Smart Dustbins: Real-Time Monitoring and Optimization for Waste Management in Smart Cities through IoT Devices

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ABSTRACT

The Internet of Things (IoT) provides a technological foundation for the development of smart cities. The technology has yielded novel possibilities for urban governance. The IoT offers a practical and cost-effective means of gathering vast quantities of data, which can be applied across a range of industries with the aim of increasing production. One of the most pressing challenges currently facing the development of smart cities is the issue of waste collection beyond the municipal corporation. The IoT has the potential to streamline the waste collection process across a smart city. The proposed model is designed to facilitate more efficient location determination of smart dustbins through the use of IoT enabling technologies. The primary objective of the proposed models is to monitor the status of the smart dustbin. The smart dustbins are equipped with a GPS module, a GSM module, ultrasonic sensors, and a Liquid-Crystal Display (LCD). The primary function of the proposed model is to ascertain whether the smart dustbin is full, medium, or empty. In the event that the smart dustbin is full, the GPS location and status of the smart dustbin are automatically transmitted via SMS by GSM module. This SMS is sent to the relevant authorities of the Municipal Corporation, who are then responsible for collecting the waste from the smart dustbin. The SMS contains longitude and latitude values, which are used to identify the correct route map for the smart dustbins. Ultimately, the city can be transformed into a smart city by using IoT-enabled smart dustbins.

Keywords-Internet of Things (IoT); GPS; GSM; ultrasonic sensor; longitude; latitude; Liquid-Crystal Display (LCD)

I. INTRODUCTION

In urban areas, the issue of waste management represents a significant challenge. To maintain cleanliness and hygiene, it is imperative to implement effective rubbish monitoring. The absence of real-time monitoring in traditional waste collection systems can result in inefficiencies and environmental risks. To address this issue, the proposed model designated smart dustbins, using Arduino and IoT enabling technology in conjunction with GSM, GPS, an LCD display, and LED waste level indicators. It is a technology-based solution that is both advanced and cost-effective, providing municipalities and waste management authorities with the ability to effectively monitor and manage garbage bins. The system employs a combination of sensors, microcontrollers, and IoT connectivity to track the fill level of garbage bins and provide real-time information to waste collection teams. The principal advantage is the consolidation of numerous communication technologies and devices into a unified, highly functional system, facilitating the secure and intelligent dissemination and usage of vast quantities of data. The proposed model comprises five functions:

- The detection of waste levels in the garbage dustbin with the assistance of an ultrasonic sensor module (HC-SRO4).

- The determination of the GPS location of the smart dustbin, along with the module NEO-6M-0-001, is used to obtain the latitude and longitude values from nearby satellites.
- The GPS location and status of the smart dustbin are sent via SMS to the relevant municipal authorities using the GSM module SIM900A, which is used to transmit SMS messages via AT commands.
- The status of the smart dustbin is displayed on the LCD, which indicates the status of the dustbin as empty, medium, or full. It is necessary to determine which information will be displayed on the LCD and subsequently sent to the SMS form.
- The status of the smart dustbin indicated by the LED. Three LEDs are attached to the smart dustbin: red, yellow, and green. The red LED indicates that the dustbin is full, the yellow LED indicates that the dustbin is medium, and the green LED indicates that the dustbin is empty.

