

Development of a Smart Waste Management System with Automatic Bin Lid Control for Smart City Environment

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Abstract

As cities worldwide transform into smart interconnected urban environments, the management of municipal waste emerges as a pressing challenge. This paper, offers a sophisticated solution that integrates seamlessly within the concept of smart cities. This system harnesses the power of the Internet of Things (IoT) to optimize waste collection and enhance urban cleanliness. The primary aim of this research is to create a smart waste management system that extends beyond traditional waste bins. It introduces a network of intelligent waste containers equipped with automatic lid control mechanisms that operate based on real-time waste level data. When approaching these bins, the lid control mechanism automatically opens the bin only if the waste level is not full thereby, facilitating convenient waste disposal. In the context of smart cities, this innovative approach presents several advantages. It optimizes waste collection efficiency by prioritizing bins in need of immediate attention and ensures that waste containers are not prematurely emptied, reducing unnecessary waste disposal trips. Moreover, the system enables city authorities to gain insights into waste level trends, fostering data-driven and proactive waste management strategies for a cleaner, more sustainable urban environment.

Keywords: Smart City, Smart bin, Internet of Things, Waste Management System, Machine Learning

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1. Introduction

Smart cities are at the forefront of urban development, harnessing technology to create efficient, sustainable, and connected urban environments [1][2]. One of the key challenges faced by smart cities is the effective management of municipal waste. [3] The conventional waste collection systems are often characterized by inefficiencies, resource wastage, and the lack of real-time data, hindering the transition to truly smart and eco-friendly urban areas.

This research work responds to the challenge by offering a groundbreaking solution that aligns perfectly with the

smart city paradigm. It introduces an advanced waste management system that utilizes the power of the Internet of Things (IoT) to optimize waste collection, promote cleanliness, and contribute to a sustainable urban future. [4]

The core objective of this research is to develop a smart waste management system that extends beyond conventional waste bins. It envisions a network of intelligent waste containers equipped with automatic lid control mechanisms, designed to operate based on real-time waste level data. When individuals approach these bins for waste disposal, the system automatically opens the bin lid only if the waste level is not full, promoting efficient waste disposal practices.

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Within the broader context of smart cities, this innovative approach holds numerous advantages. It optimizes waste collection efficiency by prioritizing bins in need of immediate attention, thereby reducing the frequency of unnecessary waste disposal trips. This not only conserves resources but also mitigates the environmental impact of waste collection operations. Moreover, the system empowers city authorities with invaluable insights into waste level trends, allowing for data-driven and proactive waste management strategies.

Smart cities prioritize efficiency and sustainability in waste management. The objective is to optimize waste collection processes, reduce operational costs, and minimize the environmental impact of waste disposal. IoT technology enables real-time data collection and analytics for more informed decision-making [9]. Effective waste management in smart cities necessitates the ability to monitor and control waste levels in containers. Several studies have explored the implementation of waste level control systems:

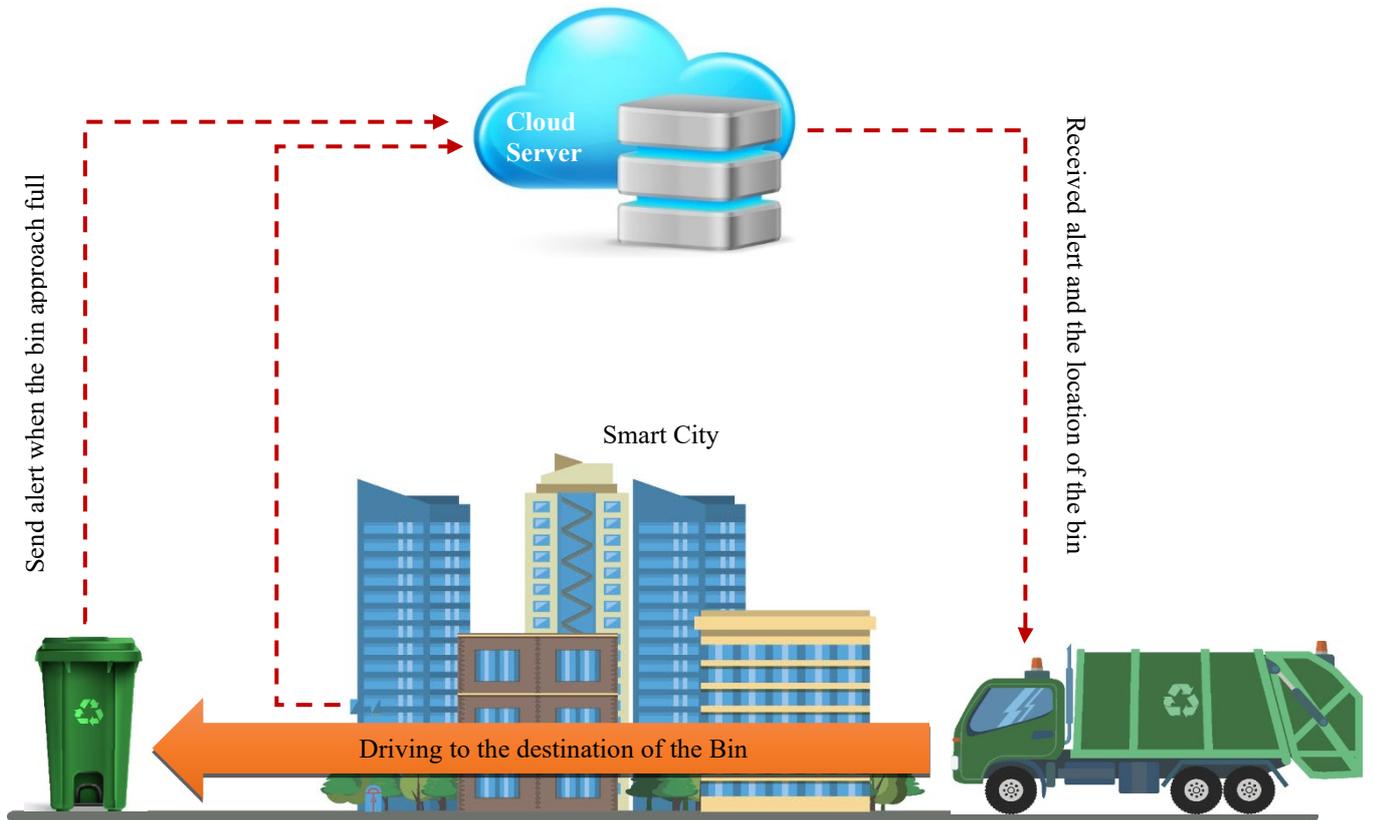


Figure 1 Waste Management Infrastructure

The significance of this research is rooted in its potential to revolutionize waste management within smart cities, contributing to a cleaner, more efficient, and environmentally responsible urban landscape [5] [6] [7].

IoT-Enabled Waste Bins: Research has shown how IoT-enabled waste bins equipped with sensors can continuously monitor the waste level. When the bins approach full capacity, these systems can trigger alerts for waste collection, ensuring bins are serviced only when necessary [10].

2. Literature Review

The concept of smart cities has gained momentum in urban planning, aiming to create more efficient, sustainable, and interconnected urban environments. Smart city initiatives leverage advanced technologies, such as the Internet of Things (IoT), to improve various aspects of urban living, including waste management. The integration of IoT technology plays a pivotal role in smart city projects. IoT devices and sensors are used to collect and transmit data, allowing for real-time monitoring and control of various urban systems. These systems include waste management, traffic management, energy consumption, and more [8].

Optimizing Collection Routes: Waste level data collected through IoT technology can be used to optimize waste collection routes. By prioritizing bins that are nearing capacity, collection vehicles can reduce unnecessary stops and fuel consumption, contributing to cost savings and reduced emissions [11]. Incorporating automatic lid control when approaching waste bins represents a cutting-edge feature in waste management systems:

The research aims to optimize waste collection processes, enhance user experience, and promote environmentally responsible waste management practices.

