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A survey of smart dustbin systems using the IoT and deep learning

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Abstract

With massive population growth and a shift in the urban culture in smart cities, the constant generation of waste continues to create unsanitary living conditions for city dwellers. Overflowing solid waste in the garbage and the rapid generation of non-degradable solid waste produce a slew of infectious illnesses that proliferate throughout the ecosystem. Conventional solid waste management systems have proved to be increasingly harmful in densely populated areas like smart cities. Also, such systems require real-time manual monitoring of garbage, high labor costs, and constant maintenance. Monitoring waste management on a timely basis and reducing labor costs is scarcely possible, realistically, for a municipal corporation. A Smart Dustbin System (SDS) is proposed that is to be implemented in densely populated urban areas to ensure hygiene. This paper undertakes a comprehensive analysis of the application of smart dustbin systems, following an extensive literature review and a discussion of recent research that is expected to help improve waste management systems. A current SDS used in real-time is implemented with the most recent advances from deep learning, computer vision, and the Internet of Things. The smart dustbin system used in day-to-day life minimizes the overloading of bins, lowers labor costs, and saves energy and time. It also helps keep cities clean, lowering the risk of disease transmission. The primary users of the SDS are universities, malls, and high-rise buildings. The evolution of the SDS over the years with various features and technologies is well analyzed. The datasets used for Smart Waste Management and benchmark garbage image datasets are presented under AI perception. The results of the existing works are compared to highlight the potential limitations of these works.

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Keywords Waste management · Smart bin machine learning · IoT · Classification

1 Introduction

Waste management is the process of managing waste from disposal to demolition. Waste might be in gaseous, liquid, or solid form and can be categorized as industrial and biological, or that generated by buildings, universities, and households, among others (Thada et al. 2019). Waste is segregated on the basis of the collection made by each category. The segregated waste may be biodegradable or non-biodegradable. A rapidly expanding population, technological advancements, urbanization, and unprecedented development have all contributed to the increased growth of the consumer goods industry. Consequently, the business of dealing with increasingly complex forms of waste has become a reality for the sustenance of a healthy environment. The government has taken measures to manage waste by differentiating between degradable and non-degradable items through the use of differently-colored dustbins, particularly for the hygienic disposal of medical waste, and creating a phase-by-phase time schedule for source segregation and a door-to-door subsidy collection of waste.

However, the basic issue with standard dustbins is that the garbage tends to spill over and is often found thrown in and around the bin rather than into it, which makes the surroundings filthy. The focus of this paper is the disposal and collection of garbage at regular time intervals, monitoring garbage levels, and notifying the nearest station about the same. Several studies on solid waste monitoring and management have been conducted over the years. Waste management tasks (Aravindaraman and Ranjana 2019) present a number of technological difficulties. The approach proposed in Reddy et al. (2017) detects the volume of garbage in the dustbin. Depending upon the level of garbage the dustbin is filled with, a decision is taken on whether to keep the lid open or shut, notwithstanding the fact that people might still intend to continue dumping their trash in the dustbin. The containers are equipped with a sensor that detects the weight and volume of the trash thrown into them. Every dustbin in the city is provided a unique ID that identifies the location of full bins.

Another study (Huang and Koroteev 2021; Gopalakrishnan et al. 2021) advanced a scheme that collects pictures of bins to check the level of trash in each. Given that the center does not get real-time status updates on bins, a picture is taken when the garbage collection truck reaches the location of a particular dustbin. The central location only has at its disposal all of the previously collected data. This research (Medvedev et al. 2015) focused on a framework that employs different types of sensors to detect bin levels sufficiently early. Sensors such as ultrasonics, pressure, toxicity, force, and level, as well as light-emitting diodes (LED), are used for miscellaneous purposes (Al Mamun et al. 2015). However, the data gathered in the system are not adequate enough for a dynamic assessment to be carried out. Trash management encompasses all of the procedures and actions required to handle waste from beginning to end, and may be accomplished by deploying smart dustbins to enable IoT-based waste management (Catarinucci et al. 2020; Saha et al. 2023; Yadav et al. 2022). Smart cities are a popular concept in today's technology-driven world. An urban metropolis is incomplete without an integrated waste management system.

Developing countries like India (Thada et al. 2019; Ayush et al. 2019; Pereira et al. 2019; Shamin et al. 2019; Aravindaraman and Ranjana 2019; Raaju et al. 2019; Lopes and Machado 2019; Huang and Koroteev 2021; Sinha et al. 2020; Nidhya et al. 2020; Bharadwaj et al. 2017; Jagtap et al. 2020; Nirde et al. 2017; Reddy et al. 2017; Jardosh et al.

2020; Paul et al. 2018; Shaikh et al. 2020; Sidharth et al. 2020; Anitha et al. 2018; Tripathi et al. 2018; Ashwinet al. 2021; Misra et al. 2018; Rao et al. 2020; Shetty and Salvi 2020; Dubey et al. 2020; Susanth et al. 2021; Mohapatra and Shirapuri 2020; Kansara et al. 2019; Chakraborty 2020; Pal et al. 2022), South Korea (Arindam et al. 2022), Malaysia (Al Mamun et al. 2015; Sheng et al. 2020), Bangladesh (Sarker et al. 2020), Philippines (Rabano et al. 2018), Indonesia (Maulana et al. 2018), Iran (Zaeimi and Rassafi 2021), Tunisia (Jammeli et al. 2023), Egypt (Alsobky et al. 2023) focus on design a smart waste management system and smart garbage bin in a cost-efficient manner. The high population and large landscape in countries such as India and China demand large-scale and complex working structures of smart waste management systems. One biggest challenges in the smart waste management systems of these countries is to find an efficient method for garbage collection around the city at peak hours. At the same time, developed countries like USA (Ramson et al. 2021), Japan (Wang et al. 2021), Italy (Catarinucci et al. 2020; Castellano et al. 2021), Qatar (Sheng et al. 2020; Alqahtani et al. 2020), Saudi Arabia (Sheng et al. 2020; Alqahtani et al. 2020), and China (Peng et al. 2021; Lu et al. 2017b; Xin et al. 2022) enhance smart waste management systems to cope with smart city requirements and technologies. The landscape nature of the hill regions especially India, China and South Korea introduces an additional design requirement to find an optimal route for the waste collection process.

The objectives of our review of smart waste management systems include the following:

- Examining the evolution over time of smart waste management systems (SWMs) and smart garbage bins (SGBs) with publication statistics
- Analysing core SGB techniques such as sensors, data communication, Artificial Intelligence models, IoT-enabled embedded devices, vehicle routing, and self-driving bins
- Discovering the unique intent behind every SWM and SGB design
- Analysing and comparing existing and self-made garbage image datasets and trained classification models
- Identifying research gaps to improve SWM and SGB designs in line with their performance and user demands

This review paper is structured as follows. Section 1 and Sect. 2 introduce viable approaches to smart waste management (SWM) and smart garbage bin (SGB) systems. Section 3 presents the publication statistics of this state-of-the-art work. Section 4 surveys the existing literature on the subject and draws comparisons. Section 5 describes the advances made in SWM and SGB systems alongside rapid improvements in technology. Section 6 and Sect. 7 detail the technologies and datasets used for the SWM and SGB systems. Section 8 compares the performance metrics of existing methodologies. Section 9 highlights the research scope identified in this study area using the review and Sect. 10 concludes the work.

2 Smart dustbin

The goal of the initiative is to recycle rubbish and put it to good use for the environment. Waste management includes the collection, treatment, and disposal of solid waste that is no longer usable. Figure 1 depicts the overall architecture of a smart waste management

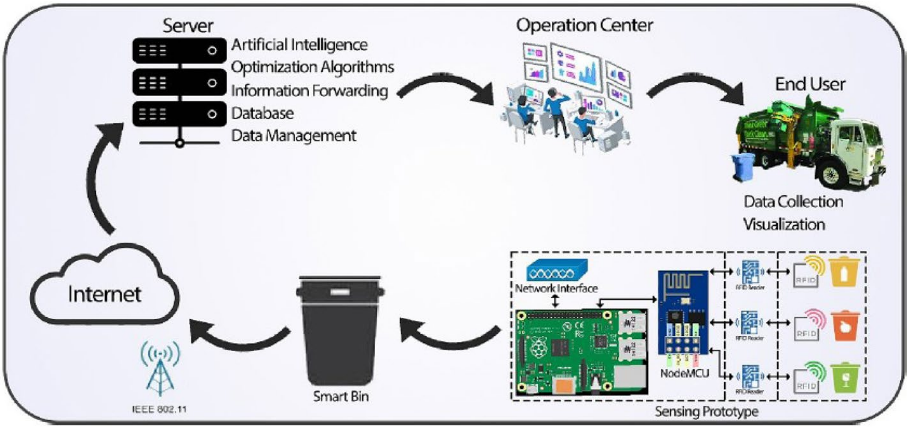

Fig. 1 Architecture of smart waste management system (Saha et al. 2023)

system. Unsafe conditions stemming from improper waste management in cities engender air pollution and the spread of rodent- and insect-borne diseases. A smart dustbin scheme is to be implemented.to ensure a safe, clean, and hygienic environment. The overall objectives of smart bin use are presented in Table 1 and its continuation in Table 2.

Technology drives smart bin use and makes for an efficient system through waste segregation. Much research has been carried out on waste management systems. An efficient smart bin waste management system advanced in Thada et al. (2019) and Al Mamun et al. (2015) displays the level of solid waste in the bin. Further, the research moves towards the direction of segregating the waste in an automatic manner using multiple sensors (Jardosh et al. 2020; Rabano et al. 2018; Shaikh et al. 2020; Sidharth et al. 2020; Wang et al. 2021; Shetty and Salvi 2020; Susanth et al. 2021). An ultrasonic sensor used in Ayush et al. (2019) and Pereira et al. (2019) opens and shuts lids to check bin levels. An LED light (Kansara et al. 2019) indicator provided alongside shows the updated status of the bin in the database, using a cloud (Lopes and Machado 2019). Later, degradable and non-degradable waste (Shamin et al. 2019) are classified automatically using machine learning algorithms. Employing sensors in smart dustbins furthers the process and reduces manpower.

