heart Rate (HR) was calculated using a pulse sensor. A pulse sensor uses a mathematical model to represent the transmitted light oximeter and the reflected light oximeter. They also enhanced time-series signal recognition by disregarding motion impacts and focusing on the Area of Interest (ROI) positions. Depending on blood electrical characteristics and frequencies, they utilized the COMSOL model to calculate the volume of Red Blood Cells (RBC)s, White Blood Cells (WBC)s, and Platelets. They modified a mathematical model that characterized the earlobe's resistance at various frequencies. After calculating the HR, RBCs, WBCs, and Platelets, the suggested method was utilized to determine if the subject had COVID-19 symptoms.

Saha et al. (2021) demonstrated a system for measuring oxygen levels, calculating severity, and making a probabilistic judgment on whether or not to be a COVID-19 patient. In addition, the approach could keep patient information private and employ probabilistic categorization to assess severity. The delay of blockchain formation, overall response, detection, throughput, and severity accuracy, were used to evaluate the outcomes. The hummingbird method and photon hash were used as inter-modular operations to make the solution less statistically difficult. The investigation discovered an effective and important answer for the current global health threat in the IoT architecture.

Also, Shalabi (2020) introduced a layout and simulation of COVID-19 Symptoms Monitoring Mechanism (CSMM) depending on IoT and sensor networks to track people through their quarantine, particularly the elderly suffering from chronic illnesses or immune deficiency, making them more susceptible to serious illness. The technique was based on remote patient health data tracking. A doctor or a medical practitioner might carry out the procedure of monitoring. The system can quickly identify an urgent or unusual patient, such as a high temperature or difficulty breathing. Thus, the system may send an urgent Short Message Service (SMS) to the doctor or medical practitioner detailing the time and patient status, alerting them to save the patient's life as soon as possible.

Mingdong Zhang et al. (2021a, b,) studied the possibility of using CT images of the lungs as diagnostic signals in order to develop an efficient and valid alternative to NAT (Nucleic Acid Testing). COVID-19-infected lungs developed lesions, ground-glass opacity, and bronchiectasis that were not present in healthy lungs. They suggested an enhanced Residual Learning Diagnosis Detection (RLDD) approach for the COVID-19 methodology, which was aimed to differentiate positive COVID-19 cases from heterogeneous lung pictures using a publicly available dataset. Aside from its excellent diagnostic accuracy, the residual-based COVID-19 detection network rapidly identified lung characteristics from tiny COVID-19 samples, eliminating the need for pre-training on other medical datasets. They had an accuracy of 91.33 percent, precision of 91.30 percent, and recall of 90 percent in the test set. The evaluation time for the batch of 150 samples was only 4.7 s. To increase the detection efficiency of COVID-19, RLDD can be implemented into the API and medical device.

Finally, Rani, Selvakumar, Kumar, Tai, and Chelvi (2021) demonstrated a novel COVID-19 diagnostic model based on IoMT that used several ML-based categorization models on chest X-rays. The suggested concept gathers patient samples utilizing IoT devices and sends the data to a cloud server, where the real diagnosis is performed. When the diagnosis is finished, the report is sent to the appropriate healthcare facility for further processing. The procedures used in diagnosis are texture feature extraction and classification. They used a chest X-ray dataset to validate the suggested model's performance. According to practical data, the AdaBoost with random forest model beats other approaches with the highest precision of 90.13 percent, a kappa value of 89.59 percent, an F-score of 90.28 percent, and an MCC of 87.44 percent.

Table 4 summarizes the contents of this section. The aim, techniques, and results of each article are summarized in the table.

3.3 Role of IoT and cloud computing in patients care

The rising number of individuals in hospitals is causing widespread worry, owing to population aging, chronic illnesses, and, most recently, the COVID-19 epidemic. The IoT appears as a promising approach to address this issue since it offers the necessary scalability, allowing for persistent and reliable HM on a worldwide scale. Moreover, recent advancements in low power usage, biosensors, and miniaturization have transformed the procedure of tracking and detecting health issues, providing comfort, customization, and usefulness to patients via unobtrusive healthcare equipment (de Moraes Barroca Filho, Aquino, Malaquias, Girão, and Melo 2021).

Castiglione, Umer, Sadiq, Obaidat, and Vijayakumar (2021) offered a road map by emphasizing IoT solutions to assist its management. They also recommended identifying and tracking COVID-19 patients in real time. Data collection of illness symptoms (utilizing IoT-based devices), health center or quarantine center (data gathered utilizing IoT devices), data warehouse (assessment utilizing ML models), and medical experts (providing treatment) were all part of the recommended structure. They tested five ML models to forecast the severity degree of COVID-19 patients based on IoT-based real-time data. Random Forest outperformed all other models based on the findings.

Masud et al. (2020) devised a simple and practically secure mutual authentication and secret key generation technique that relied on Physical Unclonable Functions (PUF) to allow network devices to validate the validity (user) and sensor node of the doctor before generating a session key. PUF also prevented manipulation, cloning, and side-channel assaults on sensor nodes installed in an unsupervised and hostile setting. Authentication, secrecy, anonymity, and integrity are all security qualities that the recommended protocol possesses, making it ideal for protecting IoMT networks. According to professional AVISPA security analyses and unofficial security assessments, it is immune to attacks like replay, impersonation, and man-in-the-middle. The suggested protocol is more suited for IoT-enabled medical networks since it uses fewer resources and is resistant to physical threats.

To address the security threat in IoMT, Gupta (2020) designed a simple reciprocal authentication and secret key generation technique that used PUF to allow network equipment to validate the legality of the doctor (user) and sensor node before generating a session key. PUF also prevented manipulation, cloning, and side-channel assaults on sensor nodes installed in an unsupervised and hostile setting. The suggested methodology demonstrated all of the essential security qualities for protecting IoMT networks, such as authentication, confidentiality, anonymity, integrity, and untraceability. The formal (AVISPA) and informal security analyses showed that it was resistant to attacks such as replay, impersonation, and a man in the middle, among others.

