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# Artificial intelligence and IoT driven system architecture for municipality waste management in smart cities: A review

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ABSTRACT

Numerous devices, including sensors, RF ID, and other types of smart devices, have been developed as a result of the Artificial Intelligence (AI), and Internet of Things (IoT) revolution. Urban areas can become smart by monitoring and collecting data about their surroundings through the deployment of technologies with powerful computational capabilities and those that are converted into intelligent things. Waste management is among the most significant issues in smart cities, a rise in metropolitan regions and faster increases in population are the main reasons. When it comes to gathering data about waste management, intelligent services can serve as the front line. Waste management with IoT support is a common example of a service offered by smart cities. Various duties, like gathering, processing, and use of waste in appropriate facilities, are included in waste management. The present study proposed an updated waste management system architecture design after reviewing existing artificial intelligence and IoT-based waste management systems and automation in smart cities. The proposed system architecture deals with the automation of municipality trash in smarter urban areas, using IoT technology and sending notification messages based on sensor data relating to the dustbin state, such as full or empty. The notifications are sent simultaneously to the municipality office and the waste carrier vehicle driver, so that waste can be emptied on time. The proposed system architecture represents a scalable and adaptable model for municipalities that aim to transform their waste collection processes and play a key step in minimizing municipality waste in smart cities. By deploying this proposed system architecture with smart sensors and IoT devices, municipalities can monitor waste levels to ensure that bins are emptied when it is necessary. This reduces the frequency of waste collection, lowers fuel consumption, and minimizes operational costs. The Route optimization algorithms further enhance efficiency by determining the most efficient paths for waste collection trucks, so they can reduce travel time and fuel emissions.

## 1. Introduction

One of India's most significant environmental issues is municipal waste management. Residents are put in danger by improper handling of municipal waste. As per the numerous studies in open landfills and dumps, the environment and public health have been negatively affected by the improper disposal and collection of municipal waste. Most of the trash on earth, which makes up 23 percent of the total, comes from Eastern Asia and the Pacific, then the Middle East and the West [1]. Waste output will be estimated to exceed 3.4 billion tonnes by 2050 in these regions [2] (see Table 5).

Almost half of all waste in India is disposed of in public spaces. This rapidly increasing trend has major impacts on the environment and smart city sustainable development [3,4]. According to the TERI Institute, India ranked among the top ten nations globally, which creates around 62 million tonnes of household garbage annually. Out of 62 million tonnes, barely 43 million tonnes of the total is collected, 12 million tonnes are processed before disposal and 31 million tonnes are deposited in landfills [5]. The idea of technologically advanced cities has gained traction and recently become popular due to its potential solutions related to automation [6,7]. The meteoric advancement in Artificial Intelligence (AI) with IoT-enabled smart technology has made numerous new opportunities possible in a variety of life domains [8]. AI gives a machine the capability to learn and act on its own without

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explicit instructions. Recent data from Statista 2022 indicates that the market for AI-based technologies increased by $1.4 billion (bn) in 2016 and is estimated to increase by $59.8 billion by 2025 [9]. Whereas IoT is predicted to have a $1.1 trillion industry by 2023. These numbers demonstrate how crucial AI and IoT are in the management of municipality waste in urban areas [10].

The proposed system architecture addresses issues such as overflowing waste cans, high operational expenses, and inefficient collection schedules integrating IoT and AI into municipal waste management. This architecture tracks the filled levels of waste bins continuously, and AI may analyze the data for better waste pickup routes and schedules. Cities may limit their influence on the environment, save operating expenses, and enhance general cleanliness by implementing these kinds of technologies. It additionally reduces air pollution and traffic jams. The proposed system architecture for municipality waste management in a smart city includes a waste bin integrated with NodeMCU and sensors that connect the city municipality to the waste bin, as well as carrier trucks so that bins can be tracked easily and emptied as soon as possible from various remote locations throughout the city. This system architecture provides a user-friendly interface that offers information through mobile applications about the waste bin, whether it is full or not, the location of the bin, and also provides the shortest traffic path to the carrier truck drivers using Google Maps. This smooth communication is facilitated using a smartphone with the help of the internet.

## 2. Related work

India's population growth, industry, and urbanization have all grown rapidly during the past few years, which has made waste management a major issue. According to World Bank Data, 20 to 50 percent of municipal corporation's financial resources are allocated to sustaining solid waste management. The author presented the ISWM plan, a document that contains initial data, suggested goals, challenges raised by the management system, answers from the system, a plan for execution, surveillance, and system input [11]. To send a truck for garbage collection, the author created an electronic tracking device with GSM that sends a text message to the administrator when the dustbin is to capacity [12]. This research, employed an inaudible sensor for measuring the quantity of waste in the wastebasket and the sending messages using a GSM module a message informing the recipient of the current condition of the dustbin that is, whether it had been filled or emptied. Similar techniques were presented for waste collection along with an Arduino UNO board connected inbuilt global positioning system and a sensor that emits sound. The author of the paper covered issues related to smart dustbin cost-effectiveness, longevity, and maintenance [13]. A system to handle waste which collects waste from hard-to-reach places in the city employing a camera, an Arduino UNO with an inbuilt module with wireless connectivity that connects to the internet through the Blynk app, which manages all of the participants' communications [14]. Based on the Internet of Things prototype, an intelligent dustbin was proposed in the Indian city of Pune. Making choices, spotting patterns, and evaluating enormous amounts of data from sensors used in IoT devices are all made possible by artificial intelligence. Therefore, AI is a technique for making decisions upon data [15]. Agarwal et al. provided in-depth information regarding India's waste management programs for human welfare. It was pointed out that waste management may need some improvement for the betterment of society [16]. Managing waste is essential to building a metropolitan area, but it involves more than just gathering and getting rid of waste. The incorrect disposal of waste items is also causing harmful gases to be released into the atmosphere. This must be managed appropriately. Toxic gasses like methane are produced in part by municipality waste and other untreated decomposing items [17]. The appendix given below shows a comparative analysis using Artificial Intelligence techniques for the waste management system in Table 1.