Ultrasonic sensors are used to open dustbin lids automatically (Ashwinet al. 2021; Misra et al. 2018). Gas sensors sense the emission of harmful/toxic gases (Aravindaraman and Ranjana 2019; Reddy et al. 2017) and, depending on the volume emitted, a warning is issued to the garbage collector in the form of an alert for the lid to be kept shut (Dubey et al. 2020; Kansara et al. 2019). The use of an electrical connection, however, renders smart bins immobile. Advances made in this direction include the embedding of solar panels for energy efficiency (Raaju et al. 2019; Sarker et al. 2020). Also, the use of GPS location (Tripathi et al. 2018; Zaeimi and Rassafi 2021; Ramson et al. 2021) helps users find the nearest dustbins. Machine learning algorithms (Huang and Koroteev 2021; Nidhya et al. 2020) are applied to segregate different energy-based products. Sustainability is enhanced with the use of smart bins, given the efficiency and effectiveness of improved models (Lu et al. 2017b; Bharadwaj et al. 2017). The extensive application of the Internet of Things (IoT) in urban areas, coupled with GPS location and an array of sensors, has helped in waste segregation, particularly in terms of the status of dustbin levels (Jagtap et al. 2020; Anitha et al. 2018; Alqahtani et al. 2020; Ramson et al. 2021). The work in

Maulana et al. (2018) and Zaeimi and Rassafi (2021) focused on garbage collection, recycling, and disposal in line with municipal solid waste management system guidelines.

Weighted goal programming (WGP) and fuzzy chance-constrained programming are used to cut costs and reduce pollutant emissions. A blockchain model is applied for efficient waste management (Gopalakrishnan et al. 2021), while social media-driven sentiment dynamics are used for better waste segregation and recycling in order to exert maximum impact on waste management policies (Peng et al. 2021). Users are authorized to access bins and segregation is automated (Sheng et al. 2020; Catarinucci et al. 2020). Waste is segregated into three categories—biodegradable, non-biodegradable, and recyclable (Paul et al. 2018) - from the point of view of hygiene. The introduction of smart bins with IoT technologies, machine learning algorithms, and sensors alone will not suffice to meet the specific needs of waste management systems. Raising awareness among the general public and involving its members in waste management is central to keeping the surroundings clean. In Castellano et al. (2021), an interesting framework for recycling waste is presented through a game-based robot dustbin to underscore the importance of recycling and managing waste. The playing robot is so built that it puts together a history of the daily waste collected so as to create a database and, additionally, it forecasts the future development of dustbins using deep learning algorithms (Misra et al. 2018). Collecting garbage and segregating waste are not the only tasks of smart waste management systems. The status of bins is to be ascertained and their locations within the city are checked (Rao et al. 2020; Mohapatra and Shirapuri 2020; Ghahramani et al. 2022; Arindam et al. 2022; Alsobky et al. 2023; Pal et al. 2022; Xin et al. 2022) using the IoT to connect networks (Ramson et al. 2021; Kansara et al. 2019). Finally, an analysis is made of the waste material collected and segregated, as well as the type of dustbin used Alqahtani et al. (2020). Figures 2 and 3 show sample 3D models of smart garbage bins and the real-time hardware used to operate them, as seen in existing work on the subject (Sheng et al. 2020; Jin et al. 2023).

The application of transfer learning models, with or without sensors in garbage bins, enhances the automatic garbage segregation process, and is discussed in detail in Section 5.2. The use of deep learning models automatically resolves the manual checking of

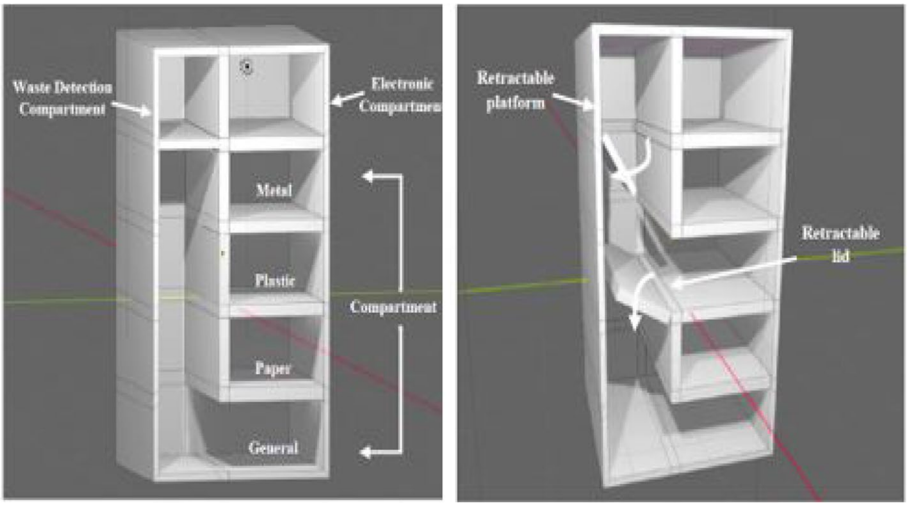

Fig. 2 3D model of smart garbage bin before and after waste identification (Sheng et al. 2020)

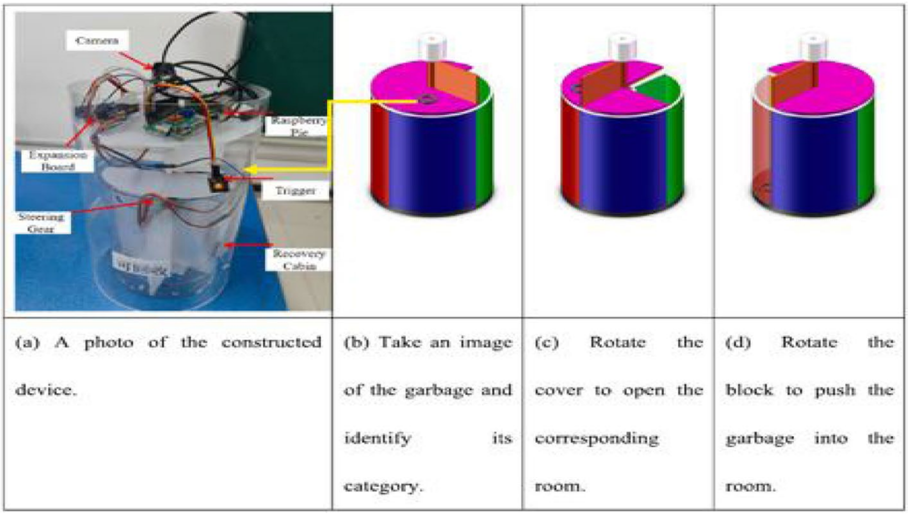

Fig. 3 Smart garbage device (Jin et al. 2023)

bins for their status (He et al. 2022; Agnew et al. 2023; Oğuz et al. 2023; Yadav et al. 2022). Bins located all along entire city streets are continuously monitored by cameras in the vicinity and their status is determined using trained models. The location of the city's filled bins and the kind of garbage in them help the waste management department plan the waste collection process accordingly. The truck type, number of trucks and workers, type of garbage collection, disposal based on garbage type, and a cost-efficient dynamic route that covers every filled bin are mandatory components of the waste collection process. The GPS, IoT, blockchain, deep learning, computer vision, VANET, and optimized dynamic routing are the techniques chiefly used for this purpose in SWM systems. The required number of waste bins and their optimal locations in the city are discussed using dynamic shortest path optimized algorithms (Jin et al. 2023), a deep learning model (Pal et al. 2022) and Voronoi technology with a clustering algorithm (Xin et al. 2022). Apart from these, the uses listed in Table 1 and Table 2 include smart waste management for a Covid-19 pandemic environment (Saha et al. 2023) and robots for garbage grabbing and sorting in real-time (Chunxiang et al. 2022).

3 Statistical report

Current work pertaining to smart bins was sourced from major research paper publications such as the IEEE, Elsevier, Springer, and ACM, to mention only a few. Conference and journal publications were considered for the duration of the search commencing 2015. Relevant keywords like "intelligent dustbin", "intelligent bin", "smart bin", "smart dustbin", "smart bin with automatic garbage segregation", "smart bin with IoT", "smart bin with ML", and "smart bin with DL" were used to examine research from the publishers selected. Following the exclusion of a few papers that were irrelevant to the problem statement, 83 papers in all were finally used for the literature survey. Figure 4 depicts the publication statistics of the existing papers, especially in terms of the number of publications brought

Table 1 Objectives of smart dustbin system

Intention of the smart dustbin systems	Year of publication	Type of garbage
Efficient Work Management System for Cleaners by observing the status of the bin (Thada et al. 2019; Al Mamun et al. 2015)	2019, 2015	Solid waste
Voice control system to move the robot bin towards you and open the lid to collect the trash. LED in the robot bin shows the status of the bin. It avoids the user to touch the bin or go nearer to the bin (Ayush et al. 2019; Kansara et al. 2019)	2019, 2018	–
Automatic segregation of waste based on the type along with LED to show the bin level (Pereira et al. 2019; Jardosh et al. 2020; Rabano et al. 2018; Shaikh et al. 2020; Sidharth et al. 2020; Wang et al. 2021; Shetty and Salvi 2020; Susanth et al. 2021)	2019, 2020, 2018, 2020, 2020, 2021, 2020, 2020	dry, wet and plastic wastes/glass, paper, cardboard, plastic, metal, and other trash / bio-degradable and non-biodegradables wastes / plastic, paper, cardboard, metals wastes/raw, dry and metallic wastage / 6 types of glass wastes
Classify the degradable and non-degradable waste and alarm buzzer if any wrong placement of garbage. Filling status of the bin is updated in the cloud (Shamin et al. 2019; Lopes and Machado 2019)	2019	Metal and Non-metal objects
Senses the user presence to automatic lid open for garbage collection from the user. If any harmful gases are emitted or bis is filled then it won't open the lid and send a message to the garbage collector (Aravindaraman and Ranjana 2019; Reddy et al. 2017; Ashwinet al. 2021; Misra et al. 2018; Dubey et al. 2020; Kansara et al. 2019)	2019, 2017, 2021, 2018, 2020, 2018	Dry and wet wastes/biodegradable and non-biodegradable wastes/ Dry, wet and metallic wastes
Energy efficient bin embedded with solar panel and informs the filled status of the bin with GPS location (Raaju et al. 2019; Sarker et al. 2020; Tripathi et al. 2018; Zaeimi and Rassafi 2021; Ramson et al. 2021)	2019, 2020, 2018, 2021, 2020	All
Energy efficient path to collect the waste (Huang and Koroteev 2021; Nidhya et al. 2020; Lu et al. 2017b; Bharadwaj et al. 2017; Jagtap et al. 2020; Anitha et al. 2018; Maulana et al. 2018; Zaeimi and Rassafi 2021; Alqahtani et al. 2020; Ramson et al. 2021)	2021, 2020, 2015, 2017, 2020, 2018, 2021, 2020, 2020	All
Efficient waste collection, sorting, and selling management system using Block Chain technique (Gopalakrishnan et al. 2021; Saad et al. 2023)	2021, 2023	All