Naji, Goga, Karkar, Marin, and Ali (2021) reported a study to determine the most critical needs for a remote tracking system for COVID-19 patients. As the epidemic spreads, such systems are becoming increasingly important. The needs and value of the suggested approach, which includes a smart wristband that helps indicate patient vital signs, were evaluated. 376 people conducted the online quantitative survey. Based on the survey, most healthcare experts (97.9%) said that the automated

Table 4 Details of articles on the role of IoT in the detection of disease

Work	Aim	Proposed technique	Result
Oyenyi et al. (2020)	Practical and cost-effective solution to combat the problem arising as a result of the pandemic	Introducing IoT applications for COVID-19 epidemics	Enabling equipment to be linked across a network in the hospital and crucial locations to improve the battle over the COVID-19 epidemic
Barnawi et al. (2021)	Fever testing to see whether COVID-19 is a possibility	An IoT-based UAV system that uses the TCCD to identify COVID-19 from thermal photos at a faster rate and with practically no human interaction	The suggested system uses a UAV swarm to gather skin temperature data, then extracts face areas and analyzes thermal comfort conditions. The suggested technique also determines whether or not a person is wearing a MASK
Elagan et al. (2021)	Concentrating on linking multiple sensors to form a system that can remotely detect persons afflicted with the COVID-19	A novel method for remotely identifying COVID-19 patients based on AI technologies	The sensor-based system's results match those of the planned medical system
Saha et al. (2021)	An observation of oxygen levels in the blood to analyze the COVID-19 infection	An IoT and fog computing framework	The network-based variables have been assessed and deemed to be suitable for IoT-based healthcare. Nevertheless, adaptability has yet to be tested
Shalabi (2020)	Live to monitor of the quarantined persons, especially the eldest, during their quarantine period	Designing of a COVID-19 symptoms monitoring mechanism for isolated cases of the eldest who contacted with confirming cases of COVID-19 disease	The suggested technique aids clinicians in remotely managing this vast number of confined people The ThingSpeak IoT platform generates a graphical representation of the observed data, making analysis as simple as possible
Mingdong Zhang et al. (2021a, b)	Early diagnosis and isolation as the critical components of effective and necessary pandemic prevention and control techniques	A residual learning diagnosis detection scheme A complete workflow of RLDD	The COVID-19 detection network, based on residuals, can easily uncover lung abnormalities among positive and negative samples and simplify pre-training and diagnosis operations

Table 4 (continued)

Work	Aim	Proposed technique	Result
Rami et al. (2021)	COVID-19 diagnosis from CT scans and radiological characteristics investigation for reliable COVID-19 diagnosis	An IoMT-based COVID-19 diagnosis model utilizing diverse ML-based ranking models	The suggested model successfully diagnoses COVID-19 and severe acute respiratory syndrome compared to other approaches

wearable gadget is beneficial, affects normal healthcare chores (quarantine enforcement, early diagnosis, and patient status monitoring), and streamlines their routine healthcare operations outcomes. Furthermore, according to their professional opinion, the major vital signs should be temperature (66 percent of participants) and oxygenation level (95 percent of participants).

Mukati et al. (2021) analyzed IoT's main achievements utilizing a process diagram. Afterward, throughout the COVID-19 epidemic, seven essential IoT technologies that appear to be beneficial in healthcare were selected and demonstrated. Ultimately, they highlighted possible basic IoT applications for the medical industry in the COVID-19 epidemic, along with a brief description. Physicians may easily detect variations in COVID-19's essential characteristics using this technology.

In Ismael and Malood (2021), a medical infrastructure with a middleware and database framework that serves persons with COVID-19 mostly relies on three participants. The administrators are the first users and are divided into two groups: doctors and patients. Suppose the patient does not possess a smartphone screen or Internet access. In that case, the doctor has an app that asks questions to identify the patient being seen and collects the patient's health identification. He also asks the patient to email him an OTP (Time Programmable). If QR (Quick Response code), on the other hand, asks if his laptop is smart and connected to the Internet, the patient will be able to use the system once the doctor has inspected them. The person will evaluate himself using his equipment, and the system will inform him of his doctor's findings. When the doctor delivers new readings, he can prescribe medication. The patient can maintain it and raise the dose if it is acceptable. Doctors will operate on the prescribing console, transmitting the prescription to the cloud for verification and generating an encrypted QR code sent to the medicine receiver. The patient gets access to medication information through the recipient's app. Examining QR-protected cloud data is a once-in-a-lifetime opportunity. Until the QR's expiration date, the medication issuing outlet can only decode and provide the prescription as recommended. The initiative conforms to the General Data Protection Regulation (GDPR) and is aimed to promote and give access to care facilities for doctors and patients.

Table 5 summarizes some of the available details to summarize the articles in this section. The aim, techniques, and results of each article are summarized in the table.

3.4 Techniques used in the IoT to prevent all COVID-19 broadcasts from being broadcast

Thus, the most relevant IoT strategies and applications for preventing COVID-19 transmission and making treatment simpler were highlight in this part. In three sections, at IoT-related technologies were looked: "Detection of Disease," "Reducing Transmission," and "Patients Care." The significance of IoT-enabled/linked innovations in combatting COVID-19 in each step were assessed, including drones, wearables, IoT buttons, robots, and smartphone applications. To combat the coronavirus outbreak, IoT offers a large unified and wireless network for healthcare (Li et al. 2020). IoT wearable devices may track the sufferer's present position and

Table 5 Details of articles on the role of IoT in patient care

Work	Aim	Proposed technique	Result
Castiglione et al. (2021)	Assisting patients, physicians, and the healthcare system in identifying sufferers based on their symptoms and managing positive cases more effectively and efficiently on a global scale	The framework is made up of four parts that are linked through cloud architecture: disease symptom data collection, data warehouse, health centers/quarantine centers, and medical experts	On a real-time symptom-based dataset, random forest produced the best results, with an accuracy of 0.754
Masud et al. (2020)	Controlling COVID-19 patients remotely using IoT-enabled sensor nodes	A robust, lightweight, and physically secure MASK generating methodology	The MASK protocol uses just 656 μ l of energy and 0.0008% of a node's memory in terms of preventing attacks, computing and communicating efficiency, etc., the MASK approach exceeds the other standard protocols
Gupta (2020)	Tackling the IoMT security concern	A reciprocal verification and secret key generation technique that is both lightweight and physically safe	The formal (AVISPA) and informal security analyses showed that it was resistant to assaults such as replay, impersonation, and a man in the middle, among others
Naji et al. (2021)	The goal of this investigation was to determine the utility and needs of a remote surveillance system for COVID-19 sufferers	Implementation smart bracelets	The main criteria of these electronic wearable devices are the evaluation and supervision of vital indicators (like temperature (66%) and oxygenation level (95%))
Mukati et al. (2021)	Managing a variety of medical issues, like pace, cost, and complexity, in a suitable manner	Recognizing seven important IoT innovations that might be beneficial in the COVID-19 epidemic	As a result, these innovations allow quick access to information and communication, enhancing the patient's life quality
Ismael and Maolood (2021)	Solving the problem of hospital scarcity and access to places through which the casualty is examined	The system is divided into two stages: software and hardware. The hardware portion covers the equipment utilized to analyze the people with COVID-19, such as temperature, heartbeats, and oxygen saturation The software element is divided into three parts that reflect the frontend, mobile, and backend interfaces	This methodology brings about a dramatic transformation in the field of prescription by removing existing procedures