Since hazardous gases from trash are endangering the environment, managing MSW remains among the most important environmental concerns affecting Indian cities (see Table 2). The dustbins by the side of the road are bursting at the seams [41]. The city's growing population and waste from hotels, businesses, etc. are to blame for the overabundance of trash cans. The overabundance of trash cans will degrade our surroundings and expose people to multiple medical conditions [42]. This encourages us to create a proposed system architecture for municipality waste management that uses AI and IoT-based technologies to deliver alert messages based on sensor data related to dustbin status whether full or empty, simultaneously send alerts to waste carrier vehicle drive as well as municipality office so that waste can be emptied on time [43]. The study ended with some fruitful future directions, it

**Table 1**
A comparative analysis using Artificial Intelligence techniques for the waste management system.

| References | Input | | | Methods | | | | Output | | | Proposed | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Image | | Video | ML | ANN | DL | Manual | Image Clclassification | Location Identification | Object Detection | Artificial Intelligence | IoT |
| | Satellite | Manual | | | | | | | | | | |
| [18] | ✔ | ✘ | ✘ | ✘ | ✘ | ✔ | ✘ | ✔ | ✘ | ✘ | ✔ | ✔ |
| [19] | ✔ | ✘ | ✘ | ✘ | ✘ | ✔ | ✘ | ✘ | ✘ | ✔ | ✔ | ✔ |
| [20] | ✔ | ✘ | ✘ | ✔ | ✘ | ✘ | ✘ | ✔ | ✔ | ✘ | ✔ | ✔ |
| [21] | ✘ | ✘ | ✔ | ✘ | ✘ | ✔ | ✘ | ✔ | ✘ | ✔ | ✔ | ✔ |
| [22] | ✔ | ✘ | ✘ | ✘ | ✘ | ✔ | ✘ | ✘ | ✘ | ✔ | ✔ | ✔ |
| [23] | ✔ | ✘ | ✘ | ✔ | ✘ | ✘ | ✘ | ✔ | ✔ | ✘ | ✔ | ✔ |
| [24] | ✔ | ✘ | ✘ | ✔ | ✘ | ✘ | ✘ | ✔ | ✔ | ✘ | ✔ | ✔ |
| [25] | ✔ | ✘ | ✘ | ✔ | ✘ | ✘ | ✘ | ✘ | ✔ | ✘ | ✔ | ✔ |
| [26] | ✘ | ✔ | ✘ | ✔ | ✘ | ✘ | ✘ | ✔ | ✘ | ✘ | ✔ | ✔ |
| [27] | ✘ | ✔ | ✘ | ✘ | ✘ | ✔ | ✘ | ✘ | ✘ | ✔ | ✔ | ✔ |
| [28] | ✔ | ✘ | ✘ | ✘ | ✘ | ✘ | ✔ | ✔ | ✘ | ✘ | ✔ | ✔ |
| [29] | ✘ | ✔ | ✘ | ✘ | ✘ | ✔ | ✘ | ✘ | ✘ | ✔ | ✔ | ✔ |
| [30] | ✔ | ✘ | ✘ | ✘ | ✘ | ✘ | ✔ | ✔ | ✔ | ✘ | ✔ | ✔ |
| [31] | ✔ | ✘ | ✘ | ✔ | ✘ | ✘ | ✘ | ✔ | ✘ | ✘ | ✔ | ✔ |
| [32] | ✘ | ✔ | ✘ | ✘ | ✘ | ✔ | ✘ | ✔ | ✘ | ✔ | ✔ | ✔ |
| [33] | ✘ | ✔ | ✘ | ✘ | ✘ | ✔ | ✘ | ✔ | ✘ | ✔ | ✔ | ✔ |
| [34] | ✘ | ✔ | ✘ | ✘ | ✘ | ✔ | ✘ | ✘ | ✘ | ✔ | ✔ | ✔ |
| [35] | ✔ | ✘ | ✘ | ✔ | ✘ | ✘ | ✘ | ✘ | ✔ | ✘ | ✔ | ✔ |
| [36] | ✔ | ✘ | ✘ | ✔ | ✘ | ✘ | ✘ | ✘ | ✔ | ✘ | ✔ | ✔ |
| [37] | ✔ | ✘ | ✘ | ✔ | ✘ | ✘ | ✔ | ✘ | ✔ | ✘ | ✔ | ✔ |
| [38] | ✔ | ✘ | ✘ | ✔ | ✘ | ✘ | ✘ | ✘ | ✔ | ✘ | ✔ | ✔ |
| [39] | ✔ | ✘ | ✘ | ✔ | ✘ | ✘ | ✘ | ✘ | ✔ | ✘ | ✔ | ✔ |
| [40] | ✔ | ✘ | ✘ | ✔ | ✘ | ✘ | ✘ | ✔ | ✘ | ✘ | ✔ | ✔ |

**Table 2**
Analysis of existing waste management systems and their results.

| Reference | Author and Year | Techniques | Results |
|---|---|---|---|
| [53] | Debdas et al., 2023 | Cutting-edge technologies | Waste management needs to be done correctly to save the environment and enhance public health. To efficiently manage waste, a smart garbage management system makes use of cutting-edge technologies. The objective of this system is to efficiently and environmentally friendly collect, sort, and recycle waste. Waste collectors can adjust their routes and schedules Using data that is current about the trash levels by utilizing smart sensors and bin fill-level mjonitoring devices. This data is presented on a webpage for convenient observation. By using this technique, communities may become more sustainable, waste's effects on the climate could be lessened, and hygiene could be enhanced. An overview of the current situation with smart waste is given in the study. |
| [54] | Thiagarajah et al., 2023 | IOT with ultrasonic sensor, and GPS. | Many people dispose of their rubbish in already-filled garbage cans. Wastes are therefore poured outside the garbage can as a result. In addition to disease spreading, animals might become fatally ill from eating the feces that are strewn all over the place. To prevent these issues, a clever and vigilant system that continually checks the amount of rubbish in the bin using an ultrasonic sensor is in place to monitor the rubbish. When the level hits a specific point, the Arduino Uno uses GPS to determine where the bins are located. An IoT device displays the trash cans on the map along with the proportion of trash therein. So that waste collector collects the waste easily. |
| [55] | Ismail et al. 2023 | Raspberry Pi with NodeMCU | By integrating other technologies with IoT into the garbage can system, this study seeks to address the issue. This study's goal is to use a Raspberry Pi equipped with an ultrasonic sensor to sense what's inside the trashcan. There are numerous benefits to using Raspberry Pi, including a dashboard that displays data in real-time and an integrated database that can store and monitor data. The sensor's ability to accurately forecast the rubbish bin's contents is one of the project's outcomes. The outcomes are transmitted to the MySQL database and shown on the It panel for extra observation when the bin fills up to 80percent of its capacity. Furthermore, waste management received an email notification official to provide updates on the waste can's condition. In conclusion, by alerting the waste management authorities when the garbage can is full and enhancing the clean areas this technology has made their job easier. |
| [56] | Holanda Filho et al. 2023 | IOT, LPWAN and Block Chain | The recent post-pandemic scenario has led to changes in a wide range of disciplines, which has increased the focus on this topic when it comes to environmental challenges. However, most garbage cans in cities appear to be overflowing because of antiquated or ineffective waste management techniques. To notify the appropriate authority for trash clearance of the amount of garbage in bins, a remote monitoring system is required. By monitoring and controlling municipal procedures, the Internet of Things (IoT) paradigm in this case greatly enhances smart city applications. This study presents an implementation of an LPWAN and blockchain solution to supply the necessary data to improve solid waste collection efficiency. Finally, an assessment of the suggested design in terms of latency and throughput metrics is given in this study. |
| [57] | Mousavi et al., 2023 | ICT | Global concerns about waste management are growing in importance due to the increase of citizens and changing consumer behaviors. Waste pickup is one efficient IoT service that leverages energy and cost optimization. The primary objective of this study is to analyze how IoT is used in garbage collection and to present environmentally friendly waste collection techniques. This study looked at information and communication technologies including data communication, acquisition, identification, and spatial technologies. It also evaluates various energy harvesting gadgets to further cut expenses. The results showed that putting these technologies into practice can change the path, save costs, and consume less energy. |