Table 1 (continued)

Intention of the smart dustbin systems	Year of publication	Type of garbage
Waste collection management system with dynamic scheduling and routing for smart cities (Medvedev et al. 2015; Sinha et al. 2020; Lu et al. 2017b; Bharadwaj et al. 2017; Jagtap et al. 2020; Nirde et al. 2017; Ghahramani et al. 2022; Arindam et al. 2022; Alsobky et al. 2023; Yuvaraj et al. 2022; Pal et al. 2022; Xin et al. 2022)	2015, 2020, 2015, 2017, 2020, 2017, 2022, 2022, 2023, 2022, 2022, 2020	All
Waste management and segregation-related social media platforms to allow a user to post their comments related to this issue (Peng et al. 2021)	2021	All
Automatic garbage segregation and user authorization to access the bin and trace their usage of the garbage (Sheng et al. 2020; Catarinucci et al. 2020)	2020	All

Table 2 Objectives of smart dustbin system (Table1 Continuation)

Intention of the smart dustbin systems	Year of publication	Type of garbage
Find the objectionable object in the dustbin and then send the warning message to the garbage collector. Automatic segregation of different garbage is also embedded in the dustbin (Paul et al. 2018)	2018	Biodegradable, non-biodegradable and recyclable wastes
Recyclable wastes awareness game for children using robot dustbin (Castellano et al. 2021)	2021	Recyclable and non-recyclable wastes
Forecast future state of dustbin from its history of daily collection (Misra et al. 2018; Jammeli et al. 2023; Likotiko et al. 2023; John et al. 2022)	2018, 2021, 2023, 2021	
Inform the garbage collector if the bin is full with its location within the city (Rao et al. 2020; Mohapatra and Shirapuri 2020; Ramson et al. 2021; Kansara et al. 2019)	2020, 2020, 2020, 2018	All
Analyze the waste, bin size, truck type and waste materials (Alqahtani et al. 2020)	2020	All
Garbage Image classification using Transfer Learning based Deep Learning Models (Li et al. 2022; Wu et al. 2022; Thamarai et al. 2023; Li et al. 2023a; Jin et al. 2023; Chen et al. 2023; Fatma et al. 2023; Gupta et al. 2022; Li et al. 2023b)	2021, 2022, 2023, 2023, 2023, 2023, 2023, 2021, 2023	Organic & inorganic household wastes / Recycling & non-recycling wastes / Bio & non-bio wastes
Automatic Bin Status (Open Full/Open Empty/Close Full/Close Empty) Identification using Computer Vision and Deep Learning Models and Initiate the garbage collection process accordingly (He et al. 2022; Agnew et al. 2023; Oğuz et al. 2023; Yadav et al. 2022)	2022, 2023, 2023, 2022	Bin Status
Data Communication in IoT Enabled Garbage Bin using LoRaWAN gateway vs Lifetime of the Bin (Ramson 2022)	2021	–
Bin location problem vs Efficient garbage collection vehicle routing (Jin et al. 2023; Pal et al. 2022; Xin et al. 2022)	2023, 2022, 2020	–
Smart Waste Management for Covid-19 affected houses using IoT and garbage collection vehicle dynamic routing (Saha et al. 2023)	2023	–
Real-time garbage grabbing and sorting using Deep Learning model (Chunxiang et al. 2022)	2022	All

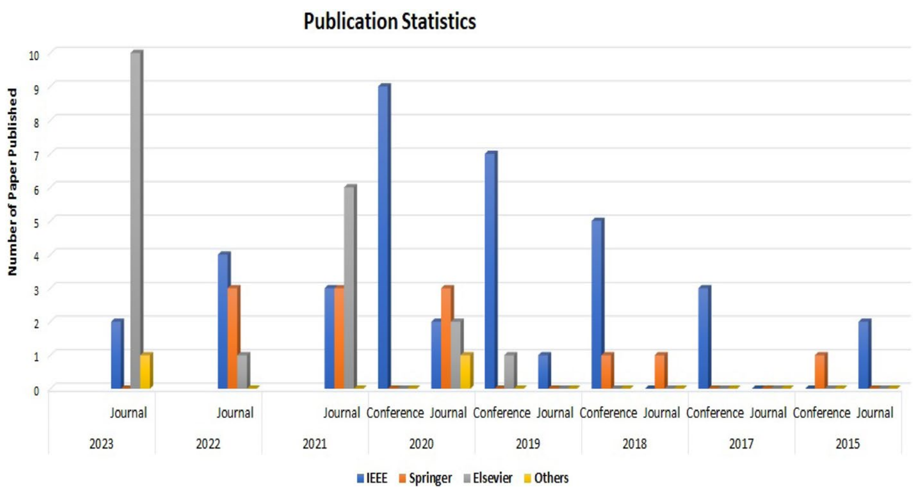

Fig. 4 Year-wise publication detail from different publishers

out every year by different publishers. Figure 4 also presents the classification of the papers into conference and journal publications, except for 2021, 2022 and 2023, when there were more conference than journal papers. The following conclusions were drawn from a study of the information above (Fig. 4):

1. Nearly 65% of all papers were published by the IEEE during the timeline considered.
2. The highest publication percentages were in 2021 and 2023.
3. Outstanding work was duly published in equal measure both in journals and conference proceedings.
4. Elsevier had a very high publication percentage of 72
5. Existing reviews on smart waste management systems were collated from the material examined.

4 Existing reviews in the smart waste management system

Existing state-of-the-art reviews in the study area of smart garbage bins, published by leading publishers such as the IEEE, Elsevier, Springer, Wiley, and others were scrutinized. The top five keywords used to search for review articles in academic research search engines were smart/intelligent bin/bins, smart dustbin/garbage bin/dustbin, IoT-enabled bins, smart waste collection system, and smart/intelligent waste management system. In total, 14 review articles were downloaded and the 10 best identified for further study were drawn from the top research paper publishers and aligned with the study objectives stated. The 10 review articles were classified into four major categories, based on the objectives of the study. The taxonomy of the review articles is shown in Fig. 5. Details pertaining to the existing reviews are analyzed under different perspectives and shown in Table 3. This meticulous analysis of existing review works in the study domain can help us to highlight our work's novelty and intention.

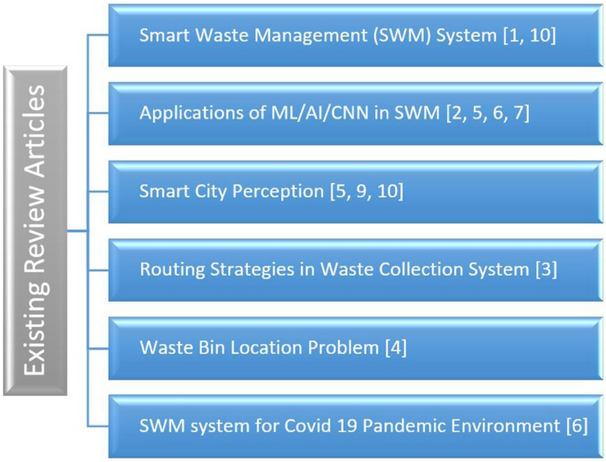

Fig. 5 Grouping of existing review works in smart waste management systems

We can majorly divide existing review works into two categories; Smart Waste Management for Smart Cities and Artificial Intelligence-based Smart Waste Management Systems. Smart city perception-based review papers focused on the research works published on bin location problems, garbage collection vehicle routing problems, secure garbage collection during the pandemic situation, and stakeholders of the waste management systems. AI-based review papers focused on publication statistics and the application of CNN-based Transfer Learning models for waste image classification. The design of the smart garbage bin review paper (Huh et al. 2021) also restricted its content only to garbage image classification to reduce the labor cost for smart cities. Our intention for this review work is to highlight all uncovered points in the design of smart bin systems-related research papers rather than overall smart waste management systems. In our work, we analyze the evolution of smart bin design and various technologies including IoT and AI in the smart bin using appropriate recent works published in this problem domain. The dataset used in previous works is also discussed in detail under Artificial Intelligence perception. We analyze various features adopted in existing garbage bins like self-driving bins for automatic waste collection and deposition. These different perceptions of our literature review work helped us to highlight the missing features in the smart garbage bins. This study triggers various future research works in the design of smart bins.

5 Smart bin evolution path

The evolution of smart bins is very interesting to follow. It happened as per the demand and creativity of the researchers. It's shown in Fig. 6. The smart bin focuses on the concept of reducing, recycling, and reuse. The initial work of the smart dustbin system (SDS) is that of automating the bin in order to determine its level as being empty or full (Thada et al. 2019). An efficient garbage collection management SDS system proposed in 2015 (Al Mamun et al. 2015) and implemented in a smart city finds the best path to cover every filled bin (Mohapatra and Shirapuri 2020). An enhanced SDS system is executed by means of an automatic lid close/open option activated through a voice command (Kansara et al. 2019). Novel ideas are constantly being added to the existing SDS system with the application

Table 3 Existing review works in smart waste management systems

Ref. no.	Major objectives	Minor objectives	Focus	Insights	Unique perception	Points analyzed	Limitations
Mousavi et al. (2023)	ICT in Waste Management Systems (WMS)	• Growth of data acquisition and sensor-based technique • Data communication • Truck Routing and scheduling collection • Energy harvesting techniques	IoT enabled WMS	Progress on WMS for Smart Cities over time	Covers waste identification, collection, transport, and storage management system for smart cities	• Sensors in bins • Communication Technologies • Location Information • Microcontroller used	Since it covers all the aspects of smart WMS, it can only give an abstract view of it. In-depth analysis and study findings are not very limited
Wu et al. (2023)	Intelligent Waste Identification and Recycling (IWIR)	Image analysis process in IWIR using advanced models of CNN	• Waste classification • Garbage object detection • Segmentation	• Subtopics of CNN approach in IWIR • Data security and quality • Model training and optimization	In-depth analysis of all possible datasets in IWIR	• Datasets and CNN models in IWIR • Publication statistics • Representative images from all datasets • Notable Performance accuracy of the models is presented	CNN models for garbage object detection and classification are only highlighted. Open-source garbage datasets are presented without any analysis
Lu et al. (2017a)	Smart and green urban solid waste collection system	Optimization schemes for waste collection and vehicle routing	Routing strategies for distributed waste collection	Two-stage waste collection system	Optimal location of the collection nodes and analysis of vehicle routing problems for waste collection	• Simultaneous node and arc routing problem • Roll-on roll-off routing problem • Informatics technologies • Publication statistics	Narrow down the problem to the routing problem and its optimization solutions for garbage collection vehicles

Table 3 (continued)