II. RELATED WORK

Authors in [1] proposed a solid waste bin monitoring system comprising a camera that monitors the contents of a public trash receptacle. The camera captured an image of the receptacle designated for waste disposal. Radio frequency identification (RFID), GIS, and GPS transmit images to the workstation. The vehicle is equipped with a camera and an RFID reader. Upon approaching the receptacle, the RFID establishes communication with the RFID label, transmitting all pertinent data. The hut is subject to the authority of the system. The control hut is equipped with SMS technology for operational purposes. The GPS and General Packet Radio Service (GPRS) mapping server is employed for the analysis of data from disparate locations. The control station collated the data and subsequently stored it in the system database. The container and rubbish truck were subjected to observation. Authors in [2] proposed an Arduino-based automated trash monitoring system. The objective of such systems is not only to prevent improper rubbish management but also to enhance societal cleanliness. The proposed system employs an ultrasonic sensor to ascertain the composition of the waste, while a GSM is used to relay this data to the relevant waste management agency. At this juncture, there has been a notable shift in policy, with an increased emphasis on promoting recycling and reuse initiatives. This is largely driven by the recognition that there is a growing concern among the general public about the rate of resource consumption and waste generation. Authors in [3] put forth the concept of an intelligent trash tracking device for waste handling, emphasizing the critical role solid waste management plays in municipal operations. In the corporate setting, an integrated system was developed that incorporated a webcam, a GIS, RFID, GPS, and GPRS. The integrated RFID reader on the truck would automatically extract various client and bin details from the RFID tags placed on each garbage bucket. The location of the collection vehicle is determined by GPS technology. The central server would be updated with the entirety of the database. The GPS communication system is employed for the purpose of data updating. Truck monitoring is conducted via a GIS map server. The system's database has expanded to include a comprehensive set of information, including the bin ID, the vehicle ID, the scheduled collection time, and the GPS coordinates of both the bin and the vehicle. The data packets are combined into a single entity comprising both the volume of waste and the status of the bin. The system serves to show that the Graphical User Interface (GUI) has the capacity for real-time image processing and the ability to display other information. Authors in [4] put forth a proposal that includes the integration of GSM and Zigbee technologies, which is one of the more effective combinations employed in that methodology. A variety of strategies are employed and under development for effective waste management. The sensors are situated within the typical receptacles used for general waste disposal, thereby providing an understanding of the system's functionality. When the sensor detects movement of the waste, the ARM7 controller is employed, and the microcontroller receives the indication. The ARM7 controller will notify the garbage collection truck driver of which rubbish bin is full. The ARM7 will facilitate communication via SMS using GSM technology. Authors in [5] proposed that the technology of smart trash using IR sensors, was designed with two primary objectives: the elimination of disorder and the reduction of unsightliness. The smart garbage system employs two types of sensors: IR and gas sensors. An IR sensor is employed to detect the internal level of the garbage, while a gas sensor is used to detect any harmful gases. Upon reaching its maximum capacity, the RFID within the trash will transmit a notification to the corporate office indicating an overflow. The current system for monitoring the nation's garbage is entirely manual. The trial-and-error process is one of data collection. Periodically, the garbage truck visits the trash cans in order to empty them. Authors in [6] proposed an IoT-based real-time environmental monitoring system using Arduino and cloud services. This system was designed to collect and transfer temperature and humidity data. The authors used a DHT11 sensor and ESP8266 Wi-Fi modules to achieve this objective. Additionally, they put forth a cost-effective design for home automation. Authors in [7] proposed a methodology for reducing the necessity for waste disposal and recycling processes while maintaining environmental integrity. Authors in [8] targeted health awareness and different strategies for environmental management by using a modified Bidirectional Long Short-Term Memory (BLSTM) model. The existing models are constrained by several factors, including scalability, data collection methods, integration challenges, energy consumption, limited predictive analytics, and user engagement [9-16]. This paper proposes a solution to these limitations in the form of the smart dustbin model.

III. THE PROPOSED MODEL

The effective management of waste is a significant challenge in the context of smart cities. The implementation of efficient garbage monitoring systems is a crucial aspect of maintaining the requisite standards of cleanliness and hygiene. The lack of real-time monitoring capabilities inherent to traditional waste collection systems often results in inefficiencies and environmental hazards. To address this issue, we propose the implementation of a smart dustbin using Arduino and IoT technology in conjunction with GSM, GPS, an LCD display, and LED waste level indicators. This solution is cost-effective, assisting municipalities and waste management authorities in the effective monitoring and management of garbage bins. The system employs a combination of sensors, microcontrollers, and IoT connectivity to track the fill level of garbage bins and provide real-time information to waste collection teams.

A. Working Principle

The proposed system is comprised of a mechanical setup that employs automation to segregate and process waste materials in a manner that deviates from the conventional approach. The system is capable of differentiating between dry and moist waste, subsequently separating these two categories of refuse. When a system of this nature is installed in multiple locations, all data is collated and managed by a single node using IoT technology. The system will transmit notifications via GSM. The smart dustbin represents an innovative IoT-enabled solution for waste management. In the event that the smart dustbin reaches its maximum capacity, a text message will be sent to the relevant individuals, accompanied by a Google map indicating the location of the bin.