health-related metrics like blood oxygen saturation, pulse, and body temperature. The technologies have the potential to provide significant benefits, such as remote monitoring of the symptoms. The data acquired utilizing the created IoT wearable gadget will aid us in completely comprehending the COVID-19 virus's propagation (Lavric et al. 2022). IoT technology can potentially be tremendously helpful in combating this epidemic; however, it is vital to address data privacy (Yang et al. 2021). More individuals can engage in their therapy utilizing IoT devices with peace of mind if IoT technology is implemented effectively and securely. If this technology is applied correctly, researchers, physicians, the government, and academicians may create a better environment to combat this condition. Hence, officials and medical personnel will be better prepared to respond to pandemics. Thus, the burden of various diseases, such as hospitalizations, infections, and death rates, can be lowered dramatically. Furthermore, future research should focus on data storage and management (Wang et al. 2022). Further research will look at the procedure of building cost-effective adoption apps (Nasajpour et al. 2020a).

The following sections will discuss numerous IoT implementations throughout the coronavirus timeframe. The use of IoT to support COVID-19 requires a fully interconnected network throughout the hospital. Patients and caregivers will be able to respond more swiftly and efficiently due to this integrated network. The use of automated therapy processes is efficient and aids in properly handling situations. Telehealth consultations make healthcare more accessible to those in need. Authentic applications may also be loaded on cellphones to make the identification process more smoothly and efficiently. Because devices, places, channels, and other components are well-informed and linked, real-time information exchange and precise case handling are possible. The right diagnosis will be tried using smart linked therapy equipment as soon as the situation is discovered. Hence, the total screening procedure becomes more excellent. Using various statistical methods based on the data report provided can also assist in anticipating the future scenario. It would also help government officials, physicians, academics, and others plan a more productive working environment (Singh et al. 2020a, b).

4 Results and discussion

It is feasible to ensure the correct surveillance of patients and suspected cases in the COVID-19 epidemic by using cloud and IoT technology. It may also be utilized in COVID-19 treatment, diagnosis, pandemic management, and health care for afflicted persons. The key IoT implications for the COVID-19 outbreak are depicted in Fig. 4 (Elansary, Darwish, and Hassanien 2021).

IoT is one of these smartly used widespread technologies that play crucial roles in combating the COVID-19 pandemic. This technique showed great encouragement in the early detection of global pandemic infections (Mondal, Ghosh, Ghosh, Gupta, and Basu 2021). COVID-19 is a substantial standard and serious problem globally because of its high infectivity and transmission of severe acute respiratory syndrome COVID-19 and its elevated hospitalization rate (Mahase 2020; Sohrabi et al. 2020). For online exams, computer-based evaluation tools can be employed. It guarantees

that the system continues to work and that the stakeholders' health (trainers/lecturers, pupils, and administrative personnel) is not jeopardized. Pupil evaluation may be performed securely with these technologies because physical interaction is minimized. To protect the safety of employees, staff performance evaluations, promotion interviews, and surveys can be conducted utilizing an internet platform in the workplace. It is critical for controlling the COVID-19 pandemic's development (Mohammed and Isa 2021).

IoT plays a number of roles in healthcare in addressing the COVID-19 sufferer's issues. The effective application of IoT in health care has resulted in huge development (Bai et al. 2020). IoT devices aid in the correct therapy of infected patients. These technologies provide the foundation for creating a smart hospital that can react autonomously in an emergency. It aids in determining the most effective therapy for the diseased patient. Surveillance and supervision are done correctly and aid in providing intellectual assistance to improve the quality of COVID-19 patients' therapy. IoT may also be used to give relevant data in order to get consistent outcomes. It gives fast information about the patient in an emergency and aids in detecting errors made throughout the care of COVID-19 patients (Haleem et al. 2020).

AI schemes such as cognitive computing, deep learning, convolutional neural networks, and machine learning can aid in identification, large-scale inspection, surveillance, lowering caregiver workload, and detecting possible interactions with new antiviral medications, to name a few (Adly, Adly, and Adly 2020; Long et al. 2017; McCall 2020; Yeung et al. 2018).

The transmission of COVID-19 can be slowed by social isolation. It implies that healthcare providers must limit their contact with patients in order to avoid contracting the illness (Khan et al. 2021).

This technique allows for effective hospital administration throughout the epidemic. It serves an important role in medication surveillance by giving verified data. This info can also aid in appropriately delivering the suitable equipment/device to the right patient. This technology can help hospitals reduce wastage if they have the correct information system. The help of correctly documented data reduces the danger of hospital accidents and maintains track of all difficulties. This technique may be useful in preventing the theft of expensive medical devices. IoT produces relevant, superior, and trustworthy data with a better technological solution. It enables investigators to do human testing with the least amount of danger (Javaid and Khan 2021).

Scarcity of health tools, checking lab capacity, restricted clinical necessities, insufficient specific and defensive equipment kits, inadequate training, lack of safety throughout sample gathering, and other concerns are serious barriers that require instant focus from policymakers to prevent infection among health care workers. Blockchain, AI, IoT, robots, Drone, and auto-sanitization are examples of technologies that can reduce the direct engagement of healthcare workers at various stages, lowering the risk of healthcare worker contamination (Celesti et al. 2020; Kumar et al. 2020).

In the continuation of this section, the main features of the analyzed articles are presented in comparison to Table 6. As shown in the table, researchers in this field

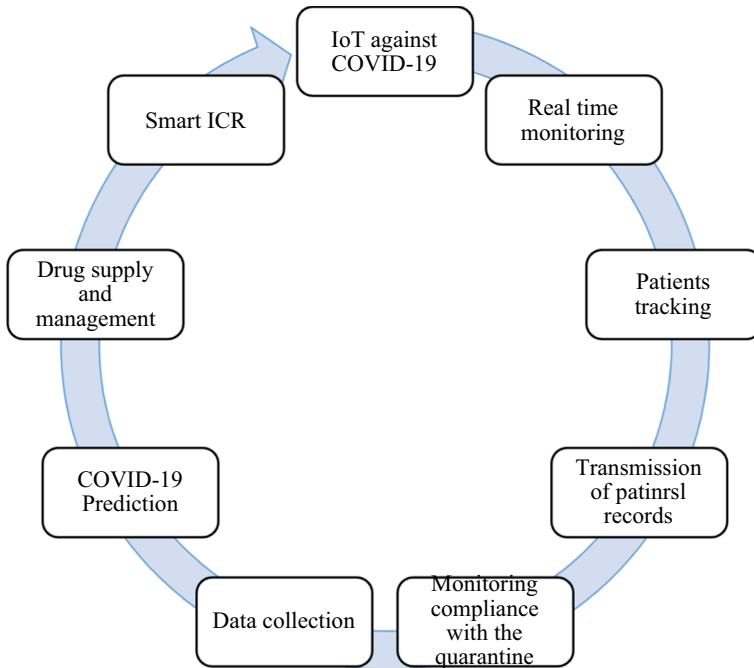


Fig. 4 The IoT main applications for the COVID-19 pandemic

have tried to provide techniques and tools to monitor people in the fastest time and with the greatest accuracy and remotely perform prevention and treatment measures.