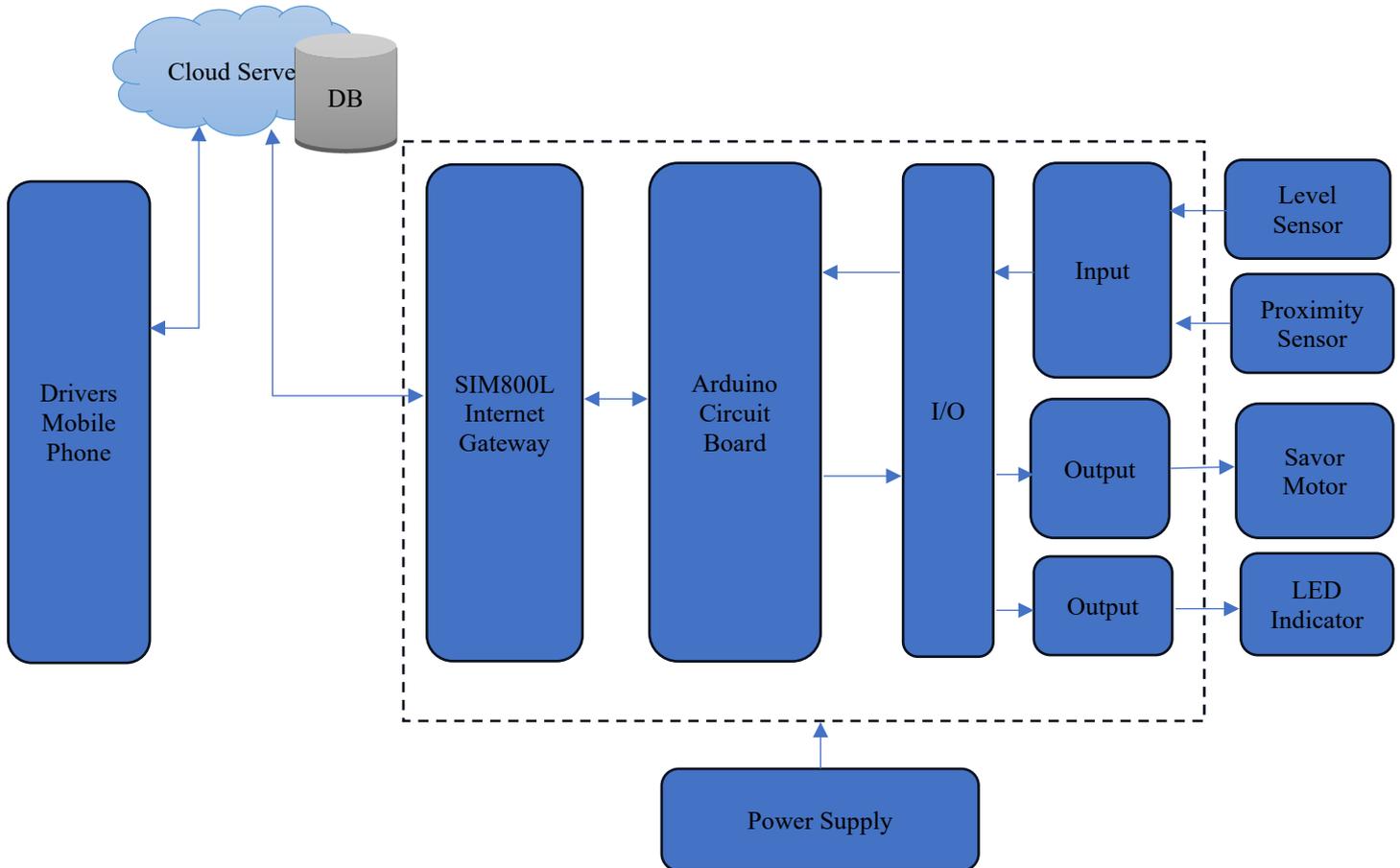


Figure 2. Block Diagram of the Proposed System

User-Friendly Approach: Automatic lid control simplifies waste disposal for users. When an individual approaches a bin, the lid automatically opens only if the waste level is not full, creating a user-friendly and hygienic experience [12].

Efficiency and Aesthetics: The automatic lid control mechanism reduces the risk of overfilled bins and litter, enhancing the aesthetics of the urban environment. This feature ensures that waste bins are used efficiently and cleanly [13]. The proposed research, integrates these concepts by combining waste level control, notification when the bins approach full capacity and automatic lid control when approaching the bin, aligning with the principles of smart city initiatives.