Ref. no.	Major objectives	Minor objectives	Focus	Insights	Unique perception	Points analyzed	Limitations
Rossit et al. (2022)	Storage stage of the Municipal Solid Waste (MSW) Reverse logistic chain	Waste bin location problem	Optimization criteria and resolution methods for computationally complex bin location problem	The trade-off between quality of service and cost of the system in the waste bin location problem	• Configuration of networks of bins creates an impact on the efficiency of the MSW collection • Integrated approach to bin location and collection routing	• Reverse logistic chain in MSW • Publication statistics related to year and continent • Bin location in the urban area—conflicting factors	Limited only on bin location problem
Fang et al. (2023)	AI for Waste Management Systems (WMS)	• AI in the garbage bin and waste robotics sorting • Sensor networks for solid WMS	• AI in waste sorting, monitoring, and tracking of waste materials • AI in Chemical analysis of waste	• Lack of AI models for WMS • Blackbox in the AI-based WMS operation • Lack of data in WMS to train the AI model	Impact of Coronavirus disease on solid WMS	• Types of AI for waste classification • Types of AI for cost-efficient garbage collection • Types of AI for different garbage identification and handling	Focus only on applications of AI for waste detection and chemical analysis of the waste materials
Rubab et al. (2022)	AI-based Waste Management Strategies	Applications of AI and ML for Covid-19 waste management cycle	AI and ML models	Handling wastes in the Covid-19 pandemic environment	Ensure safety using AI even in Covid-19 waste management systems	AI in different phases of the waste management cycle	Restricted garbage like Covid-19 wastes
Umer et al. (2022)	Machine Learning in Smart Waste Management	Systematic literature review on SWM via publication statistics	Identified mostly used techniques in the SWM; IoT, RFID, Logistic Regression and CNN	Challenges identified in SWM	The challenges listed in SWM are totally unique ways to analysis the design of the SWM	• Publication detail in the study area • Techniques in SWM • Challenges in SWM	Mostly focus on the publication statistics

Table 3 (continued)

Ref. no.	Major objectives	Minor objectives	Focus	Insights	Unique perception	Points analyzed	Limitations
Huh et al. (2021)	Smart Trash Bins for Smart Cities	Design of smart trash bins	Operation of smart trash bins with respect to trash image classification	Image Processing and Spectroscope-based future smart bin design	Analysis of the number of smart bins and sanitation workers in Seoul. This study helps the importance of designing an efficient trash bin for metropolitan cities	• Solution for the future implementation of smart trash bins • Comparison of trash image classification models • Model design of smart trash bins	Focusing majorly on trash image classification models. Other features of smart trash bins are not discussed
Sosunova et al. (2022)	SWM systems for Smart cities	IoT-enabled SWM system	Data collected from SGB and SWM	Data production and consumption in SWM systems	• City-level SWM systems • Stakeholders in SWM systems	• SLR methodology for systematic review • Trends in SWM systems	Data generated by SWM systems are mostly focused
Mukherjee (2021)	Modern Waste Disposal Management Systems	Dealing waste materials with chemical contents	Waste Management Process for solid, liquid, gaseous and radioactive wastes	Plasma gasification, transmutation, etc related to chemical wastes	Mr.Trash Wheel technique	Novel ideas adopted in different countries for chemical wastes management process	Chemical wastes related issues are discussed

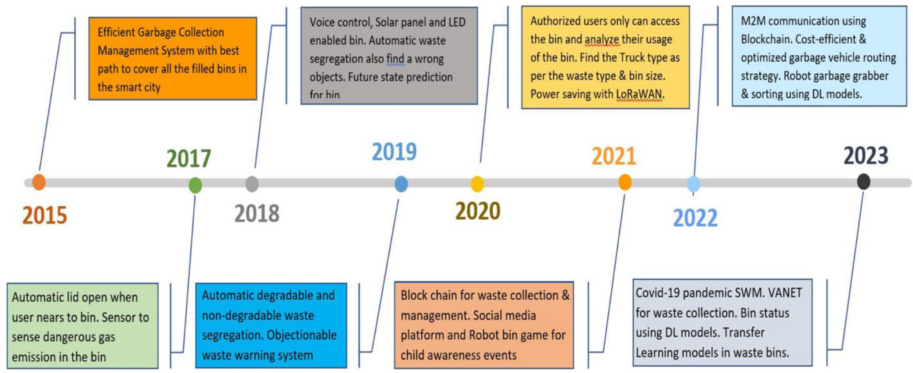

Fig. 6 Evolution of smart bin

of sensors. The SDS system senses dangerous gas emissions through a gas sensor, detects metals using a metal sensor, recognizes plastic and paper using a capacitive/inductive sensor, determines weight through a weight sensor, establishes climatic conditions through a rain or moisture sensor, and decides distance measures using an ultrasonic sensor. Sensors play a crucial role in the SDS and IoT (Sinha et al. 2020), while the use of solar panels is a contributory factor in an efficient smart bin network system. Advances in SDS systems include a voice control technique that provides speech commands, solar panels placed in bins for energy storage, and LED indicator lights (Jardosh et al. 2020).

Further developments include the segregation of waste into degradable and non-degradable objects (Shamin et al. 2019; Lopes and Machado 2019), using a warning message intended for the collector/user (Paul et al. 2018). Users are given authorized access to note down the number of times a bin is used (Sheng et al. 2020; Catarinucci et al. 2020). In addition, the management receives information about the garbage type (Paul et al. 2018). Blockchain technology is used for sorting and selling waste management systems (Gopalakrishnan et al. 2021). Users of all ages are educated on the use of the smart bin management system through an application on a social media platform (Peng et al. 2021) as well as by means of a robot bin game designed to build awareness in children Castellano et al. (2021). The bin cleaning process is confirmed by blockchain technology, which checks data communication between the IoT-enabled garbage bin and the collection vehicle (Saad et al. 2023). The bin location problem is considered as a main research work to find the dynamic efficient route for waste collection vehicles (Jin et al. 2023; Pal et al. 2022; Xin et al. 2022). The automatic garbage classification and segregation processes of the garbage grabber and smart bins are enhanced by advanced transfer learning models and the YOLO object detection technique (Li et al. 2022; Wu et al. 2022; Chunxiang et al. 2022; Thamarai et al. 2023; Li et al. 2023a; Jin et al. 2023; Chen et al. 2023; Fatma et al. 2023; Gupta et al. 2022; Li et al. 2023b).

6 Techniques adapted in smart bin use

6.1 Sensors used in smart dustbin

Figure 7 shows the sensors used with existing smart bins.

- *Capacity Sensor/Plastic sensor:* A capacitance proximity sensor/plastic sensor that is placed under the conveyor belt separates plastic and wooden debris. Plastics detected by the proximity sensor are moved to the collection box. Such sensors change the capacitance value. Charging the capacitor via positive and negative plates is done by applying a supply voltage that generates an electric field. The plastic sensor segregates biodegradable and non-biodegradable waste and vegetable peel as well.
- *RFID sensor:* A tag antenna converts electrical current into electromagnetic waves that are projected into space and picked up by a reader antenna for radio frequency identification (RFID) readers in order to read tags. Similar to tag antennas, reader antennas

Fig. 7 Various sensors in smart bins

and optical antennas come in a wide range, based on the unique solutions they offer and the environment they are used in. A reader antenna collects the information that is stored in ID cards from individuals. The details are sent to specific individuals by means of a notification, along with a message informing them of the contents of their garbage and thanking them for their thoughtfulness in getting rid of it.

- *Infrared Sensor:* An infrared sensor used in a smart bin opens its lid and measures the level of trash in the bin. The data thus acquired is sent to a web server and displayed in the Android app developed for the purpose.
- *Weight sensor:* The weight of the dustbin is measured by a weight sensor that is generally placed under the bin. The RFID and infrared sensors in the bin capture information, on a calendar basis, on the garbage contained in the bin.
- *Gas sensor:* Poisonous/harmful gases are detected using a gas sensor that identifies different gas odors automatically.
- *Temperature and Humidity sensor:* This sensor presents information on the prevailing temperature and humidity levels. Information on humidity is added during garbage disposal. The sensor not only determines the temperature but also converts it into mechanical energy and electrical signals.
- *Light Dependent Resistor (LDR):* An LDR sensor is a resistor component, and the resistance value changes, depending on how much light is shining on it. The resistance value decreases as more light is received by the LDR sensor. When the resistance value increases, little light and electric current strike the sensor.
- *Magnetic Electronic sensor:* A magnetic sensor identifies the presence of metal or non-metal in the garbage, which is scanned when it surfaces in front of the sensor.
- *Strain Gauge sensor:* This sensor utilizes a strain gauge load cell to convert a force-like strain into an electrical signal. The power generated by the cell is applied to the sensor and used in smart bin systems. The strain gauge sensor reduces battery power by generating an electrical signal.
- *Rain sensor:* This sensor helps to determine the onset of the rain and stops the garbage bin from getting wet. It protects against germs that release a foul stench, senses a drizzle, and shuts the lid before rainwater can enter the bin.
- *Inductive Proximity sensor:* This sensor, which is usually placed atop the lid, detects metal waste in the incoming garbage and indicates what type of metal it is.
- *Moisture sensor:* This sensor identifies wet garbage and controls the level of humidity in the bin.
- *Ultrasonic sensor:* This sensor estimates the distance at which trash bins are placed. The distance of the garbage level in the bin is measured by the emission of a sound pulse, following which the time delay that is returned as an echo signal is computed.
- *Metal Sensor:* Metal sensors produce high-frequency and high-voltage ringing electromagnetic waves. When metal is detected, the coil detunes and lowers the segregated waste onto the conveyor belt. Inductive proximity sensors handle metal garbage segregation as well.

6.2 Deep learning and machine learning approach

Current research on smart bin use has adopted machine learning or deep learning models for garbage object identification and classification. Figure 9 presents the different technologies associated with smart bin use. The appropriate lids of the specific internal bin will be opened automatically based on the type of garbage object detected by the loaded trained model in the smart bins. Running deep learning and machine learning models using resource-constrained edge devices like smart bins is a challenge. Alternatively, these systems can use cloud services for memory and the computational power requirements of model training. Machine learning algorithms such as logistic regression, kNN, rule-based classification and regression, and the GA-SVM have been adopted for garbage classification with smart bins. Further, cuckoo search, the MCMC-RORO (multi-constrained and multi-compartment roll-on and roll-of algorithm) model, and heuristic algorithms have been integral to smart bin use, particularly for finding the shortest path that covers every bin for garbage collection.