5 Challenges

Notwithstanding its value in combating the outbreak, the IoT presents numerous challenges regarding COVID-19 management. The following are a handful of them:

- Because IoT devices have limitations like low computing speed and power, standard encryption methods like 3DES, AES, and DES seem unsuitable for IoT devices. Security algorithms must be energy efficient and have minimal computing complexity to provide data protection and privacy. It inspires investigators to create IoT security solutions that are both simple and effective (Cao et al. 2021a, b, c; Malliga, Kogilavani, and Nandhini 2021).
- According to WHO data, the most at-risk age group is over 65. People with diabetes and heart disease are also at significant risk in this epidemic condition caused by COVID-19. These individuals are finding it challenging to manage IoT devices at their age. They require the assistance of humans for an accurate reading. It will be the most difficult task for IoT (Chaudhari et al. 2020).
- A large amount of data is required to build effective machine learning systems. Using ML for COVID-19 research is currently fraught with challenges (Wu et al.

2020; Zheng et al. 2022). The absence of standard data is one of the most significant obstacles to utilizing DL to diagnose COVID-19 (Chakraborty and Abougreen 2021; Xiong et al. 2022). Another problematic issue is the dataset's sample imbalance. COVID-19 samples had fewer X-ray and CT scans than pneumonia and normal case samples. The most common way of coping with an unbalanced dataset is data augmentation. To construct new lesions from COVID-19 data, this method employs techniques such as flipping, magnification, rotation, random noise addition, and others. Another benefit of this approach is that data augmentation can help with overfitting issues (Chakraborty and Abougreen 2021; Chowdhury et al. 2020; Luz, Silva, Silva, and Moreira 2020)

- With the emergence of the COVID-19 epidemic, the usage of IoT-based devices is expanding. COVID-19 is a virus that spreads through the body. Numerous sensors are used in IoT-based wearables, each of which transmits its data via the appropriate APIs. Lately, cellular networks have provided the capacity for data flow from IoT devices to cloud storage via APIs (Wu et al. 2017). Nevertheless, with the exponential growth in the use of IoT-based wearables, cellular networks' capacity is insufficient to transport real-time data. Erroneous data is sometimes delivered to cloud storage due to a deficiency of latency and bandwidth, which significantly impacts the operational performance of IoT wearable's for COVID-19 protection (Castiglione et al. 2021).
- Indoor surveillance and forecasting have been more critical in the aftermath of the COVID-19 epidemic. Evaluating indoor air quality in a ubiquitous manner, which necessitates the placement of numerous IoT nodes at a distance from each other, is one of the work's difficulties. Grab samples or data recorded in certain windows would not offer a full indoor ambient evaluation of a workplace; hence, long-term surveillance of air purity is a requirement of the indoor workplace. Due to sensor lifetime and calibration difficulties, long-term data collecting offers hurdles (Mumtaz et al. 2021).
- The challenge with integration at the device level arises from the apps' architecture since some devices support all programming languages while others only support a few. COVID-19 uses IoT technologies and biosensors in healthcare systems to continually track critical data. As a result, continuous sensor utilization might affect skin rashes and waste more power (Elansary et al. 2021).
- A physical inspection is required to diagnose a significant percentage of health issues. Furthermore, photographs and videos transmitted by IoT-powered telemedicine may be of poor quality and require physical remediation (Mukati et al. 2021).
- In the current epidemic crisis, the key point of concern while utilizing IoT in COVID-19 is concerned with the data's privacy and security, which is distinctive and critical in terms of patient health. The second point is the care that must be taken when combining the data network among the engaged devices and procedures (Singh et al. 2020a, b).

Table 6 The comparison table

Papers	Faster	Secure	Easier to use	Accurate	Remote detec- tion	Prevent the spread of infection	Cost-effective
<i>The role of the IoT in reducing disease transmission</i>							
Angurala et al. (2020)	✗	✗	✗	✗	✗	✓	✗
Chaudhari et al. (2020)	✗	✗	✗	✗	✓	✗	✗
Singh et al. (2020a, b)	✗	✗	✗	✗	✗	✗	✓
Alrashidi (2020)	✗	✗	✗	✓	✗	✗	✗
Leila et al. (2020)	✓	✗	✗	✗	✓	✗	✗
<i>The role of IoT in the detection of disease</i>							
Oyenyi et al. (2020)	✓	✗	✓	✗	✗	✗	✗
Barnawi et al. (2021)	✓	✗	✗	✓	✗	✗	✗
Elagan et al. (2021)	✗	✗	✗	✗	✓	✗	✗
Saha et al. (2021)	✗	✗	✗	✗	✓	✗	✗
Shalabi (2020)	✓	✗	✗	✗	✓	✗	✗
Mingdong Zhang et al. (2021a, b)	✓	✗	✗	✓	✗	✗	✗
Rani et al. (2021)	✗	✗	✗	✓	✗	✗	✗
<i>The role of IoT in patient care</i>							
Castiglione et al. (2021)	✓	✗	✗	✗	✗	✗	✗
Masud et al. (2020)	✗	✓	✗	✗	✗	✗	✗
Gupta (2020)	✗	✓	✗	✗	✗	✗	✗
Naji et al. (2021)	✗	✗	✓	✗	✗	✗	✗
Mukati et al. (2021)	✗	✗	✓	✗	✗	✗	✗
Ismael and Maolood (2021)	✗	✗	✓	✗	✗	✗	✗

6 Future direction

We must change and enhance our tactics at various stages to learn more about the virus and its activities. For instance, it would be exciting to use AI power to reduce communication between healthcare providers and patients at all stages by merging AI with IoT technology. Another example is the application of touchless technology in concert with other inputs (such as gesture and speech) to slow the spread of illness and end the epidemic more quickly (Agarwal et al. 2020; Nasa-jpour et al. 2020b).