(continued on next page)

**Table 2** (*continued*)

| Reference | Author and Year | Techniques | Results |
|---|---|---|---|
| [58] | Cai et al., 2022 | NodeMCU controller and Machine Learning | The burden on municipal trash treatment is rising these days due to the rising volume of municipal waste. In this instance, it's becoming common practice to use inexpensive, low-power Internet of Things technologies to enhance urban waste management research using Trash Manager, a smart garbage disposal system proposed for metropolitan populations. Using data visualization and IoT technologies, the Garbage Manager seeks to develop waste detection that is both energy-efficient and real-time. In this study, the height of the rubbish in the garbage can is measured using a high-precision ultrasonic sensor built into the NodeMCU chip. The data is subsequently transmitted to the database using the cloud IoT platform. To display the garbage cans' present state in real-time, a webpage is also built as an interface with graphics. The Garbage Manager may reduce garbage overflow times by 83.33percent, based on experimental data, and the amount of labor required to clear the rubbish by 24.07percent. |
| [59] | Vishnu et al. 2021 | Artificial Intelligence | AI-based Intelligent waste containers with sensors can keep an eye on the bins' fill levels in real-time moment. These devices transmit data to a central management system, allowing for optimized waste collection routes. |
| [60] | Xenya et al. 2020 | NodeMCU enabled with Gsm module | This study presents a suggested approach that addresses the problems of spillage and ineffective collection techniques by utilizing several different alternatives. Once a utilizer is full, a work order is issued and sent to the drivers, and a routing system with information about the condition of the bins distributed in a certain area can be evaluated via the driver's phone. The system is successfully installed, allowing real-time trash bin condition monitoring. However, there have periodically been high latency issues, mainly because the GSM module is used for GSM/GPRS connectivity. |
| [61] | Zeb et al. 2019 | IoT based technologies | IoT can modernize traditional processes. It offers positive results for the growth of automatizing, cities, industries, and smart surroundings. Within this paper, we investigate whole-system delay reduction for intelligent waste, The duration needed for a single packet to travel from its source node to its destination is referred to as the end-to-end delay. The recommended strategy considers how far |
| [62] | Nasir and Masri et al., 2018 | IoT enabled technologies | It's becoming more and more difficult to manage trash in an environmentally responsible way. The issue of how quickly waste is produced as a result of expanding people exacerbates this situation even further. Recycling and reduction at the source are two different approaches to waste management. However, improving garbage collection can be costly, particularly when it comes to the source separation process that follows the gathering of garbage. If a system was in place to assist cities, waste disposal firms, and municipalities in identifying the root causes of violations, that would be fantastic before the waste removal process ever got underway. Our work introduces recycle; a serverless waste management solution enabled by the Internet of Things (IoT). |

may be beneficial in motivating knowledgeable authorities or researchers to discover more improvements to this proposed architecture for municipality waste management.

### 2.1. Population growth and waste generation

India has 1.21 billion people living there, making it the second-biggest country in the world by population [44]. This represents 17.7 percent of all people on the planet and the largest proportion of young people. A few decades ago, the majority of Indians were mostly dependent on agriculture and related industries for their living. Agriculture and related industries accounted for one-third of India's overall revenue at the time when the country's economy was heavily dependent on agriculture. India's economy is currently shifting from agriculture to industry and services. Approximately 18.80 percent of India's GDP in 2021 came from agriculture and related sectors, compared to 51.45 percent in 1951 [45]. As a result, industrial and service-oriented jobs are rapidly replacing agriculture in India's labor market. As a result over 31.16 percent of Indians reside in urban areas, indicating the country's rapid urbanization. These 7933 towns and cities are home to 377.1 million urban residents [46]. With 28 States and 8 Union Territories, India is an enormous country that is home to over 53 major cities with an estimated population of one million or more, accounting for more than 37 percent of all urban residents [47]. By 2030, there will be 575 million people living in urban areas, and by 2050, half of the nation's people are anticipated to reside in metropolitan areas. Rapid economic expansion and urbanization are affecting Indian cities not just in terms of their actual size but also in terms of the infrastructure services they provide.

Low-wage individuals also find themselves living in haphazard suburban housing as a result of rapid urbanization. To manage the urban and suburban settlement, the urban economy needs to be established. India's urbanization is impressive, which is crucial for the country to progress [48]. The rapid growth of cities and expanding economies have a direct effect on waste management in Indian cities.

### 2.2. Waste collection Mechanisms

This subsection presents an investigation of waste collection truck optimization of routes. The substantial uncertainty regarding waste container fill levels is resolved by utilizing sensors to transmit data in real time. optimal paths for collecting are determined by sensors and optimization algorithms required to maximize waste while lowering transportation costs [49].