B. Objectives

The implementation of a proposed working model of the IoT and Arduino presents a multifaceted set of considerations:

- The proposed model aims to reduce the amount of waste collected, which will in turn reduce the costs associated with waste collection. The system endeavors to optimize garbage collection routes and schedules, thereby reducing the necessity for superfluous collections and related expenditures, through the precise monitoring of waste levels in real time.
- The objective is to optimize the environmental impact. The system assists in the reduction of carbon emissions and environmental pollution from transportation and landfill operations by facilitating the effective collection and disposal of waste.
- The proposed working model will extend public health and hygiene. The method contributes to the maintenance of cleanliness in public areas, thereby reducing the risk of disease transmission and enhancing general public health. This is achieved by ensuring the prompt collection of garbage and preventing overflowing bins.
- Resource efficiency is a core objective of the system. The system reduces expenditure on fuel and labour costs by controlling waste collection in an intelligent manner based on the actual levels of waste present. This results in enhanced operational efficiency and a reduction in expenditure for waste management agencies.
- The promotion of recycling and sustainability is another key benefit of this technology. The technology enables the implementation of targeted recycling programs and the promotion of sustainable waste management practices among communities and organizations, facilitating the acquisition of insights into the patterns of garbage generation.
- The objective of this initiative is to enhance urban planning. The system gathers data that may be used by legislators and urban planners to gain insight into waste creation patterns, thereby enabling the formulation of well-informed decisions concerning environmental regulations, waste disposal facilities, and infrastructure development.
- The objective is to enhance the user experience. The technology enables users to actively engage in waste management initiatives and contribute to a cleaner environment by providing convenient remote monitoring and control capabilities via an intuitive interface.
- Facilitating data-driven decision making: The system generates valuable data on the generation and collection of waste, which can be analyzed to identify patterns, optimize workflow, and inform data-driven decisions for continuous improvement of the waste management strategy.

C. Smart Dustbin Block Diagram

The block diagram in Figure 1 presents the components used for the effective monitoring of smart dustbins: ATMega 328 Board, SIM900A is a global system for mobile communication, NEO-6M-0-001 component is a GPS, HC-SR04 is a distance measuring sensor and an LCD display 16×2 module is also included. The LED indicator is available in three colors: red, green, and yellow.

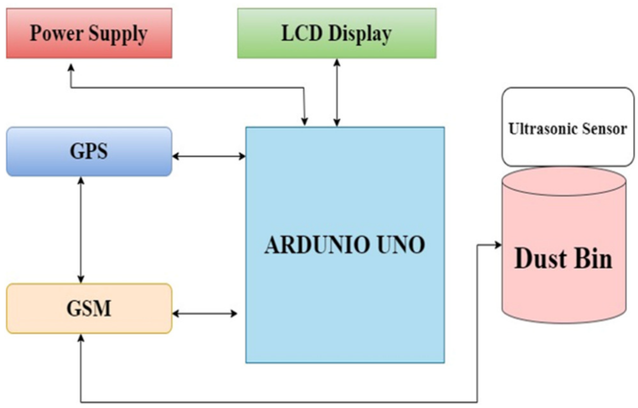

Fig. 1. Smart dustbin block diagram.

D. Modules-Connectivity Diagram

Figure 2 shows the configuration of the Arduino board, which is connected to a GPS receiver, a GSM modem, an ultrasonic sensor, an LCD display, and a dust bin. The aforementioned components are connected to the Arduino board via both analog and digital ports. The board's power supply, designated as Vcc, operates at a voltage of 5 volts. The power supply was connected to the GPS, ultrasonic sensor, LCD, and LEDs. However, the GSM module uses a distinct DC adapter, comprising a 12-volt power source, to operate the device. It is possible to draw power from both the USB port and the external power adapter for all devices that are connected to the operational model. The following connection mechanism was employed in the working model:

- The connection of the GPS is: GPS-NEO-6M-0-001 device features four ports, Vcc, Rx, Tx, and GND. The digital ports 11 and 12 should be connected to the Rx and Tx of the GPS device, respectively, using jumper pins. Similarly, the Vcc and GND ports on the Arduino board must be connected to the corresponding ports on the GPS device.
- A GSM connection was established. The GSM-SIM900A device has four ports: Vcc, Rx, Tx, and GND. In the aforementioned configuration, the jumper pins should be inserted into digital ports 5 and 4, which correspond to the Rx and Tx ports of the GSM device, respectively. Similarly, the ground connection should be made to the Arduino board's ground port. However, the power supply is provided by a DC adapter. In this instance, 12 volts of power are supplied from the adapter.
- Ultrasonic Sensor connection: the device's ultrasonic sensor (HC-SR04) has four ports, GND, Echo, Trig, and Vcc. In the aforementioned configuration, the digital ports 10 and 9 should be connected with jumper wires to the Echo and Trig ports, respectively. The remaining ports should be linked to the Vcc and GND ports, either on the analog or digital side, as appropriate. The device is positioned at the upper portion of the dust bin.
- The LCD connection requires the use of a LCD with four ports, GND, VCC, SDA, and SCL. The SDA and SCL ports are located on the board, allowing the insertion of jumper pins from the LCD to the board. Similarly, the remaining ports, GND and Vcc, can be connected to either the analog or digital ports of GND and Vcc, respectively.
- The connection of the LED is provided, with colors corresponding to red, green, and yellow. The aforementioned LEDs are to be connected to the analog side 5, 6, and 7 ports of the Arduino. The three LEDs are affixed to the receptacle.

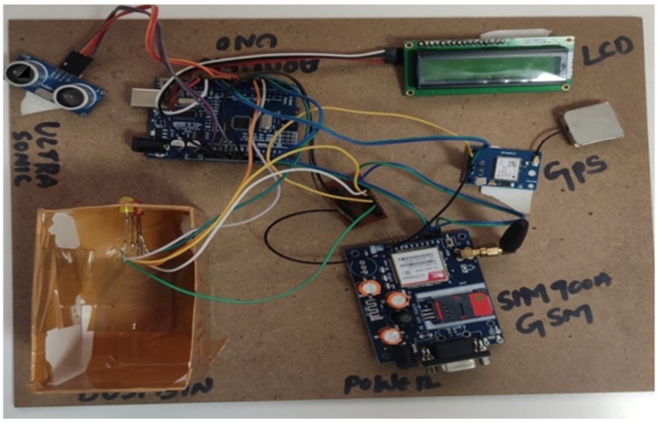

Fig. 2. Wiring diagram of working model.

IV. IMPLEMENTATION

There are two steps to perform the programming in Arduino: Arduino IDE, programming interface, and Serial Monitor, output interface.

A. Arduino IDE

All the code is written and executed in Arduino IDE sketch. The following main functions, as shown in Figure 3, are implanted in Arduino IDE programming. There are three important functions implemented in sketch: measuring the level of the smart dustbin, send SMS and GPS location using AT commands, display the information using LCD display.

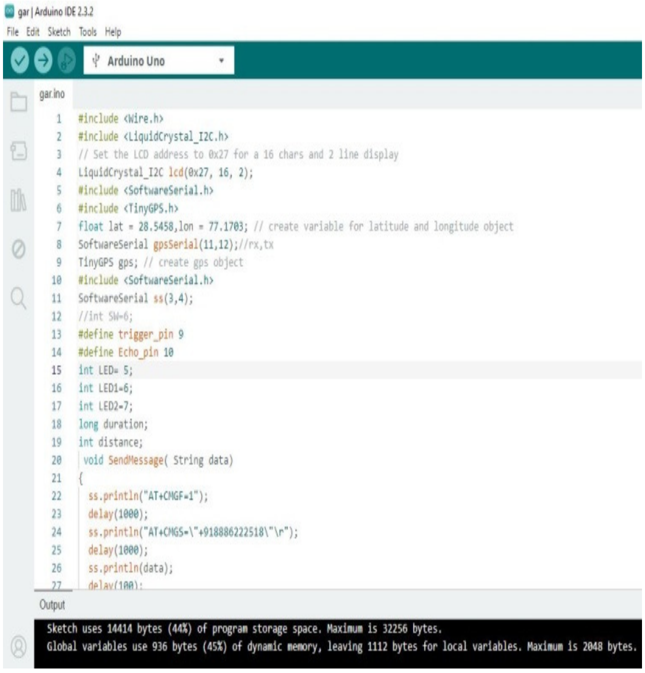

Fig. 3. Smart dustbin Arduino IDE programming interface.