UAVs (Unmanned Aerial Vehicles) may be extremely dependable and cost-effective when tracking individuals in real-time. Drones equipped with hot infra-red cameras can produce high-definition photos that may be used to investigate regions safely. Drones can be employed to identify people with a high temperature, monitor people with gadgets, and track those who come in touch with them. To emphasize the health and welfare of healthcare workers, a variety of robots may be utilized to limit their exposure to physical labor and allow them to concentrate on all patients (Manavi et al. 2020).

Developing a ‘Smart Ambulance’ might be a new study topic for the motor industry. The ambulance should be equipped with IoT, GPS, AI-enabled voice recognition systems, biosensors, and auto sanitization devices that can link to the hospital’s server (Cao et al. 2021a, b, c). Ambulance smart services lower the danger of infection among health care workers and decrease the requirement for medical personnel (Kumar et al., 2020).

Although the cognitive IoMT can aid in the management of this worldwide epidemic to a larger level, several obstacles and loopholes must be solved. Individual data security and privacy are major concerns that might become a future study issue (Liu, Zhao, Li, Cao, and Lv 2022; Yang et al. 2020a, b). Additional issues in a highly linked heterogeneous multimodal data network include connectivity methods and resistance to malevolent assaults. This research will focus on the design and production of low-power devices, dependable communication, and energy efficiency in the future. Wearable sensors based on intelligent textiles for the IoMT can be investigated further (Swayamsiddha and Mohanty 2020).

The WHO gathers specialists from all across the globe, including government officials, to support the cycle of research and innovation, formulate global strategies to manage the COVID-19 outbreak, and give additional help to people who have been affected. In the future, mobile testing of COVID-19 may be conceivable. Mobile phones are already being used to test for malaria, human immunodeficiency virus, and tuberculosis. Antibodies created against viruses would be identified and checked using people. Although it may seem far-fetched, the cell phone can be utilized to diagnose medical ailments (Alam 2020; Feng et al. 2021). The IoT, which is based on big data, pervasive global digital connection, and real-time data analysis techniques like AI, can also be effective in an epidemic response (Azizy, Fayaz, and Agirbasli 2020).

7 Conclusion

Great attempts have been undertaken to limit the influence of the COVID-19 epidemic since it began. Around the world, the hunt for viable therapies, vaccinations, and societal management methods has escalated. AI and other developing technologies have surely played a significant impact, providing academics with fresh insights and techniques. As a result, scientific production has exploded in terms of fresh data, techniques, and conclusions, making it difficult to keep up with COVID-19's devastating effect on humanity. It has wiped off humanity's living. It has altered how we engage with one another in society. It impacted almost every area, including business, education, etc. Numerous apps and approaches have been created to help mitigate the consequences of the epidemic. By 2020, a wide range of IoT tools and technologies will be available to help address the current public-health situation. The health metrics tracked by IoT devices are uploaded to the cloud, where any doctor may analyze the patient's history. IoT points to Internet-connected devices having built-in sensors that may record, process, and/or send data to the cloud for many purposes, such as system diagnostics, control, remote surveillance, and trend analysis. The effective application of IoT can aid in the correct resolution of numerous clinical issues like speed, cost, and complexity. Additionally, by maintaining a comprehensive database for simulating and forecasting disease activity for enhanced decision-making, preparation, and online consultation, emergency remedies may be implemented at a cheap cost, minimizing the stress of medical equipment shortages. The IoT and other associated technologies like AI, robots, drones, big data, and e-learning have been identified as platforms that can help break the viral transmission cycle. AI has been used to aid in the battle against this illness. ML is used to combat COVID-19 in new ways, including detection and diagnosis, prediction, segmentation, and medication development.

ML is a promising branch of AI that has demonstrated its effectiveness in extracting information in various sectors, including medicine. This literature-based research might assist experts in devising solutions to linked difficulties and combating the COVID-19 epidemic. As a result, the current study-based investigation aims to address the benefits of emerging cloud and IoT technologies by providing perspectives on how to control the COVID-19 epidemic. Finally, this research suffers from a limitation. The main rule of this study is that only English articles have been studied here, and non-English articles have been excluded from the study. Future studies can study all articles in all languages.

Acknowledgements The second and third authors present their appreciation to King Saud University for funding this research through Researchers Supporting Program (Project number RSP-2021/323), King Saud University, Riyadh, Saudi Arabia.

Funding The research is funded by Researchers Supporting Program at King Saud University, Project number (RSP-2021/323).