ML Algorithms: The contents of household waste garbage bins are estimated and identified by machine learning algorithms such as the Random Forest, Naive Bayes, XGBoost, and Decision Tree (Likotiko et al. 2023). ML algorithms also analyze user behavior in terms of garbage disposal.

K-Nearest Neighbor(KNN) Algorithm: Aravindaraman and Ranjana (2019) have designed a machine learning model to classify garbage into wet and dry. Pattern recognition for classification is learned by the KNN algorithm. The classification model predicts the garbage type and then automatically opens the appropriate trash barrel to throw the trash into it. The associated sensors of the trash bin generate the real-time dataset for training and testing. Shamin et al. (2019) used kNN algorithm for image comparison among metallic and non-metallic waste, wet and dry in a smart garbage segregation and maintenance system. The SURF image processing technique of the proposed system extracts features from images and converts 3D into 2D images for further processing. The SURF algorithm improves the quality of the training samples. Dubey et al. (2020) have designed a household waste management system using kNN. The system can classify bio and non-biodegradable and poisonous gas garbage waste. Sensors of the garbage bin can observe the filling level of bins, the metal level of the waste objects, and the poisonous gas value emitted by the garbage object. Normalization is used as the preprocessing technique for classification. K-value in the kNN algorithm changed from 1 to 15 to observe the accuracy of the classification algorithm. The system can generate high accuracy of 93% with a number of neighbors is 3 or 4 or 6.

ANN (Artificial Neural Networks): The waste amount prediction model for planning waste management systems has been built using ANN (Huang and Koroteev 2021) in smart bins. Huang and Koroteev (2021) designed a system with 2 models; to predict waste amount of the garbage bin and detect abnormalities in the waste collection.

CNN (Convolutional Neural Networks): Sidharth et al. (2020) adopted the deep learning architecture of CNN to build a model that classifies plastic, paper, cardboard, and metals. The proposed CNN architecture consists of 3 convolutional layers, 2 hidden layers, and 1 output layer with softmax for multi-classification. ReLu is the activation function in the layers. Domestic waste is detected and classified by the Multi-model cascaded Convolutional Neural Network (MCCNN) (Li et al. 2022) that combines the three subnetworks of the DSSD, YOLOv4, and Faster R CNN. The Vision Transformer based on the Multilayer Hybrid Convolution Neural Network (VT-MLH-CNN) (Fatma et al. 2023) is used to enhance the model for automatic waste classification. CNN-based transfer learning models such as the Yolov3, Yolov4, EfficientDet, Faster R CNN, M2Det, SSD, DenseNet-169, EfficientNet B0, EfficientNet-B3, MobileNetV3-Large, VGG19-Bn, VGG-16, AlexNet, InceptionNet, ShuffleNet and ResNET-50 are used to train the models for smart waste identification and segregation (Wu et al. 2022; Oğuz et al. 2023; Gupta et al. 2022; Li et al. 2023b).

MobileNet: Shamin et al. (2019) proposed a system for smart waste management using 2 techniques; garbage object detection and waste classification. The garbage object detection is carried out by the SSD (Single Shot Detector). SSD can detect multiple objects within a single image. The activation function Relu is replaced by a linear transformation layer at the output layer in order to improve the accuracy of the system. SSD is the feed-forward kind of CNN. The transfer learning model MobileNet v2 has been used for real-time garbage object detection. The objects can be classified into metal, plastic, paper, and general waste. MobileNet model can avoid the usage of the cloud service for deep learning model execution. Its lightweight model can run on small edge devices like mobile phones. Rabano et al. (2018) designed a garbage classification system using ImageNet with 2527 images for training. The MobileNet model is compared with other transfer learning models in Inception v3. Glass, paper, cardboard, plastic, metal and trash objects can be classified using this system. Reddy et al. (2017) proposed a system for municipal waste management system using MobileNet v3 and compared this model with other transfer learning models InceptionV3, MobileNetV2, ResNet50, 108, 151, XCeption and CNN. The waste types are classified as plastic, glass, paper, cardboard, metal, fabric, and other hazardous wastes. Inception v3 and MobileNet v3 show the best test accuracy with 100 epochs. The fullness of street garbage containers is identified by MobileNet (Oğuz et al. 2023). The waste classification is also done by MobileNet trained model in Jin et al. (2023) and Li et al. (2023b).

DenseNet: Dubey et al. (2020) designed a system to classify cardboard, glass, metal, paper, plastic, and other trash, using the ImageNet dataset to train the classification model. The system is analyzed with the AlexNet, VGG16, ResNet50, and DenseNet-169 transfer learning models. It was observed that the DenseNet-169 undertakes garbage object classification better than the rest.

Inception: The Inception v3 transfer learning model is used for the waste profiling and analysis of smart bins (Shaikh et al. 2020). Biodegradable and non-biodegradable objects are classified using this system.

ShuffleNet: Chiefly invented for limited-capacity devices, the ShuffleNet model is designed to detect waste. The model consists of two units, one of which extracts basic features while the other undertakes double sampling with YOLO (Chen et al. 2023).

LSTM: A sequential neural network model is used to forecast urban waste generation so bins can be placed at appropriate locations in the city (Jammeli et al. 2023). Sequential AI models offer high accuracy with the LSTM and the BiLSTM. The LSTM predicts the quantum of upcoming waste from its efficient learning derived from waste generation patterns (John et al. 2022).

YOLO: In the MCCNN model, YOLO is a subnetwork for domestic waste classification (Li et al. 2022). A depth-wise separable convolution YOLO has the computational speed to identify the status of garbage bins on the street from video cameras in the vicinity and schedule a garbage collection vehicle accordingly (He et al. 2022). YOLOX is combined with TensorRT to enhance the accuracy and speed with which garbage is located in real-time for the garbage grabber and the sorting to follow (Chunxiang et al. 2022). YOLOX is intended for low-cost embedded devices like garbage bins, while YOLOv5 is used to classify and position recyclable waste (Chen et al. 2023).

6.3 Internet of things in smart bins

The general IoT framework for smart bins is shown in Fig. 10. The IoT module is connected to a set of sensors associated with the garbage bin via a microcontroller (Bharadwaj et al. 2017; Paul et al. 2018; Ashwinet al. 2021; Rao et al. 2020). The information collected from the sensors is to be transferred to cloud storage (Shamin et al. 2019) or a parent node/an IoT gateway/web applications/a garbage collector. The IoT module collects, integrates, and processes the information relayed by the smart bin sensors (Wang et al. 2021; Alqahtani et al. 2020). The processed data are used to send an appropriate signal to the garbage collector or smart bin user (Nidhya et al. 2020; Jagtap et al. 2020; Anitha et al. 2018; Misra et al. 2018). In a few cases, the Web of Things (Aravindaraman and Ranjana 2019; Nirde et al. 2017) lets the user monitor and control smart bins using web applications from anywhere and at any time. Smart control of garbage bins is possible using IoT devices (Dubey et al. 2020; Ramson et al. 2021) like sensors, RFID tags (Catarinucci et al. 2020), cameras, servo motors, and actuators. In a few smart bin designs, IoT devices use the LoRa (Sheng et al. 2020) or ZigBee (Raaju et al. 2019) communication protocols for rapid data delivery to an IoT gateway or other IoT devices over long distances and with very little power. These IoT device communication protocols reduce the rate of power consumption in smart bins, making the entire system energy-efficient. A few smart bin designs (Lopes and Machado 2019) incorporate GSM technology which is used to send the garbage collector a message. A hierarchy of bins is adapted to include child-and-parent (Raaju et al. 2019) and sensor-and-IoT gateway (Sheng et al. 2020) designs. Such designs reduce the burden of edge devices with respect to data integration and processing, given that the parent node or IoT gateway takes on all the responsibility. A key characteristic of IoT mechanisms in smart bins is dynamic route identification (Medvedev et al. 2015) to facilitate the movement of garbage collection vehicles so the whole city is covered using the fastest possible route.

6.4 Communication technologies in smart bin

Figure 8 illustrates the technologies used in existing smart bins.

Bluetooth: Smart bins communicate the fastest with other bins or mobile users nearby via a Bluetooth module. Data, which are continuously generated by sensors linked to the smart bins, are transmitted serially to the mobile app or other paired devices or cloud storage (Ashwinet al. 2021; Wang et al. 2021; Rao et al. 2020). The Bluetooth SPP (Serial Port Protocol) module enables a transparent wireless serial connection setup between devices. A few smart bins (Ayush et al. 2019) have an 'Android Bluetooth Controller' installed for device pairing and data transmission.

Wi-Fi: Wi-Fi technology simplifies the smart bin communication setup. Access to a hotspot nearby makes the system work best for data communication. The Wi-Fi module of the smart bin sends the data to the dedicated app or cloud or edge server (Misra et al. 2018; Rao et al. 2020; Shetty and Salvi 2020; Dubey et al. 2020; Ramson et al. 2021) using existing Wi-Fi networks. The receiver processes the data to deliver the outcome of the sensed data.

RFID: RFID (Catarinucci et al. 2020; Lu et al. 2017b) tags and readers are used in smart bins for data collection and transmission. The garbage bin data are sensed by RFID tags linked to the bins, following which the RFID reader reads the data. A server looking to extract data from a specific bin uses the unique identification number of the RFID tag to pull up the information needed. Such bidirectional communication makes smart bin systems most efficient, and the relevant data are forwarded to the collection center via the GPRS or a Wi-Fi network.

Fig. 8 Technologies adapted in smart bins

LoRa: The garbage bin and data collection device are considered to be LoRa nodes in IoT-enabled smart bin data communication. Smart bin sensors use microcontrollers to send their data to the edge or a cloud server via an attached IoT module. In smart city plans, especially when smart bins are located within distances of a few kilometers, the efficient LoRa method ensures QoS in data communication between bins as well as between bins and data collectors (Shamin et al. 2019; Aravindaraman and Ranjana 2019; Nidhya et al.