A free intelligent software solution called BIN–CT was designed and made available by Ferrer in 2019. It planned trash pickup paths using data from forecasts and previous records. The method was designed to lower truck travel distance and, consequently, fuel consumption, which would lower waste collection expenses [50]. A further investigation conducted by Hannan in 2020 used an LP algorithm approach for optimization to combine fixed and variable routing improving to increase household waste collection ability, minimize expenses, and decrease emissions. The goal was to optimize a waste collection by combining fixed and variable route optimization. Technology would save expenses, reduce pollutants, and increase fuel efficiency [51]. Two frameworks were developed by Salehi-Amiri in 2022 using the concept of vehicle routing. Although the subsequent model considers waste classification as well as transmission to the recovery value center, the first model collects data in real time using contemporary traceability IoT-based devices. A mixed-integer nonlinear programming approach was presented by the author in 2023 to improve agricultural waste collecting and transportation systems. By repurposing agricultural waste to make bio-organic fertilizer, the goal was to minimize waste burning. The model assists rural planners in identifying waste storage sites and devising the most efficient routes for a group of vehicles to transport garbage from these bins to a facility that produces biologically based fertilizer. To lower operating expenses and lessen its impact on the environment, Rahmanifar in 2023 proposed a two-stage approach for managing garbage based on the Industry 4.0 concept [52].

For smart cities to be developed and run smoothly, route optimization is essential. Route optimization allows for better control of traffic flow, which minimizes congestion on major thoroughfares and roadways. This results in less time wasted in traffic and more comfortable journeys. less time and distance spent traveling, which lowers fuel use and toxic gas emissions thus also improving air quality.

Existing hardware components required for proposed smart waste management architecture. Hardware components used in other smart waste management systems are microcontrollers with wi-fi capabilities [73] which control all other sensors connected and connectivity to these components provided with wi-fi, GPS modules Useful to locate and monitor deployed bins so that carrier's trucks can track the location of the bin [74], ultrasonic sensors or other sensor for filling level for waste bins, ultrasonic sensors or other fill-level sensors for waste bins and Blynk app for mobile plans interface [75] (see Fig. 1).

## 3. Proposed municipality waste management system architecture for smart cities

Utilizing sensors and smart bins, unmanned waste collection in smart cities employing the IoT, and AI technologies makes rubbish collection easier to monitor and control. IoT sensors track the fill levels of trash cans available whenever, and AI may analyze the data for better garbage pickup routes and schedules. Cities may limit their influence on the environment, save operating expenses, and enhance general cleanliness by putting this technology into practice. It can also aid in lessening air pollution and road congestion brought on by conventional trash-collecting techniques the architecture diagram of the proposed system for municipality waste management in a smart city includes a waste bin integrated with NodeMCU and sensors that connect the city municipality office of the city to the waste bin and also carriers' truck so that bins can be located easily and empty as soon as possible from the different remote location of the city. This system provides a user-friendly interface, which provides information about the waste bin whether it is full or not, the location of the bin, and also provides the shortest traffic path to the carrier's truck driver using Google map so that smooth communication can be governed using smartphone with the help of internet as shown in Fig. 2.

This suggested architecture system is based on reviewed literature related to IoT and artificial intelligence in automation, the working of this architecture is explained in Figs. 2 and 3 in detail. In intelligent trash disposal methods, IoT plays a crucial role by connecting end devices, such as smart trash cans, to a single command hub. The optimization software at the control center processes the data received from these devices and determines the most efficient administration of the fleet of collector trucks. This not only streamlines the waste collection process but also contributes to economic and ecological advantages.

The control unit consists of a micro-controller NodeMCU ESP8266, LCD unit, light emitting diodes, ultrasonic sensors, GPS module, and power supply. It integrates the ESP8266, which is a versatile and cost-effective Wi-Fi-enabled system-on-a-chip (SoC), with a Lua script interpreter [76]. The NodeMCU offers an intuitive interface for the Internet of Things and embedded systems development using artificial intelligence [77]. The core of NodeMCU is the ESP8266 chip, which provides Wi-Fi connectivity for IoT applications. The ESP8266 module includes a microcontroller unit (MCU) with an integrated TCP/IP protocol stack, making it suitable for IoT projects that require wireless communication we also use a GPS module to access the automatic system globally. While Lua scripting is the default firmware, NodeMCU also supports the Arduino IDE, making it compatible with the Arduino programming language. This allows us (developers) to use familiar Arduino libraries and functions. We used an LCD MODULE 128x64 Character (Green) Graphic LCD to Display information related to bin location, and whether the installed bin is full or not and needs to be empty or not around based on sensors used in the proposed municipality waste management system in the smart city [78]. The light-emitting diode indicates the level of bins using RGB light red indicates It is time to empty the full bin. immediately yellow light indicates a half-filled bin and the green light indicates that the bin is empty with the help of Ultrasonic sensors. These sensors are used to monitor the fill levels of waste bins or containers in real-time [79]. Ultrasonic sensors emit ultrasonic waves, and how long it takes for the waves to reflect from the surface. The amount of trash is determined by the garbage. By continuously monitoring fill levels, Waste management authorities can optimize collection routes, ensuring that trucks are deployed to bins that are approaching capacity and reducing wasteful collections at full bins.

In the context of municipality waste management in smart cities, these sensors contribute to a more sustainable and efficient waste collection process and engage citizens. Waste collection vehicles are equipped with GPS modules to enable real-time tracking of their location. Waste carrier truckers can monitor the position, speed, and route of each vehicle, allowing for better fleet management and coordination [80]. By optimizing routes using GPS data, waste management systems can reduce fuel consumption. Efficient route planning ensures that vehicles take the shortest and most fuel-efficient paths, contributing to cost savings and environmental sustainability in smart cities [81]. Geofencing technology, often integrated with GPS, allows waste management authorities to define virtual boundaries for specific areas. Alerts can be triggered when waste collection vehicles enter or leave designated zones, providing insights into operational activities. This system can be powered using a city grid system can enhance the operationality of the proposed system. Artificial Intelligence (AI) and Internet of Things