References

- Abbasi S, Naderi Z, Amra B, Atapour A, Dadkhahi SA, Eslami MJ, Iraj B (2021) Hemoperfusion in patients with severe COVID-19 respiratory failure, lifesaving or not? *J Res Med Sci* 26(1):34
- Abdulsalam Y, Hossain MS (2020) Covid-19 networking demand: an auction-based mechanism for automated selection of edge computing services. *IEEE Trans Netw Sci Eng* 9:308–318
- Adly AS, Adly AS, Adly MS (2020) Approaches based on artificial intelligence and the internet of intelligent things to prevent the spread of COVID-19: scoping review. *J Med Internet Res* 22(8):e19104
- Agarwal S, Punn NS, Sonbhadra SK, Tanveer M, Nagabhushan P, Pandian K & Saxena P (2020) Unleashing the power of disruptive and emerging technologies amid COVID-19: a detailed review. *arXiv preprint arXiv:2005.11507*.
- Alam T (2020) Internet of things and blockchain-based framework for coronavirus (COVID-19) disease. Available at SSRN 3660503.
- Alashhab ZR, Anbar M, Singh MM, Leau Y-B, Al-Sai ZA, Alhayja'a SA (2021) Impact of coronavirus pandemic crisis on technologies and cloud computing applications. *J Electron Sci Technol* 19(1):100059
- Alhussein M, Muhammad G, Hossain MS, Amin SU (2018) Cognitive IoT-cloud integration for smart healthcare: case study for epileptic seizure detection and monitoring. *Mob Netw Appl* 23(6):1624–1635
- Alrashidi M (2020) Social distancing in indoor spaces: an intelligent guide based on the internet of things: covid-19 as a case study. *Computers* 9(4):91
- Angurala M, Bala M, Bamber SS, Kaur R, Singh P (2020) An internet of things assisted drone based approach to reduce rapid spread of COVID-19. *J Saf Sci Resil* 1(1):31–35
- Azam F, Munir R, Ahmed M, Ayub M, Sajid A, Abbasi Z (2019) Internet of things (Iot), security issues and its solutions. *Sci Herit J (GWS)* 3(2):18–21
- Azizy A, Fayaz M, Agirbasli M (2020) Do not forget Afghanistan in times of COVID-19: telemedicine and the internet of things to strengthen planetary health systems. *Omics J Integr Biol* 24(6):311–313
- Bai L, Yang D, Wang X et al (2020) Chinese experts' consensus on the internet of things-aided diagnosis and treatment of coronavirus disease 2019 (COVID-19). *Clinical eHealth* 3:7–15
- Baker SB, Xiang W, Atkinson I (2017) Internet of things for smart healthcare: technologies, challenges, and opportunities. *IEEE Access* 5:26521–26544
- Barnawi A, Chhikara P, Tekchandani R, Kumar N, Alzahrani B (2021) Artificial intelligence-enabled internet of things-based system for COVID-19 screening using aerial thermal imaging. *Future Gener Comput Syst* 124:119–132
- Bernheim A, Mei X, Huang M et al (2020) Chest CT findings in coronavirus disease-19 (COVID-19): relationship to duration of infection. *Radiology* 295:200463
- Cao B, Sun Z, Zhang J, Gu Y (2021a) Resource allocation in 5G IoV architecture based on SDN and fog-cloud computing. *IEEE Trans Intell Transp Syst* 22(6):3832–3840
- Cao B, Zhang W, Wang X, Zhao J, Gu Y, Zhang Y (2021b) A memetic algorithm based on two_Arch2 for multi-depot heterogeneous-vehicle capacitated arc routing problem. *Swarm Evol Comput* 63:100864
- Cao B, Zhang Y, Zhao J, Liu X, Skonieczny Ł, Lv Z (2021c) Recommendation based on large-scale many-objective optimization for the intelligent Internet of things system. *IEEE Internet Things J* 9:15030–15038
- Castiglione A, Umer M, Sadiq S, Obaidat MS, Vijayakumar P (2021) The role of internet of things to control the outbreak of COVID-19 pandemic. *IEEE Internet of Things J* 8:16072–16082
- Celesti A, Ruggeri A, Fazio M, Galletta A, Villari M, Romano A (2020) Blockchain-based healthcare workflow for tele-medical laboratory in federated hospital IoT clouds. *Sensors* 20(9):2590
- Chakraborty C, Abougreen AN (2021) Intelligent internet of things and advanced machine learning techniques for COVID-19. *EAI Endorsed Trans Pervasive Health Technol* 7(26):e1
- Chaudhari SN, Mene SP, Bora RM, Somavanshi KN (2020) Role of internet of things (IOT) in pandemic Covid-19 condition. Retrieved September, 9, 2020.
- Chowdhury ME, Rahman T, Khandakar A et al (2020) Can AI help in screening viral and COVID-19 pneumonia? *IEEE Access* 8:132665–132676
- Christaki E (2015) New technologies in predicting, preventing and controlling emerging infectious diseases. *Virulence* 6(6):558–565

- de Moraes Barroca I, Aquino Filho G, Malaquias RS, Girão G, Melo SRM (2021) An IoT-based healthcare platform for patients in ICU beds during the COVID-19 outbreak. *IEEE Access* 9:27262–27277
- Elagan S, Abdelwahab SF, Zanaty E, Alkinani MH, Alotaibi H, Zanaty ME (2021) Remote diagnostic and detection of coronavirus disease (COVID-19) system based on intelligent healthcare and Internet of things. *Results in Physics* 22:103910
- Elansary I, Darwish A, Hassanien AE (2021) In: The future scope of internet of things for monitoring and prediction of COVID-19 patients.
- Feng Y, Zhang B, Liu Y, Niu Z, Dai B, Fan Y, Chen X (2021) A 200–225-GHz manifold-coupled multiplexer utilizing metal waveguides. *IEEE Trans Microw Theory Tech* 69(12):5327–5333
- Ferrag MA, Shu L, Choo K-KR (2021) Fighting COVID-19 and future pandemics with the internet of things: security and privacy perspectives. *IEEE/CAA J Autom Sinica* 8(9):1477–1499
- Gupta B (2020) A lightweight and robust secure key establishment protocol for internet of medical things in COVID-19 patients care.
- Haleem A, Javaid M, Vaishya R, Vaish A (2020) Role of internet of things for healthcare monitoring during COVID-19 pandemic. *Apollo Med* 17(5):55
- Hanafizadeh P, Hatami P, Analoui M, Albadvi A (2021) Business model innovation driven by the internet of things technology, in internet service providers' business context. *Inf Syst e-Bus Manag* 19(4):1175–1243
- Hassen HB, Ayari N, Hamdi B (2020) A home hospitalization system based on the internet of things, fog computing and cloud computing. *Inf Med Unlocked* 20:100368
- Islam SR, Kwak D, Kabir MH, Hossain M, Kwak K-S (2015) The internet of things for health care: a comprehensive survey. *IEEE Access* 3:678–708
- Ismael MH, Maolood AT (2021) Developing modern system in healthcare to detect COVID 19 based on internet of things. *Materials today. Proceedings*.
- Janiesch C, Fischer M, Winkelmann A, Nentwich V (2019) Specifying autonomy in the internet of things: the autonomy model and notation. *IseB* 17(1):159–194
- Javaid M, Khan IH (2021) Internet of things (IoT) enabled healthcare helps to take the challenges of COVID-19 pandemic. *J Oral Biol Craniofac Res* 11(2):209–214
- Joyia GJ, Liaqat RM, Farooq A, Rehman S (2017) Internet of medical things (IoMT): applications, benefits and future challenges in healthcare domain. *J Commun* 12(4):240–247
- Khan ZA, Abbasi U, Kim SW (2021) Machine learning and LPWAN based internet of things applications in healthcare sector during COVID-19 pandemic. *Electronics* 10(14):1615
- Kumar S, Raut RD, Narkhede BE (2020) A proposed collaborative framework by using artificial intelligence-internet of things (AI-IoT) in COVID-19 pandemic situation for healthcare workers. *Int J Healthc Manag* 13(4):337–345
- Lavric A, Petrariu AI, Mutescu P-M, Coca E, Popa V (2022) Internet of things concept in the context of the COVID-19 pandemic: a multi-sensor application design. *Sensors* 22(2):503
- Leila E, Othman SB, Sakli H (2020) An internet of robotic things system for combating coronavirus disease pandemic (COVID-19). Paper presented at the 2020 20th International conference on sciences and techniques of automatic control and computer engineering (STA).
- Li A, Masouros C, Swindlehurst AL, Yu W (2021) 1-bit massive MIMO transmission: embracing interference with symbol-level precoding. *IEEE Commun Mag* 59(5):121–127
- Li A, Spano D, Krivovicha J et al (2020) A tutorial on interference exploitation via symbol-level precoding: overview, state-of-the-art and future directions. *IEEE Commun Surv Tutorials* 22(2):796–839
- Lin H, Garg S, Hu J, Wang X, Piran MJ, Hossain MS (2020) Privacy-enhanced data fusion for COVID-19 applications in intelligent internet of medical Things. *IEEE Internet Things J* 8:15683–15693
- Lin B, Wu S (2020) COVID-19 (Coronavirus disease 2019): opportunities and challenges for digital health and the internet of medical things in China. *OMICS J Integr Biol* 24(5):231–232
- Liu X, Zhao J, Li J, Cao B, Lv Z (2022) Federated neural architecture search for medical data security. *IEEE Trans Ind Inf.* 18:5628–5636
- Long E, Lin H, Liu Z et al (2017) An artificial intelligence platform for the multihospital collaborative management of congenital cataracts. *Nat Biomed Eng* 1(2):1–8
- Luz E, Silva PL, Silva R, Moreira G (2020) Towards an efficient deep learning model for covid-19 patterns detection in x-ray images. *arXiv preprint arXiv:2004.05717*
- Lv Z, Yu Z, Xie S, Alamri A (2022c) Deep learning-based smart predictive evaluation for interactive multimedia-enabled smart healthcare. *ACM Trans Multimed Comput Commun Appl (TOMM)* 18(1s):1–20