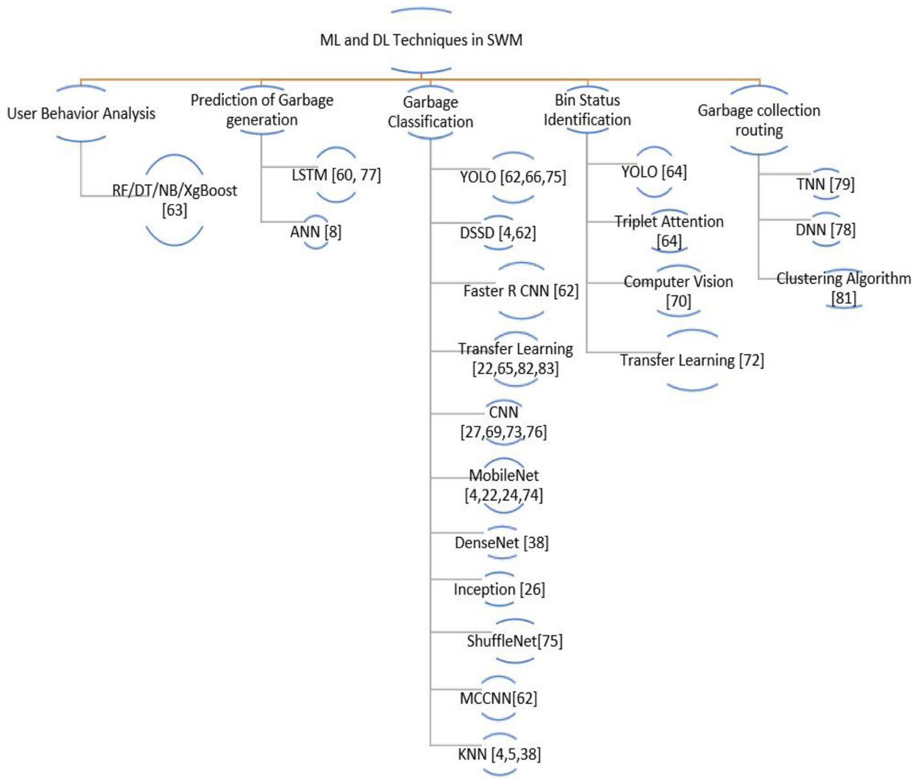

Fig. 9 Machine learning and deep learning techniques in SWM

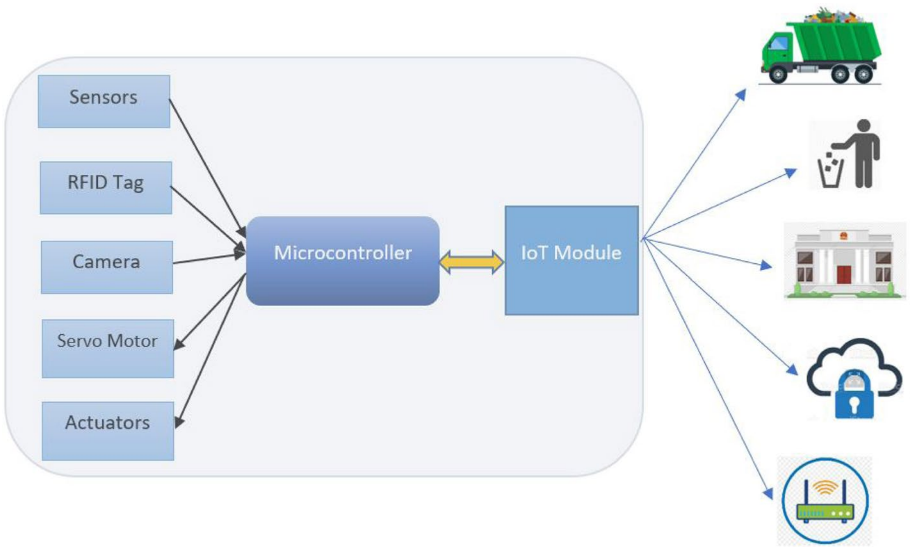

Fig. 10 IoT framework in smart bins

2020). LoRa, which excels at long-range data transmission, consumes little energy and is a key factor in smart bin design. LoRa is hence a preferred communication mechanism for IoT-enabled smart bins. The device becomes a LoRa gateway when it uses a real-time HyperTerminal (Sheng et al. 2020) to read and decode data despatched by the LoRa nodes. The limitation of LoRa is that the data transfer rate is available only in kbps and communications are via unlicensed spectrum.

ZigBee: ZigBee (Shamin et al. 2019; Raaju et al. 2019) is used to design a smart garbage collection management system with IoT-enabled child and parent nodes using ZigBee for data transmission. The child node with Arduino Pro Mini sends sensor data to the parent node using ZigBee and the parent node with Arduino Nano uses ZigBee for data collection.

GSM (Global System for Mobile): The GSM module of the smart bin sends a garbage collection and maintenance SMS message to the higher authorities, alerting the person or device when communication is urgent (Jagtap et al. 2020; Nirde et al. 2017; Reddy et al. 2017; Paul et al. 2018; Misra et al. 2018; Susanth et al. 2021; Alqahtani et al. 2020). The mechanism best ascertains the status of the garbage bins, filled or otherwise, as well as dangerous objects or gas leaks in them. The GSM mechanism facilitates device location or tracking (Ramson et al. 2021) and supports communication via messaging even during node movement. GSM modules can be connected to fixed smart bins or moving garbage collection vehicles.

6.5 Vehicle routing plans for garbage collection

Information about the filled status of the garbage bin is sent to the garbage collection center with details of its location. The garbage maintenance department uses the information to despatch garbage collection trucks to the locality to empty filled bins. Truck movements are monitored and tracked using a map (Raaju et al. 2019). Workers' wages and the time taken to clear the waste, even during the city's peak hours, can be reduced. The technique recommends the best route that covers every filled bin needing clearing. Existing systems employ the Shortest Path Algorithm such as Dijkstra's or the Traveling Salesman Problem (TSP) to discover the most efficient garbage collection route. Factors like waste type, truck size, waste sources (Alqahtani et al. 2020), workforce strength, total distance to be covered to reach every bin in the city, road conditions, workers' wages, and shift times have all been considered by the optimized route identification techniques in existing systems. In the SERGO system (Jardosh et al. 2020), the truck driver nearest a filled bin is automatically assigned to clear it. This system considers the recycling industry as the endpoint for optimized route generation using the TSP. The Vehicle Routing Plan (VRP) (Medvedev et al. 2015; Lu et al. 2017b; Wang et al. 2021) is a dominant technique in most existing smart bins for garbage collection management. An efficient adaptive routing plan for waste collection that considers information from bins and other influencing factors is recommended for waste management centers (Wang et al. 2021).

Medvedev et al. (2015) adopted a DSS (Decision Support System) to generate an efficient vehicle routing plan (VRP) for waste collection in smart cities. The DSS of this system processes real-time city reports with videos and pictures despatched by bins and movable trucks. The reasons for the inability of trucks to reach the locations of the filled bins are attached to the RT report with supporting evidence. Cameras are affixed to the trucks and present information on the current situation of the city's roads so that the adaptive path thus generated, rather than a fixed one, reaches every bin. Lu et al. (2017b) designed a system to map an efficient vehicle routing plan using a heuristic algorithm.

This system consists of two phases, an initialization setup and an improvement setup. In the first phase, the nearby customers from the unrouted set are assigned trucks for home waste collection. Factors such as the expected time of arrival of the vehicle, truck capacity, and shift time are used to decide the allocation of trucks to particular customers. The GENI TSP algorithm is used to establish the sequence of customer visits for garbage collection and avoid cycles in the collection path. This system is simulated in MATLAB for the Luohu district of Shenzhen in China. The vehicle routing plan (VRP) technique is designed for the Siliguri Municipal Corporation, with 9 trashcans placed in and around the city (Misra et al. 2018). The shortest path calculated by Dijkstra's algorithm is mapped with a Google city map. The vast web of city roads is converted into graphs by considering road sections as edges and intersections as vertices. This system predicts the shortest driving distance to cover all 9 of the city's bins. The distance is pre-calculated for all-to-all bin operations. Using their own analytical model, the cost of all possible routes is calculated to determine the most cost-efficient and shortest path for clearing waste.

6.6 Self driving smart bin

Chakraborty (2020) proposed an embedded system wherein smart bins that are instructed to collect trash from humans gravitate toward them. A mobile app developed for this system gives instructions for bin navigation, moving the bin to waiting users. Located on a movable chassis, the bin uses a Bluetooth RC controller interface to move to and from its regular location to the user. This system is most helpful for elders, patients, and the physically challenged. Cabilo (2014) developed an automatic navigation-facilitated trash bin. The bin navigates alongside a fall protection railing in the wall to reach different offices along the same corridor using its side sensors. The bin stops when it reaches the last office on a floor or covers a long distance in a day. Customized bin navigation and garbage collection are readily available and can be scheduled from different doorsteps. Sensors and actuators are major components of the system. An automatic moving trash bin is proposed in this study (Waghmare et al. 2019) for use in chemical industries to eliminate human intervention in the handling and disposal of dangerous industrial wastes. The microcontroller-based dustbin trolley moves over an auto follower path from its regular position until it reaches the garbage disposal unit. The bin that is filled to the brim with industrial waste moves to the disposal location, following which the emptied bin returns to its initial position. IR sensors attached to the bin detect obstacles along its path. A line follower robot of the bin follows a white line using four IR sensors at the front and rear of the bin.

Chiang (2015) developed a robot that looks for trash in a room, collects it, and deposits it in the bin automatically. The robot navigates all around the room using a wall-following process. This system applies a boustrophedon path planner and simple rule-based navigator techniques. The MATLAB simulation results show that it performs well.

7 Data sets of smart bins

Benchmark datasets of garbage/waste objects are limited in number. Table 6 and its continuation in Table 7 describe the benchmark garbage dataset, the contents of which are displayed in quality color images. In a few existing studies, small-sized datasets have been created by the researchers themselves, using cameras or sensors to generate data for sundry waste categories. The data type of these datasets comprises either images or data sensed by sensors affixed to the garbage bin. The limitation of such datasets is their relatively small number of samples and categories, as well as the poor quality of the images. A description of both datasets is given in Table 4 and its continuation in Table 5. The garbage datasets in Tables 6 and 7 are categorized into three major types according to the classification problem, the sample types in the dataset, and the dataset sources.

7.1 Classification problem

The datasets used in the existing research are categorized into two, multiclass and binary, based on the number of class labels in the datasets. More than 90% of the existing research used multiclass datasets to train the garbage image classification models (Peng et al. 2021; Wang et al. 2021; Rabano et al. 2018; Dubey et al. 2020; Shetty and Salvi 2020; Sidharth et al. 2020; Jardosh et al. 2020; Jagtap et al. 2020; Sheng et al. 2020; Susanth et al. 2021; Alqahtani et al. 2020; Castellano et al. 2021; Shamin et al. 2019; Li et al. 2022; He et al. 2022; Wu et al. 2022; Chunxiang et al. 2022; Li et al. 2023a; Chen et al. 2023; Fatma et al. 2023; Gupta et al. 2022; Li et al. 2023b), with the number of image categories ranging from 3 to a maximum of 52. In some studies, the images in the dataset distribution are divided into major categories and subcategories (Li et al. 2023a; Gupta et al. 2022). Images of garbage are mostly of household items grouped into several categories—biodegradable, non-bio-degradable, dry, wet, metal, non-metal, recyclable, non-recyclable, and hazardous waste. Binary datasets (Gopalakrishnan et al. 2021; Shaikh et al. 2020; Sarker et al. 2020) in smart waste management (SWM) systems are few. The research (Gopalakrishnan et al. 2021) analyzes the role played by the two major stakeholders, producers and consumers, in smart waste management systems. In the work (Shaikh et al. 2020), the major two categories of TrashNet; biodegradable and non-biodegradable are maintained by combining all subcategories under the main categories. The binary class labels in Sarker et al. (2020) are two, dry and wet garbage images. Binary datasets are used in the studies above for improved accuracy or application requirements.