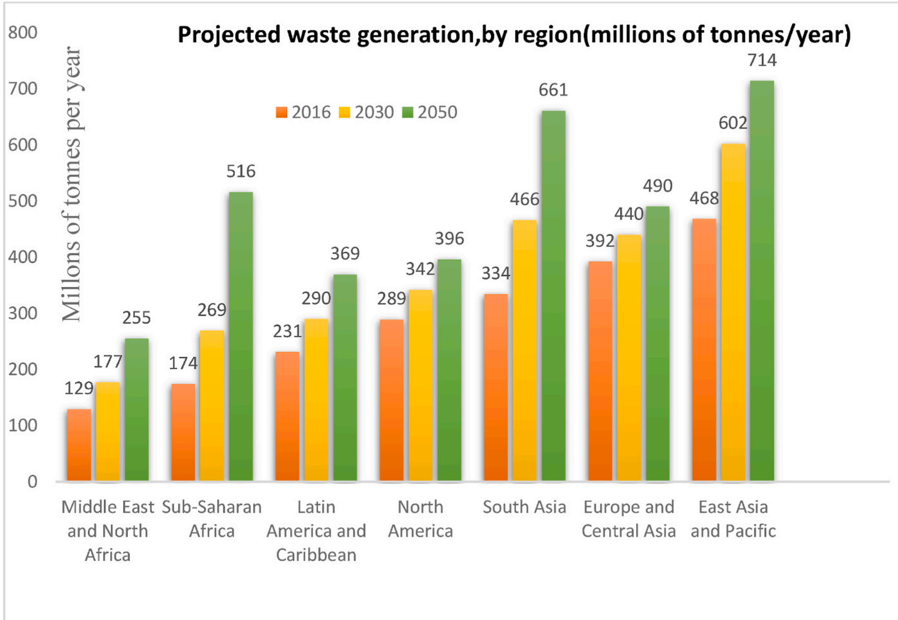


**Fig. 1.** Waste generated by regions in millions of tonnes per year.

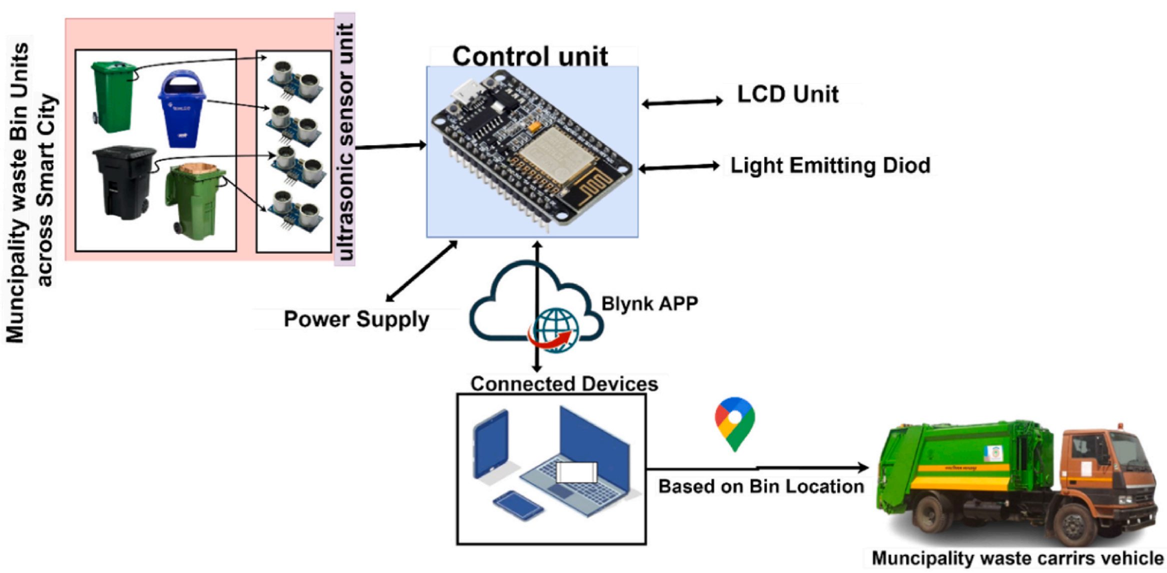


**Fig. 2.** Proposed municipality waste management system architecture for smart cities.

(IoT) enabled control unit represents a cutting-edge technology integration that empowers devices, systems, or processes with advanced capabilities for automation, optimization, and data-driven decision-making.

Concerning the acquired outcomes, the suggested model successfully divides the trash into two categories: decomposable and non-biodegradable. Based on the classification non-biodegradable substances can be recycled and reused for sustainability. The deployed sensors in the smart bins as shown in Fig. 4 generate alerts status of the waste percent filled in it. We categorize the percentage of waste filled into three levels 50 percent, 51 percent-70 percent, and above 70percent filled. If the percent of waste filled in the dustbin is less than 50 percent green LED light turns on which indicates that the dustbin is half filled and prints the distance status of the bin from the municipality office based on Google map features so that the municipality workers can empty it on time. similarly, if the percent of waste filled in the dustbin is between 51percent-70percent a yellow LED light turns on based on the waste detection sensor which indicates that the bin is near to fill and prints the distance status. If the percent of waste filled is greater than 70 percent red LED is turned on which indicates that the bin is full of waste and prints the distance between the dustbin and the municipality office so that the carrier truck can use optimal routes using Google navigation. The working of this system is shown in Fig. 3. An alert is generated to the municipality office and the waste carrier truck so that the carrier truck can choose the optimal distance route based on Google map features to monitor the locations of trash cans in the city and empty them on time. The communication between the municipality office and the waste carrier truck is governed by the blink server as shown in Fig. 5. All the information of the remotely deployed dust bin whether it is empty or full is updated on the blink application which is connected to the central municipality office and the carrier trucks using artificial intelligence and machine learning algorithms. Further research is still possible, though,