- Lv Z, Chen D, Feng H, Zhu H, Lv H (2021) Digital twins in unmanned aerial vehicles for rapid medical resource delivery in epidemics. *IEEE Tran Intell Transp Syst*
- Lv Z, Chen D, Lv H (2022a) Smart city construction and management by digital twins and BIM big data in COVID-19 scenario. *ACM Trans Multimid Comput Commun Appl*
- Lv Z, Guo J, Lv H (2022b) Safety poka yoke in zero-defect manufacturing based on digital twins. *IEEE Trans Ind Inf*
- Mahase E (2020) Coronavirus: covid-19 has killed more people than SARS and MERS combined, despite lower case fatality rate. *British Medical Journal Publishing Group*
- Malliga S, Kogilavani S, Nandhini P (2021) A comprehensive review of applications of internet of things for Covid-19 pandemic. Paper presented at the IOP conference series: materials science and engineering
- Manavi SY, Nekkanti V, Choudhary RS, Jayapandian N (2020) Review on emerging internet of things technologies to fight the COVID-19. Paper presented at the 2020 5th international conference on research in computational intelligence and communication networks (ICRCICN).
- Masud M, Gaba GS, Alqahtani S, Muhammad G, Gupta B, Kumar P, Ghoneim A (2020) A lightweight and robust secure key establishment protocol for internet of medical things in COVID-19 patients care. *IEEE Internet Things J* 8:15694–15703
- McCall B (2020) COVID-19 and artificial intelligence: protecting healthcare workers and curbing the spread. *Lancet Digit Health* 2(4):e166–e167
- Misra S, Deb PK, Koppala N, Mukherjee A, Mao S (2020) S-Nav: safety-aware IoT navigation tool for avoiding COVID-19 Hotspots. *IEEE Internet Things J* 8(8):6975–6982
- Mohammed IB, Isa SM (2021) The role of internet of things (IoT) in the containment and spread of the novel COVID-19 pandemic. *Computational intelligence methods in COVID-19: surveillance, prevention, prediction and diagnosis*. Springer, pp 109–119
- Mondal S, Ghosh I, Ghosh S, Gupta A, Basu D (2021) Role of the internet of things for early detection of Covid-19 infections: a comprehensive survey. Available at SSRN 3882424
- Muhasin HJ, Jabar MA, Abdullah S, Kasim S (2017) Managing sensitive data in cloud computing for effective information systems' decisions. *Acta Inform Malaysia* 1(2):1–2
- Mukati N, Namdev N, Dilip R, Hemalatha N, Dhiman V, Sahu B (2021) Healthcare assistance to COVID-19 patient using internet of things (IoT) enabled technologies. *Materials today: Proceedings*
- Mukherjee M, Matam R, Shu L, Maglaras L, Ferrag MA, Choudhury N, Kumar V (2017) Security and privacy in fog computing: challenges. *IEEE Access* 5:19293–19304
- Mumtaz R, Zaidi SMH, Shakir MZ et al (2021) Internet of things (IoT) based indoor air quality sensing and predictive analytic—a COVID-19 perspective. *Electronics* 10(2):184
- Munzert S, Selb P, Gohdes A, Stoetzer LF, Lowe W (2021) Tracking and promoting the usage of a COVID-19 contact tracing app. *Nat Hum Behav* 5(2):247–255
- Naji HK, Goga N, Karkar AJ, Marin I, Ali HA (2021) Internet of things and health care in pandemic COVID-19: system requirements evaluation. Paper presented at the 2021 7th international engineering conference “Research & innovation amid global pandemic” (IEC).
- Nasajpour M, Pouriyeh S, Parizi RM, Dorodchi M, Valero M, Arabia HR (2020a) Internet of things for current COVID-19 and future pandemics: an exploratory study. *J Healthc Inform Res* 4(4):325–364
- Nasajpour M, Pouriyeh S, Parizi RM, Dorodchi M, Valero M, Arabia HR (2020b) internet of things for current COVID-19 and future pandemics: An exploratory study. *J Healthc Infor Res* 1–40
- Nasser N, Emad-ul-Haq Q, Imran M, Ali A, Razzak I, Al-Helali A (2021) A smart healthcare framework for detection and monitoring of COVID-19 using IoT and cloud computing. *Neural Comput Appl* 1–15
- Oyeniya J, Ogundoyin I, Oyenan O, Omotosho L (2020) Application of internet of things (IoT) to enhance the fight against COVID-19 pandemic. *Int J Multi Sci Adv Technol* 1(3):38–42
- Qasem Y, Abdullah R, Atan R, Jusoh YY (2018) Towards developing a cloud-based education as a service (CEAAS) model for cloud computing adoption in higher education institutions. *Complexity* 6(7):19–20
- Rahman MS, Peeri NC, Shrestha N, Zaki R, Haque U, Ab Hamid SH (2020) Defending against the novel coronavirus (COVID-19) outbreak: how can the Internet of things (IoT) help to save the world? *Health Policy Technol* 9(2):136
- Rani SS, Selvakumar S, Kumar KPM, Tai DT, Chelvi ED (2021) Internet of medical things (IoMT) with machine learning–based COVID-19 diagnosis model using chest X-ray images. *Data science for COVID-19*. Elsevier, pp 627–641