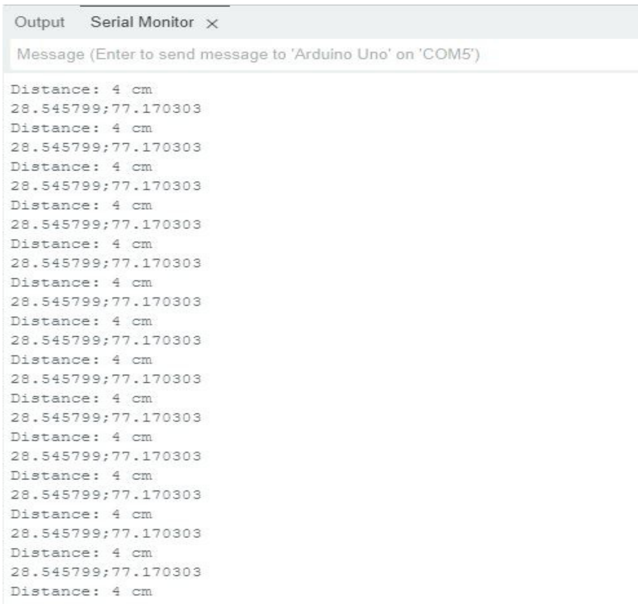

Fig. 4. Smart dustbin serial monitor.

B. Serial Monitor

The Arduino IDE has a feature called Serial Monitor that is used to send and receive serial data, interact with Arduino boards, debug code, and monitor sensor readings. The following uses Serial Monitor: Print variables, errors and messages to identify problems, display sensor readings, send and receive data between Arduino and other devices, verify code functionality and performance, and acquire data from sensors or other sources. Figure 4 shows the complete functionality of the smart trash cans.

V. RESULTS AND DISCUSSION

A. Measure the Smart Dustbin Content using Ultrasonic Sensor

The HC-SR04 Ultrasonic Distance Sensor employs sonar technology to ascertain the distance of an object from the sensor. The sensor's capacity to discern proximity allows it to be an optimal choice for any robotics project that necessitates such capabilities. The HC-SR04 comprises four pins: Vcc, Trig, Echo, and GND. The sensor provides precise measurement of the length from top to bottom. The dustbin is equipped with three LED indicators. The three levels of the trash can are measured using an ultrasonic sensor. A red LED indicates that the trash can is full, a yellow LED indicates that it is medium, and a green LED indicates that it is empty. The sensor gathers and transmits these data, as shown in figure 5.

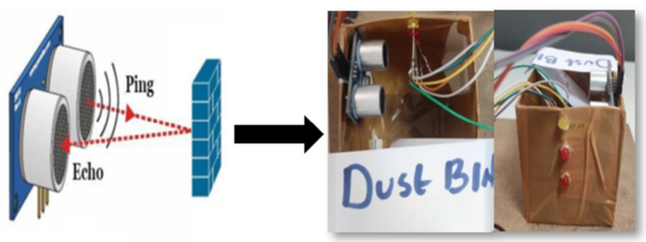

Fig. 5. Measure smart dustbin using ultrasonic sensor HC-SR04.

B. GPS Location of Smart Dustbin

The GPS is capable of measuring latitude and longitude, as well as providing precise Coordinated Universal Time (UTC) at any point on Earth. In each second, the device in question receives coordinates, along with the date and time, from the satellite. A GPS device is affixed to the dustbin, which records the dustbin's location's latitude and longitude at a rate of one measurement per second. The device acquires its coordinates from the closest satellite tower at each instance. However, it was functioning in conjunction with the GSM module to facilitate the transmission of the dustbin's precise location. A GPS module comprises four pins: Vcc for the power supply, Rx for receiving latitude and longitude values, and TX for transferring the data collected for both latitude and longitude. Figure 6 presents the GPS location of the dustbin, indicating whether it is empty, full, or medium-full. Here, GPS provides the common latitude and longitude values for the three levels of the dustbin.

C. Send SMS and GPS Location

Mobile devices are used to facilitate communication between one another via a GSM module operating within a digital cellular system. It is a widely adopted global mobile standard for long-distance communication. The user acquires the location values from GPS and sends and receives SMS and phone calls using the SIM900A module. USART communication is used by the GSM/GPRS module to connect to a microcontroller or PC terminal. The module can be configured in multiple modes and used for a variety of tasks, such as making calls and uploading data to websites, using AT commands. Figure 7 shows the transmission of GPS coordinates and the status of the dustbin via SMS. The usage of AT commands enables the transmission of both GPS and GSM location and status data for the dustbin to the Arduino Uno IDE programming environment.