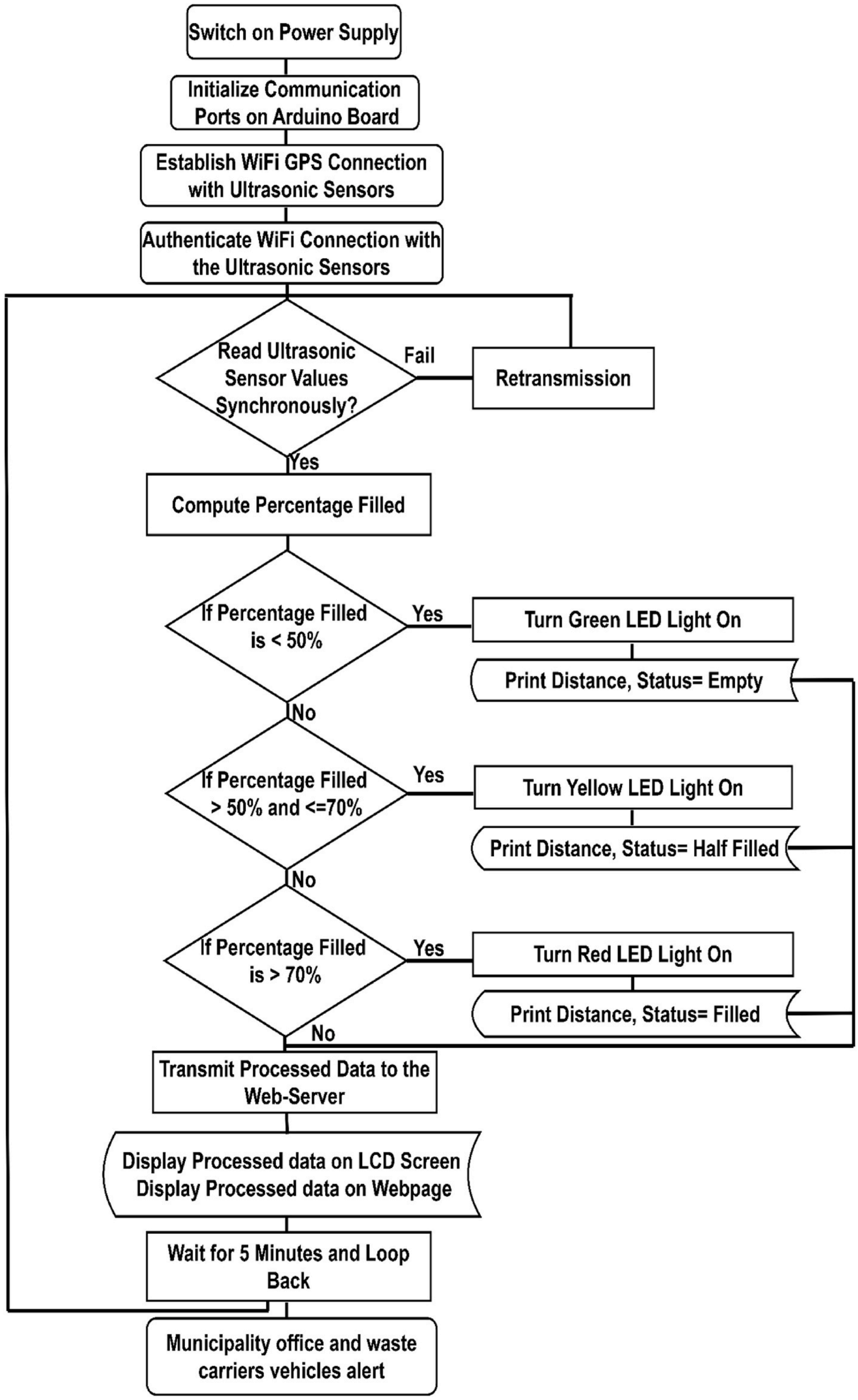


**Fig. 3.** Workflow of the proposed system architecture.

given the incredibly high prediction probability and the decrease in detection time. Future research and result optimization may focus on forecasting the possibility of additional waste products in the real world as well as results optimization [82].

### 3.1. Municipality waste bin units deployed across the city

The term "municipality waste bin units refers to distributed IoT and AI that allow dumpsters to be strategically positioned in different areas to make it easier for consumers, companies, and other institutions in smart cities to get rid of municipalities. These waste bins play a vital role in maintaining cleanliness, managing waste efficiently, and contributing to the overall well-being of a city [83]. Regarding innovative cities, technology may be integrated into waste bin units. This could involve sensors to monitor fill levels, alerting municipal authorities when bins are nearing capacity [84]. By optimizing pickup travel routes, SWMS can reduce its operational expenses using Google Maps control features.