- Roy A, Kumbhar FH, Dhillon HS, Saxena N, Shin SY, Singh S (2020) Efficient monitoring and contact tracing for COVID-19: a smart IoT-based framework. *IEEE Internet Things Mag* 3(3):17–23
- Saha R, Kumar G, Kumar N, Kim T-H, Devgun T, Thomas R, Barnawi A (2021) Internet of things framework for oxygen saturation monitoring in COVID-19 environment. *IEEE Internet Things J* 9:3631–3641
- Shalabi M (2020) COVID-19 symptoms monitoring mechanism using internet of things and wireless sensor networks. *IJCSNS* 20(8):16
- Singh RP, Javaid M, Haleem A, Suman R (2020a) Internet of things (IoT) applications to fight against COVID-19 pandemic. *Diabetes Metab Syndr* 14(4):521–524
- Singh V, Chandna H, Kumar A, Kumar S, Upadhyay N, Utkarsh K (2020b) IoT-Q-Band: a low cost internet of things based wearable band to detect and track absconding COVID-19 quarantine subjects. *EAI Endorsed Trans Internet Things* 6(21):163997
- Siriwardhana Y, De Alwis C, Gür G, Ylianttila M, Liyanage M (2020) The fight against the COVID-19 pandemic with 5G technologies. *IEEE Eng Manag Rev* 48(3):72–84
- Sohrabi C, Alsafi Z, O’neill N et al (2020) World Health Organization declares global emergency: a review of the 2019 novel coronavirus (COVID-19). *Int J Surg* 76:71–76
- Sun Q, Lin K, Si C, Xu Y, Li S, Gope P (2022) A secure and anonymous communicate scheme over the internet of things. *ACM Trans Sens Netw (TOSN)* 18:1–21
- Swayamsiddha S, Mohanty C (2020) Application of cognitive Internet of medical things for COVID-19 pandemic. *Diabetes Metab Syndr* 14(5):911–915
- Udgata SK, Suryadevara NK (2021) COVID-19, sensors, and internet of medical things (IoMT). *Internet of things and sensor network for COVID-19*. Springer, pp 39–53
- Vahdat S (2020) The role of IT-based technologies on the management of human resources in the COVID-19 era. *Kybernetes*
- Vahdat S (2022) A review of pathophysiological mechanism, diagnosis, and treatment of thrombosis risk associated with COVID-19 infection. *IJC Heart Vasc* 41:101068. <https://doi.org/10.1016/j.ijcha.2022.101068>
- Vahdat S, Samanian S, Shahidi S, Atapour A (2021) POS-497 characteristics and outcome of COVID-19 in patients on chronic hemodialysis in a dialysis center specific for COVID-19. *Kidney Int Rep* 6(4):S215
- Vahdat S, Shahidi S, Atapour A, Reiszadeh S, Soltaninejad F, Maghami-Mehr A (2021) POS-214 The outcome of COVID-19 patients with acute kidney injury and the factors affecting mortality. *Kidney Int Rep* 6(4):S90
- Wan J, Al-awlaqi MA, Li M, O’Grady M, Gu X, Wang J, Cao N (2018) Wearable IoT enabled real-time health monitoring system. *EURASIP J Wirel Commun Netw* 2018(1):1–10
- Wang K, Wang H, Li S (2022) Renewable quantile regression for streaming datasets. *Knowl-Based Syst* 235:107675
- Wu Z, Li C, Cao J, Ge Y (2020) On Scalability of Association-rule-based recommendation: a unified distributed-computing framework. *ACM Trans Web (TWEB)* 14(3):1–21
- Wu Z, Song A, Cao J, Luo J, Zhang L (2017) Efficiently translating complex SQL query to mapreduce jobflow on cloud. *IEEE Trans Cloud Comput* 8(2):508–517
- Xiong Z, Mo F, Zhao X, Xu F, Zhang X, Wu Y (2022) Dynamic texture classification based on 3D ICA-Learned filters and fisher vector encoding in big data environment. *J Signal Process Syst* 1–15.
- Yang W, Chen X, Xiong Z, Xu Z, Liu G, Zhang X (2021) A privacy-preserving aggregation scheme based on negative survey for vehicle fuel consumption data. *Inf Sci* 570:526–544
- Yang T, Gentile M, Shen C-F, Cheng C-M (2020a) Combining point of care diagnostics and internet of medical things (IoMT) to combat the COVID-19 pandemic: multidisciplinary digital publishing institute
- Yang Y, Huang J, Zhang T, Weinman J (2020b) In: fog and fogonomics: challenges and practices of fog computing, communication, networking, strategy, and economics. John Wiley & Sons
- Yeung S, Downing NL, Fei-Fei L, Milstein A (2018) Bedside computer vision-moving artificial intelligence from driver assistance to patient safety. *N Engl J Med* 378(14):1271–1273
- Yuehong Y, Zeng Y, Chen X, Fan Y (2016) The Internet of things in healthcare: an overview. *J Ind Inf Integr* 1:3–13
- Zhang M, Chen Y, Lin J (2021a) A privacy-preserving optimization of neighborhood-based recommendation for medical-aided diagnosis and treatment. *IEEE Internet Things J* 8(13):10830–10842
- Zhang M, Chen Y, Susilo W (2020) PPO-CPQ: a privacy-preserving optimization of clinical pathway query for e-healthcare systems. *IEEE Internet Things J* 7(10):10660–10672

- Zhang M, Chu R, Dong C, Wei J, Lu W, Xiong N (2021b) Residual learning diagnosis detection: an advanced residual learning diagnosis detection system for COVID-19 in industrial internet of things. *IEEE Trans Industr Inf* 17(9):6510–6518
- Zheng W, Cheng J, Wu X, Sun R, Wang X, Sun X (2022) Domain knowledge-based security bug reports prediction. *Knowl-Based Syst* 241:108293

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.

Authors and Affiliations

Mehdi Darbandi¹ · Adel F. Alrasheedi² · Khalid A. Alnowibet² · Danial Javaheri³ · Abolfazl Mehbodniya⁴ 

Adel F. Alrasheedi
aalrasheedi@ksu.edu.sa

Khalid A. Alnowibet
knowibet@ksu.edu.sa

Abolfazl Mehbodniya
a.niya@kcst.edu.kw

- ¹ Department of Electrical and Electronic Engineering, Eastern Mediterranean University, Gazimagusa, Via Mersin 10, Turkey
- ² Statistics and Operations Research Department, College of Science, King Saud University, Riyadh 11451, Kingdom of Saudi Arabia
- ³ Department of Computer Engineering, Chosun University, Gwangju 61452, Republic of Korea
- ⁴ Department of Electronics and Communication Engineering, Kuwait College of Science and Technology (KCST), 7Th Ring Road, Doha Area, Kuwait