7.2 Input type

Garbage datasets are classified into two, based on the sample data types, numerical (Gopalakrishnan et al. 2021; Dubey et al. 2020; Shetty and Salvi 2020; Jagtap et al. 2020; Likotiko et al. 2023; Sarker et al. 2020; Peng et al. 2021) and image (Rabano et al. 2018; Wang et al. 2021; Shaikh et al. 2020; Sidharth et al. 2020; Jardosh et al. 2020; Sheng et al. 2020; Susanth et al. 2021; Alqahtani et al. 2020; Castellano et al. 2021; Shamin et al. 2019; Li et al. 2022; He et al. 2022; Wu et al. 2022; Chunxiang et al. 2022; Li et al. 2023a; Chen et al. 2023; Fatma et al. 2023; Gupta et al. 2022; Li et al. 2023b). Numerical data are generated by different sensors affixed to the smart garbage bins in order to detect the garbage type. Numerical datasets are also used for two additional purposes observing the behavior of garbage bin users and predicting garbage generation. In the Image garbage datasets, different garbage object images are maintained that are captured by video cameras, cameras, or Internet images.

Table 4 Dataset used in smart dustbin system

Ref	Classification type	No & name of class labels	# of samples	Type of features	Source	Source detail	Devices to generate the dataset	Image detail	Way to image capture
Gopalakrishnan et al. (2021)	Binary	2: producers, consumers		Numerical	Self				
Peng et al. (2021)	Multiclass	3: Small, Medium, Large Confidence levels		Numerical	Existing	City Municipality			
Wang et al. (2021)	Multiclass	9: Kitchen waste, plastic, glass, paper/cardboard, metal, fabric, other recyclable waste, hazardous waste, other waste		Image	Existing	TrashNet dataset and other research datasets are merged together			
Rabano et al. (2018)	Multiclass	6: Glass, paper, cardboard, plastic, metal and organic waste	2527	Image	Existing	http://www.kaggle.com/asdasdasasdas/garbage-classification		images resized to 224 × 224 pixels	The pictures of the objects were taken by placing them on a white background with variable light coming from both natural sunlight and artificial room light in different positions

Table 4 (continued)

Ref	Classification type	No & name of class labels	# of samples	Type of features	Source	Source detail	Devices to generate the dataset	Image detail	Way to image capture
Dubey et al. (2020)	Multiclass	3: Dustbin level, Metal level, Poisonous gas level	100	Numerical	Self	Values from sensors is the dataset	level and poisonous gas sensors		
Shetty and Salvi (2020)	Multiclass	3: Metallic, Wet, Dry		Numerical	Self	Values from sensors is the dataset	inductive Proximity Sensor,Moisture Sensor,Ultrasonic Sensor		
Sidharth et al. (2020)	Multiclass	4: Paper, Metal, Plastic, Cardboard	2077	Image	Existing	TrashNet		50x50 size of images	
Shaikh et al. (2020)	Binary	2: Biodegradable, Non-Biodegradable	2700	Image	Existing	TrashNet			
Jardosh et al. (2020)	Multiclass	6: cardboard, paper, plastic, metal, trash and glass	2500	Image	Existing	TrashNet	Images rotated to certain angles	Camera	
Jagtap et al. (2020)	Multiclass	4: Full or not full, dry or wet		Numerical	Self		ultrasonic sensor, Moisture Sensor		
Sarker et al. (2020)	Binary	2: Dry, Wet		Numerical	Self		Rain Sensor		

Table 4 (continued)

Ref	Classification type	No & name of class labels	# of samples	Type of features	Source	Source detail	Devices to generate the dataset	Image detail	Way to image capture
Sheng et al. (2020)	Multiclass	3: Metal, Plastic, Paper	365	Image	Self	Camera Module used to capture images of waste	Pi Camera	1.25 w power consumption, $8, captures at a rate of around 0.75 frames per second, 5mp	different orientation, background, and lighting condition
Susanth et al. (2021)	Multiclass	6:cardboard, paper, plastic, metal, trash and glass	4163	Image	Existing	Gary Thung and Mindy Yang's dataset and google images		Random Resized Crop, Random Horizontal Flip	
Alqahtani et al. (2020)	Multiclass	6:cardboard, paper, plastic, metal, trash and glass	2527	Image	Existing	TrashNet		resized images (512x384)	sunlight and different poster board in room lighting
Castellano et al. (2021)	Multiclass	6:cardboard, paper, plastic, metal, trash and glass	2527	Image	Existing	TrashNet		resized image 512x384 pixels in dimension	Object was placed on a white poster board as background. Pictures were taken under sunlight and room lighting

Table 4 (continued)

Ref	Classification type	No & name of class labels	# of samples	Type of features	Source	Source detail	Devices to generate the dataset	Image detail	Way to image capture
Shamin et al. (2019)	Multiclass	6:wet,dry, metallic, non-metallic, biodegradable, non-biodegradable		Image	Self-made		Ultrasonic sensor, Moisture Sensor, metal sensor		captured by the camera and extracted using SURF algorithm then converted from the 3D image into 2D image

Table 5 Dataset used in smart dustbin system (Table 4 Continuation)

Ref	Classification type	No& name of class labels	# of samples	Type of features	Source	Source detail	Devices to generate the dataset	Image detail	Way to image capture
Li et al. (2022)	Multiclass	52: categories of domestic wastes	30000	Image	Self				
He et al. (2022)	Multiclass	4: Bin status open full, open empty, close full and close empty	12587	Image	Self	Video cameras in the street and garbage collection vehicles	Video camera	annotated images are added	based on CCTV angle
Wu et al. (2022)	Multiclass	30: household waste images	18000	Image	Self	HGI-30	Camera	resolutions, ranging from 300 x 400 to 3000 x 4000	viewpoint, background, illumination, resolution, augmentation, and number of objects

Table 5 (continued)

Ref	Classification type	No& name of class labels	# of samples	Type of features	Source	Source detail	Devices to generate the dataset	Image detail	Way to image capture
Chunxiang et al. (2022)	Multiclass	17: orange (intact and peeled), banana (intact and peeled), green pepper, lettuce, battery (#1, #5, #7), stone, cigarette, express box, tissue, mask (blue and white), bottle and can, etc	5000	Image	Self	Camera	Camera	1080P	
Li et al. (2023a)	Multiclass	4 categories and 37 sub-categories: Recyclable, Kitchen, Hazardous and Others	17266	Image	Self	Internet Images			ordinary optical images and infrared images

Table 5 (continued)

Ref	Classification type	No& name of class labels	# of samples	Type of features	Source	Source detail	Devices to generate the dataset	Image detail	Way to image capture
Chen et al. (2023)	Multiclass	10 Recyclable wastes: Edible oil barrels, Pop cans, Cartons, Metal cans, Beverage bottles, Plugs and wires, Book and paper, Pans, Scissors, Bowls	6332	Image	Self				640 × 640
Fatma et al. (2023)	Multiclass	6:cardboard, paper, plastic, metal, trash and glass	2842	Image	Existing	TrashNet			513 x 384
Gupta et al. (2022)	Multiclass	2 major: Bio (organic, cardboard, paper) and Non-Bio (metal, glass, plastic and others) and 7 subcategories	9516	Image	Existing	ImageNet			

Table 5 (continued)

Ref	Classification type	No& name of class labels	# of samples	Type of features	Source	Source detail	Devices to generate the dataset	Image detail	Way to image capture
Li et al. (2023b)	Multiclass	6: glass, paper, cardboard, plastic, metal, and trash	1872 self + 2390 from TrashNet	Image	Existing + Self	TrashNet + Self			512 x 384

Table 6 Benchmark dataset of garbage images

Dataset name	URL	# of images	# of class labels	Class label distribution	Place	Kind of garbage	Image size	Public/private
RECYCLEYE	https://recycleye.com/wastenet/	3 million	8	density, grade, damage, format, material, object, size, color	–	–	–	private
Domestic Garbage Dataset	https://www.kaggle.com/datasets/dataclusterlabs/domestic-trash-garbage-dataset	9000+	–	–	Captured across 500+ cities		99.9% in 1920x1080 & above	Public
yangy50/garbage-classification	https://www.kaggle.com/datasets/asdasdasasdas/garbage-classification	2467	6	cardboard(393), glass(491), metal(400), paper(584), plastic(472), trash(127)				Public
TRASHCAN	https://conservancy.umn.edu/handle/11299/214865	7212	3-categ, 34-sub-categ	–	–	Underwater Images		Public
Trash-ICRA19	https://conservancy.umn.edu/handle/11299/214366	5700	3-categ, 34-sub-categ	–	–	Underwater Images		Public

Table 6 (continued)

Dataset name	URL	# of images	# of class labels	Class label distribution	Place	Kind of garbage	Image size	Public/private
TACO	http://tacodataset.org/stats	1500+ 4784 annot + 3804 new images	28 - supercateg, 30 -categ	plastic bags and wrappers: 850, cigarette: 650, unlabelled litter:510, Bottle cap:300, Bottle: 420, Can:290, Other Plastic:290, carton:250, cup:190, straw:170, paper:125, broken glass:120, styrofoam, piece:100, pop tab:90, lid:85, plastic container:80, aluminium foil:75, plastic utensils:60, rope, strings:50, paper bag:48, scrap metal:40, food waste:20, shoe:15, squeezable tube:10-15, blister, pack:10-15, glass jar:5, plastic jar < 5, battery < 5		Litter/ garbage waste pictures in the wild	varied	Private
UAV WASTE	https://github.com/UAVVaste/UAVVaste	772images & 3718 annotations	1	–	–	Drone dataset		Public

Table 6 (continued)