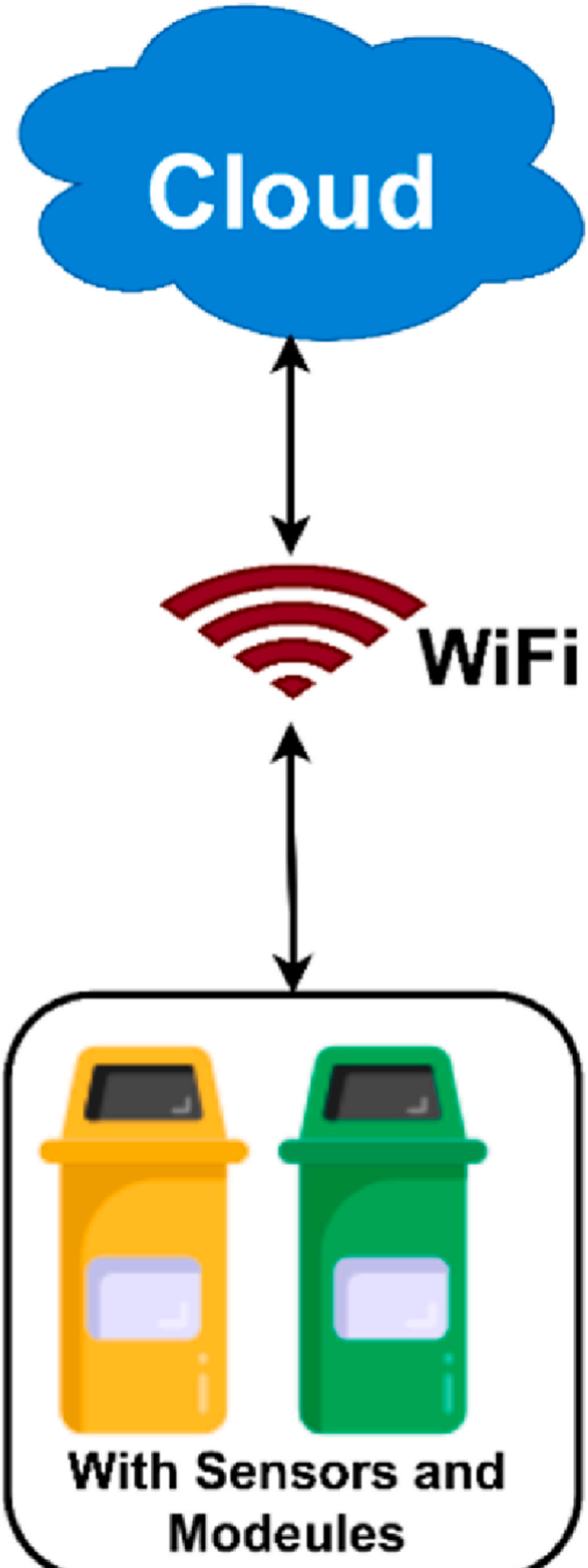


**Fig. 4.** Communication between remotely installed bins in a smart city.

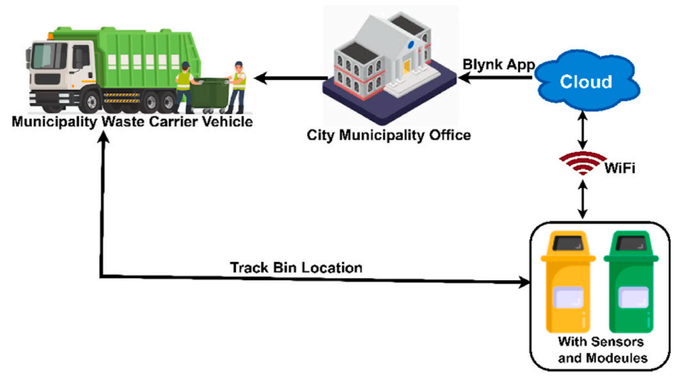


**Fig. 5.** Communication between city municipality office, carriers' truck, and deployed bins.

### *3.2. Communication between the city municipality office, waste Carrier's trucks, and remotely located waste bins across the city using the Blynk app*

Communication between the city municipality office, waste carriers' trucks, and remote waste bins across the city using the Blynk app involves integrating IoT devices, like microcontrollers, sensors, and communication modules [85] required components are listed in Table 3below (see Table 4).

This finding has given rise to the conclusion that efficient information management with a longer lifespan and lower energy consumption could enhance the proposed architecture for smart waste management systems. Consequently, the study provides an architecture using Artificial Intelligence and IoT has enormous promise for improving garbage pickup efficiency and quality in smart cities. The two primary issues with smart city waste collection are high costs and inefficiency. This paper, like other innovative technologies used by smart cities to improve city services, provides artificial intelligence with an IoT sensors-based solution to provide public works crews with detailed information about trash bins throughout the city. So that municipality waste is collected efficiently from public places in the city. The sensors can signal when bins need to be emptied when Odors become an issue, when bins have been tipped over, and even when the temperature within a bin is too high. Waste management teams may handle trash collector trucks more efficiently using this information, keeping public areas clean in the city and well-maintained. The proposed approach makes use of the ESP8286 microcontroller with GPS modules, ultrasonic sensors, RFID, and a blink App. placed inside the bin.

The Blynk application is connected to an ESP8286 microcontroller with inbuilt GPS and sends the location data to a Google Maps dashboard. These data, combined with information about the bin location are shared with municipality carriers' vehicles and the shortest path is also suggested based on Google Maps to minimize the route cost. Improved information management with reduced energy use and extended longevity could benefit this system. To lower the obstacles in the way of garbage collection in smart cities, this paper, AIEMWM, has been suggested.

## 4. Limitations of the proposed system architecture

Being reliant on electricity for functioning is one of its primary limitations, which can be challenging in locations with restricted availability of power. Furthermore, because this system needs more applicants for garbage bins for the collection of waste based on the urban population and location, the intricacy of the technology that is employed in smart garbage cans may result in greater installation and maintenance expenditures. Because smart dustbins are more expensive than other options, this results in a higher initial cost. The trashcans' sensor nodes have a small amount of memory which is also a challenge for data

**Table 3**
Comparative analysis based on IoT and AI in automation systems.

| References | Io T Service | Network | Energy source | Feasibility |
|---|---|---|---|---|
| [63] | Health | Wi-Fi and Ethernet | Battery | The feasibility of an IoT-based health monitoring system is a crucial aspect that determines its viability and effectiveness. Such a system involves the integration of AI with IoT to collect, and transmit Current health information. |
| [64] | Waste management | Wi-Fi (3G & 4G) | Rechargeable | Vehicle health can be tracked by sensors, which can identify problems before they get out of hand. This proactive strategy lowers downtime and guarantees a more constant and dependable service, improving the waste management fleet's overall reliability. |
| [65] | Air quality monitoring | Bluetooth and Wi-Fi | Battery | Maintaining a healthy living environment is crucial as urbanization picks up speed. Within the framework of smart cities, these systems continually monitor air pollution by deploying a network of sensors at strategic places. The advantages of this kind of technology are numerous. It enables focused efforts to reduce environmental concerns by enabling city officials to quickly identify pollution hotspots. Furthermore, residents have access to current data on air quality, empowering people to decide with knowledge on their daily lives and well-being. |
| [66] | Traffic congestion | Bluetooth, Wi-Fi, Ethernet | Connected to Main smart city power system | IoT devices may gather information on traffic patterns, road conditions, and vehicle movement when they are positioned strategically around the city. An IoT-based traffic congestion system not only facilitates better traffic flow but also lessens fuel consumption and emissions from stationary vehicles in traffic, which is good for the environment. Additionally, it improves the effectiveness of transportation overall, improving citizens' quality of life and convenience in the city. |
| [67] | Noise monitoring | Wi-Fi Internet | Energy harvester | Growing population of cities, controlling noise pollution becomes essential to improving people's quality of life in general. An IoT-based noise monitoring system continuously measures and analyses ambient noise levels by utilizing sensors positioned in a tactical manner throughout the city. Data in real time collection from these sensors enables a dynamic and thorough understanding of noise patterns at various places. The viability of this kind of system depends on its capacity to provide Public Awareness and Engagement, Integration with Smart Infrastructure, and Timely Response. |

(*continued on next page*)