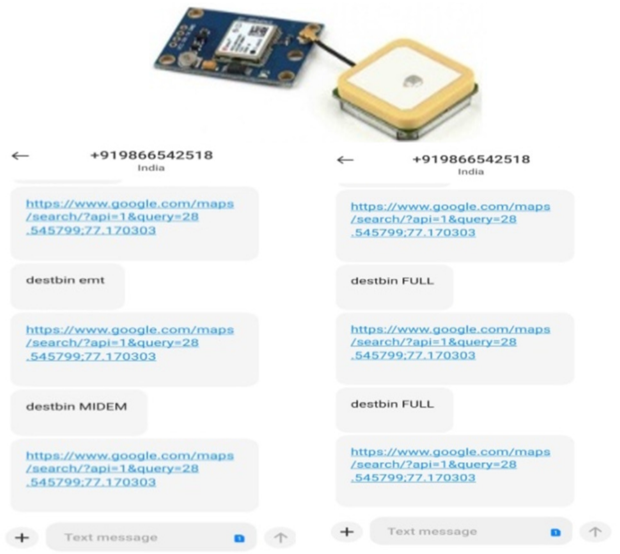

Fig. 6. GPS location of smart dustbin.

Fig. 7. Send SMS and google map for smart dustbin location using SIM900A.

VI. CONCLUSIONS

The proposed model demonstrates the potential for using the Internet of Things (IoT) to develop a smart dustbin. Should the volume of waste exceed the capacity of the receptacle, the proposed model ensures that the contents will be collected without delay. Consequently, the system will generate accurate reports, thereby enhancing its overall efficiency. The implementation of wireless communication and sensors for the real-time monitoring of garbage levels will result in a reduction in the number of trips made by the GCV, thereby lowering the overall cost of garbage collection. Consequently, the trash cans will be emptied as soon as they reach capacity, resulting in a cleaner city with enhanced infrastructure and cleanliness. The implementation of smart dustbins and IoT technology has facilitated the real-time monitoring of waste levels, thereby enabling a more efficient and effective waste management system. The capacity of smart dustbins to provide immediate data on waste levels, thereby enabling the optimization of collection routes and the reduction of superfluous trips, represents one of the system's primary advantages. This has the dual benefit of reducing the environmental impact of waste collection while also yielding substantial savings in fuel and labor costs. Furthermore, the capacity of smart dustbins to monitor recycling bin usage and assist in identifying contamination issues, facilitates the promotion of increased recycling rates. In conclusion, the installation of smart dustbins represents a critical step towards the creation of smarter, cleaner, and more sustainable cities. This is not merely a technical advancement. Adoption of this innovative concept by urban planners and legislators has the potential to significantly enhance the efficacy of waste management plans, paving the way for a more sustainable future.

The implementation of smart dustbins offers a more comprehensive and data-driven approach than that of conventional garbage management systems or other smart waste solutions. Smart dustbins provide ongoing insights that may be adjusted in real time, whereas other current solutions may rely on manual monitoring or recurring collection schedules. Their responsiveness distinguishes them from other products in the industry, including simple sensor-equipped trash cans that lack the comprehensive data analysis capabilities of smart trash cans. The innovative nature of smart dustbins lies in their capacity to transform the conventional reactive approach to trash management into a proactive one. This aligns with the broader objectives of optimizing resources and promoting sustainability. It is evident that smart dustbins will play a pivotal role in shaping the future of urban waste management, particularly as cities increasingly prioritize environmental stewardship. The principal objective was achieved through the implementation of working models, which facilitate the calculation of the optimal level of waste and provide notifications to municipal authorities and the general public. Additionally, these models serve to alert drivers to the necessity of waste collection. The Passive Infrared (PIR) sensor, which employs the use of infrared radiation to detect the presence of an object in the vicinity of the trash canister when it reaches its maximum capacity, is responsible for the process of motion detection. To enhance the system's efficacy and functionality, further investigation and enhancement of the software and interface are necessary to align them with the requirements of diverse municipal entities within urban settings. While the automated smart dustbin model is progressing as anticipated, only a few areas have been identified as requiring immediate attention.

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