Dataset name	URL	# of images	# of class labels	Class label distribution	Place	Kind of garbage	Image size	Public/private
Trashnet	https://drive.google.com/drive/folders/0B3P9oO5A3RvSUW9qTG11Ul83TEE?resourcekey=0-F-D8v2tnSfByG6ll3t9JxA	2527	6	glass:501, paper:594,cardboard:403, plastic:482, metal:410, trash:137	New York	Garbage dataset clear background	512 x 384	Public
Waste Classification data	https://www.kaggle.com/datasets/techsash/waste-classification-data	22500	2	O:12600 R:9999		Scrapped from Google search		Public
Waste Classification data v2	https://www.kaggle.com/datasets/sapal6/waste-classification-data-v2	27500	3	N: 2847 O:12600 R:7152		Scrapped from Google search		Public
Open litter map	https://openlittermap.com/	lessthan 100000	–	–	UK based	garbage in the wild		Private
Litter Dataset	https://www.imageannotation.ai/litter-dataset	14000	24	–	–	garbage in the wild		Private
Waste Classification Dataset	https://data.mendeley.com/datasets/n3gtgm9jxj/2	24705	2	Organic:13880, Recyclable: 10825		garbage dataset		Public

Table 6 (continued)

Dataset name	URL	# of images	# of class labels	Class label distribution	Place	Kind of garbage	Image size	Public/private
roboflow waste image dataset	https://universe.roboflow.com/humairah-emambakus/waste-9e9kq/dataset/1	2863	–	–	–	underwater Images	416x416	Public

Table 7 Benchmark dataset of garbage images (Table 6 Continuation)

Dataset name	URL	# of images	# of class labels	Class label distribution	Place	Kind of garbage	Image size	Public/private
WaDaBa	http://wadaba.pcz.pl/#download	4000	8	(1) a number denoting the plastic type; (2) colour; (3) type of light; (4) the deformation level; (5) the level of a dirt; (6) presence of a screw cap or a lid; (7) presence of a ring—characteristic for the bottles with a screw caps; (8) order number of a random (9) position of a photographed object	–	plastic garbage	1920 × 1277 of pixels resolution 300 dpi colour palette RBG 24 bits	Public
Glassense Vision	http://www.slipguru.unige.it/Data/glassense_vision/	2000	7	(1) Bankntes (2) Cereals (3) Medicines (4) cans (5) Tomato Sauce (6) Water Bottle (7) Deoderant Stick	–	home supplies garbage		Public

Table 7 (continued)

Dataset name	URL	# of images	# of class labels	Class label distribution	Place	Kind of garbage	Image size	Public/private
Waste Images from Sushi Restaurant	https://www.kaggle.com/datasets/arthurcen/waste-images-from-sushi-restaurant	500	16	Brown box: 20, chopstick covers:35, chopsticks:40, foil:4, food:22, paper bowl:53, paper bowl small:3, paper bowl square:42, plastic cover:39, plastic cup:61, plastic lid:47, plastic utensil:37, sauce cup:59, sauce packets:12, straw:3, tissue paper:66	USA	Clear background garbage waste		Public
Drinking Waste Classification	https://www.kaggle.com/datasets/arkadiyhacks/drinking-waste-classification	9640	4	Aluminium Cans, Glass bottles, PET bottles, HDPE milk bottles	London	garbage waste		Public
SpotGarbage	https://www.kaggle.com/datasets/apremeyan/garbage	2400	3	Ambiguous annotated images, Garbage queried Images, Non Garbage Queried Images	–	Scrapped from Bing search		Public

Table 7 (continued)

Dataset name	URL	# of images	# of class labels	Class label distribution	Place	Kind of garbage	Image size	Public/private
Deep Sea Waste	https://www.kaggle.com/datasets/henryhaefliger/deepseawaste	3055	6	Litter square can, A Packaging bag, Label for beverage, A kind of component, 18 l square can, piece of plant/wood	–	Underwater Images		Public
MJU-Waste v1.0	https://github.com/realwecan/mju-waste/	2475	1	–	–	Plain background, indoor RGBD images		Public
Cigarette Butt Dataset	https://www.immersivelimit.com/datasets/cigarette-butts	2200	1	Cigarette butts	Austin Texas USA	Waste inn the wild, synthetic images	3024 x 4032	Private
TrashBox	https://github.com/nikhilvenkatkumsetty/TrashBox	17785	7	Cardboard:2414 e-waste:2883 glass:2528 medical:2010 metal:2586 paper:2695 plastic:2669		Scrapped from web		Public
Garbage Classification	https://www.kaggle.com/datasets/asdasdasasdas/garbage-classification	2467	6	Cardboard:393 Trash:127 glass:491 metal:400 paper:584 plastic:472		Garbage dataset		Public

Table 7 (continued)

Dataset name	URL	# of images	# of class labels	Class label distribution	Place	Kind of garbage	Image size	Public/private
TIDY: Trash Image Dataset	https://github.com/gale31/TIDY	APPROX as still in development phase=275	9	cigarette butts: 84 cardboard: glass: 15 metal: 8 paper: 60 plastic: 69 plastic bag: 8 plastic bottle: 11 unknown: 20		garbage dataset		Public

7.3 Source of the garbage datasets

Garbage datasets are divided into three—existing (Peng et al. 2021; Rabano et al. 2018; Jardosh et al. 2020; Sidharth et al. 2020; Shaikh et al. 2020; Alqahtani et al. 2020; Castellano et al. 2021; Fatma et al. 2023; Gupta et al. 2022), self-made (Gopalakrishnan et al. 2021; Shetty and Salvi 2020; Dubey et al. 2020; Jagtap et al. 2020; Sarker et al. 2020; Sheng et al. 2020; Shamin et al. 2019; Li et al. 2022; He et al. 2022; Wu et al. 2022; Chunxiang et al. 2022; Li et al. 2023a; Chen et al. 2023), and hybrid (Susanth et al. 2021; Li et al. 2023b). Self-made datasets are further classified into two: self-captured images and those downloaded from the Internet or common image datasets (Susanth et al. 2021; Li et al. 2023b). The studies above used existing TrashNet, Kaggle, and ImageNet garbage datasets, as well as Gary Thung and Mindy Yang's.

8 Existing works results discussion

The three critical factors that determine the performance efficacy of existing smart waste management systems include garbage classification accuracy, the cost of SWM systems, and the garbage collection time involved. It is difficult to compare the performance of SWM systems based on the last two factors, owing to the different aims of the research in question. We therefore applied the first factor, garbage object detection and classification, for a comparison of systems. We compared the work on deep learning-based garbage classification. Accuracy, precision, recall, F1, loss, and inference time are metrics commonly applied to analyze the performance of AI models. The graph in Fig. 11 depicts a comparison of the existing work, based on accuracy. Apart from the common

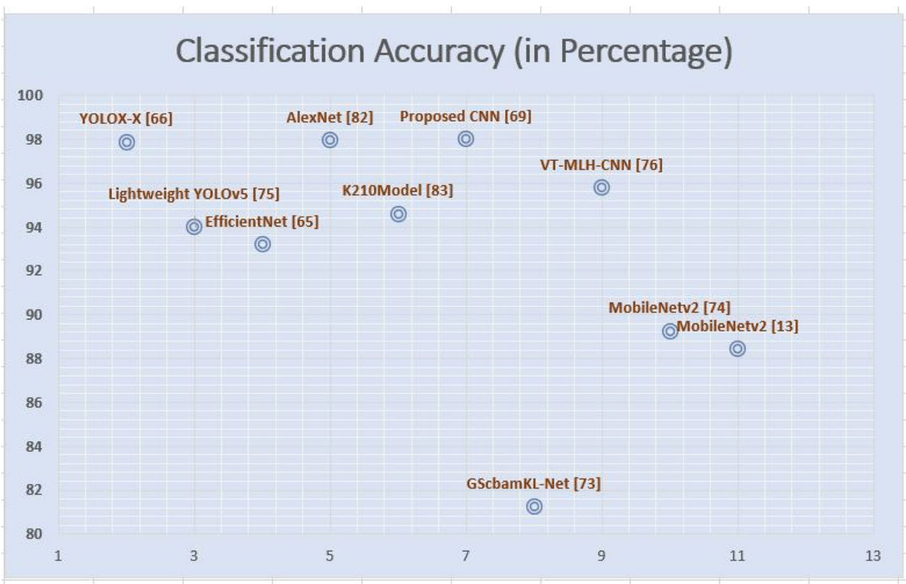

Fig. 11 Garbage image classification accuracy for SGB

benchmark garbage dataset, TrashNet, the datasets used in the models are entirely different from one another, though the work may be compared by considering images of garbage objects. Figure 11 shows that YOLOX-X gives the highest classification accuracy of 97.88% for garbage image classification, surpassing that of other models.

In this (Chunxiang et al. 2022) work, authors used their own dataset with 5000 images under 17 samples such as orange, banana, green pepper, lettuce, battery, stone, cigarette, express box, tissue, mask, bottle and can, etc. In other top-performing works, the number of class labels is more in order to identify various garbage rather than a major category of garbage such as recyclable and non-recyclable or bio-degradable and non-biodegradable or try and wet, etc. The SDS needs to be designed to classify the garbage into major categories to simplify the waste management system.

9 Future enhancement in smart bins

Existing research on smart bins has contributed greatly to the introduction of human-supportive devices that ensure hygienic environments. Our detailed study of smart bin research has identified a few major drawbacks in smart bin design that are highlighted in Fig. 12. Of the studies listed, a few on the automatic cleaning and sanitization of bins are indicative of the work being in the commencement stage, given that these are yet to become common features in smart bins. The automatic identification of garbage types and their segregation are currently the most dominant areas of research in smart bin deployment. However, object detection accuracy is not good enough to make the system commercially viable. Datasets on garbage types are limited and not environment-specific. Location-aware smart bins are in huge demand, particularly intelligent, automated bin designs that consider both the location of the installed bins and that of the user. This calls for smart bin algorithms that are cost-efficient and energy-efficient, and can incorporate context-aware notifications intended for the users concerned. The latest smart bin design focuses on a robotic arm that segregates garbage and transfers it automatically to the appropriate bins. Finally, the technique must be sure to guarantee the garbage collector's safety.

Fig. 12 Gaps identified in the existing smart bins

10 Conclusion

This study of smart dustbin systems has been undertaken to develop a smart green ecosystem that is environmentally sustainable. It has analyzed IoT developments in smart bins and discussed the array of sensors deployed at sundry spots in and around the bins. Sensors play a major role in segregating garbage types into degradable, non-degradable, wet, and dry wastes. The SDS system implemented in smart cities is used efficiently to keep the environment clean. SDS implementation in densely populated areas cuts labor costs and maintenance and increases the timely monitoring of garbage. Adding deep learning and computer vision technology to SDS systems maximizes segregation accuracy while minimizing labor time and energy simultaneously.

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