**Table 3** (*continued*)

| References | Io T Service | Network | Energy source | Feasibility |
|---|---|---|---|---|
| [68] | Energy consumption in smart city | Bluetooth and Wi-Fi | Main power | In this regard, smart grids use IoT to balance loads, distribute electricity efficiently, and quickly detect and fix defects. |
| [69] | Smart parking | Bluetooth and Wi-Fi | Battery | IoT-enabled sensors and gadgets can be strategically placed in parking spots in a smart city to gather occupancy data in real time. The potential economic and environmental benefits of IoT smart parking further bolster its viability in smart cities. An urban environment that is more sustainable can be achieved by reducing emissions and fuel consumption through effective parking management. Cities can also use the data to improve overall urban mobility, optimize parking regulations, and make well-informed decisions on infrastructure design. |
| [70] | Home automation and public building in smart city | Bluetooth and Wi-Fi | Main power and battery | The integration of IoT technology has revolutionized home automation and improved the sustainability of public buildings in the context of Smart Cities. Through seamless device communication made possible by IoT, homeowners can remotely control a variety of house functions. anything from monitoring security cameras to regulating thermostats. IoT optimizes resource utilization, which supports sustainability initiatives. Smart city projects use information from Internet of Things (IoT) devices to control energy use, cut waste, and improve productivity. This has a favourable effect on inhabitants' comfort and health in addition to the environment. In smart cities, the integration of IoT with public building management and home automation not only improves people's quality of life but also promotes a more sustainable and healthier urban environment. |
| [71] | Traffic signal services in smart city | Wi-Fi (4G & 5G) | Main power | Traffic signals can dynamically adjust to shifting traffic patterns by utilizing the Internet of Things. For example, the signals can dynamically assign green time to the busiest junctions during peak hours, which will improve traffic flow and lessen congestion. Furthermore, the road infrastructure has sensors that are integrated to identify the presence of bikes and pedestrians, guaranteeing safer crossings and encouraging multimodal mobility. |
| [72] | Security in Smarter City | Bluetooth and Wi-Fi | Battery and main power system | Smart cities need to give strict security protocol implementation top priority in order to overcome these obstacles. A thorough IoT security strategy must include encryption of data transferred between devices, authentication methods to confirm the legitimacy of linked entities |

(*continued on next page*)

**Table 3** (*continued*)

| References | Io T Service | Network | Energy source | Feasibility |
|---|---|---|---|---|
| | | | | and frequent security updates. Creating and implementing strong IoT security regulations requires cooperation between governmental organizations, IT companies, and the general public. Smart cities may foster an environment where residents can fully enjoy the advantages of IoT without sacrificing their safety or privacy by encouraging a group approach to cyber. |

**Table 4**
Hardware required for the proposed system architecture.

| | |
|---|---|
| ESP8286 and esp32 module [86] | •Modules are employed to create connections between software and hardware elements. The Arduino IDE is used to program the NodeMCU board. This allows users to simply access the smart system using the Blynk app's user interface while connecting sensors and other gear to the cloud.<br>•When integrating GPS capability into waste collection in smart cities frequently used option. It makes location-based services, tracking, and mapping possible by enabling the ESP32 to receive position data from GPS satellites. |
| Ultrasonic sensors [87] | •Sensors are mounted on top of standard waste bins to measure the amount of waste and identify any hazardous gas generation. By taking these steps, the waste management board is notified through messages from the sensors and is also able to determine which bin in a smart city has to be emptied. |
| Power Supply [88] | •Trash cans could be connected to the electrical grid in smart cities. This may require additional infrastructure to be installed, but it can also provide the bins with a stable source of electricity.<br>•Power supply is an important consideration in order to guarantee the correct and effective operation of waste management bins in smart cities. |
| RFID [89] | •However, IoT devices are utilized to instantly connect smart dustbins to the internet, allowing for real-time waste collection monitoring. |

transmissions like Wi-Fi and NodeMCU, which offer slower data speeds and shorter ranges. RFID tags in systems that rely on RFID are impacted by nearby metal items, if any. Additionally, it eliminates the need for a workforce, which raises the percentage of unemployed among workers without skills. The individuals using the smart waste management system must receive the training. Furthermore, the incorporation of various sensors and components into intelligent garbage cans may increase their vulnerability to harm or robbery. Finally, the installation of smart garbage cans may necessitate large-scale improvements and adaptations, which could be costly as well as tedious for populations of the cities.

**Table 5**
Software requirement for waste management system in the smart cities.

| | |
|---|---|
| •Arduino IDE [90] | A free program offers a way to code to Arduino boards which allow the AIEMWM system to carry out the tracking and bin location functions. |
| •BLYNK APPLICATION (GUI) [91] | The Blynk app for the Internet of Things is thriving. It helps hardware components to display sensor data. A sensor with a NodeMCU connection with bin in different location in city, providing real-time data. Developing a GUI (Graphical user interface) with Blynk is simple. User interface (GUI) enables end users to control waste management in city and provide bin carriers truck information about bin is full or not and an optimal traffic route. The Blynk app works well with both Android and Windows operating systems. Use a reasonable Gmail address to create an account and set a password. Then, utilizing the Blynk cloud, a graphical user interface is constructed to depict sensor data. Cloud-based sensor data is updated in less than 2 s. |
| •Programming Language | Python |

## 5. Conclusion

This research proposes a creative system architecture for waste collection in smart cities. The core of the system is an Internet of Things (IoT) sensing device that measures the quantity of waste in bins and sends the data to the server via Internet services. Implementing an AI-driven IoT architecture for municipal trash management in smart cities is a critical step toward establishing sustainable urban ecosystems. The IoT and computational intelligence together present several novel possibilities that can greatly improve the efficacy, performance, and environmental impact of urban localities with this proposed waste management system architecture. By deploying smart bin monitoring systems, operational costs can be reduced, and garbage pickup travel routes can be optimized. The implementation of today's technologies, like blockchain, LoRaWAN, mobile edge computing, IoT, and ML, has become crucial in transforming waste management in cities. A holistic approach to managing garbage is made possible by these technologies, which also make it possible to implement cutting-edge tactics like automated sorting and classification, route optimization, real-time monitoring, and accurate trend analysis for generating waste. IoT technologies, which provide practical insights for effective collection and disposal, have proven essential in developing a data-centric waste management system. The automatic handling of waste identification and sorting has been made possible by algorithms that use machine learning in conjunction with high-resolution image processing, which is supporting recycling initiatives and the transition to a circular economy. Concurrently, the utilization of large-scale data insights and geospatial data systems has led to more accurate tracking and mapping of waste generation, revealing inefficiencies and possible areas for improvement.

## Conflict of interest

The authors declare that they have no conflict of interest.

## 6. Future Scope

Future waste management in smart cities will be complex, necessitating a sophisticated, technologically advanced strategy that balances the needs of the environment with the quality of urban life. Modern technical innovations and creative approaches offer a promising route to a more economical, efficient, and sustainable urban life. To fully realize these benefits, education, research, technology, and the creation of policies will need to be invested in. For this reason, waste management in smart cities is an important and intriguing topic for continued investigation by scientists, decision-makers in government, and business leaders. A more responsive and all-encompassing waste management system can be developed by concentrating on the suggested future research directions, which will support the larger objectives of sustainable development in smart cities.

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## Declaration of competing interest

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## Data availability

Data will be made available on request.

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