3. Design and Implementation

The development of the Smart Waste Management System with Automatic Bin Lid Control is a multi-faceted endeavour that necessitates a systematic and well-structured design methodology. This section outlines the step-by-step approach to designing and implementing the prototype:

1. Requirements Gathering and Analysis
2. System Architecture Design
3. Sensor Integration and Lid Control Mechanism
4. Data Processing and Analysis
5. User Interface and Mobile Application
6. Testing and Validation

3.1 Algorithm

Developing an algorithm for a Smart Waste Management System with Automatic Bin Lid Control is a complex task that involves multiple components, including smart city integration, waste level control, and lid control. Table 1. presents a simplified main section of the algorithm.

Table 1. Proposed Algorithm

Proposed Algorithm for Smart Waste Management
<pre> # Initialize system parameters max_waste_level = 80 threshold_distance = 2 while True: waste_level = read_waste_level() user_proximity = read_user_proximity() if waste_level > max_waste_level: send_alert_to_smart_city() if waste_level <= max_waste_level: if user_proximity <= threshold_distance: open_lid() else: close_lid() if user_proximity <= threshold_distance: if waste_level < max_waste_level: open_lid() else: close_lid() # End of the main loop </pre>

This algorithm outlines the key steps for managing waste bins in a smart city environment with automatic lid control:

- Initialization:** Set system parameters such as the maximum waste level that triggers bin collection and the proximity threshold for lid control.
- Main Loop:** Continuously monitor waste levels and user proximity.
- Smart City Integration:** If the waste level exceeds the threshold, it sends an alert to the smart city waste collection team to initiate and schedule the collection process.
- Waste Level Control:** If the waste level is below the maximum threshold, check user proximity. If a user is

nearby, it automatically opens the bin's lid to allow waste disposal.

- Lid Control When Approaching Bin:** When a user approaches the bin, check the waste level. If the waste level is not full and the user is within the proximity threshold, open the bin's lid for convenient waste disposal.

3.2 Design Analysis

Implementing a Smart Waste Management System with Automatic Bin Lid Control involves integrating key technologies to ensure efficient waste collection, lid control, and smart city interaction. Table 2. Lists the outline of the key technologies for the implementation, including smart city integration, waste level control, and lid control when approaching the bin if the level is not full:

Table 2. Hardware Components

Hardware Components	
Devices	Module
On-Board Computer Subsystem	Arduino Nano
Bin Lid Control Mechanisms	Savor Motor
Proximity and Level Detection	Ultrasonic Sensor
IoT Communication Gateway	SIM800L Module

A. On-board Computer Subsystem

This subsystem is based on the Arduino single board on the Atmega328P microcontroller as the core dedicated system in charge of processing the data obtained by the sensors to transmit the information the information using communication module. [14]



Figure 3 Arduino Uno

B. Proximity and Level Detection Sensor

The HC-SR04 Ultrasonic Sensor was used to measure the level of waste in the bin and to detect user when approaching the bin. HC-SR04 is a popular module for

measuring non-contact distances ranging from 2cm to 400cm. It employs sonar (similar to bats and dolphins) to determine distance with excellent precision and consistency. It is made up of three parts: an ultrasonic transmitter, a receiver, and a control circuit. [15]



Figure 4 Ultrasonic Sensor

The transmitter sends out short bursts of energy that are reflected by the target and picked up by the receiver. The time difference between ultrasonic signal transmission and reception is calculated. The distance between the source and target can be easily determined using the speed of sound and the equation.

$$Speed = Distance/Time$$

The microcontroller transmits an ultrasonic 10uS pulse to trigger, followed by eight 40 kHz pulses. The time it takes for an ultrasonic burst to leave and return to the transmitter microcontroller.

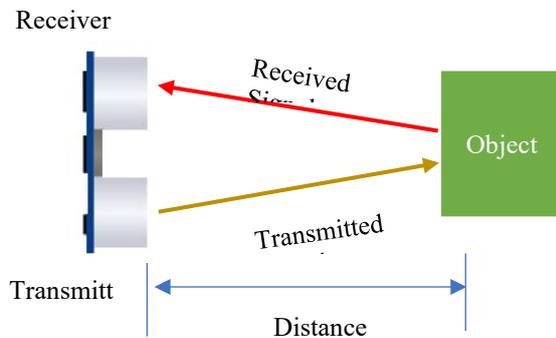


Figure 5 Ultrasonic Sensor Detection state

Calculate Distance

The time required by pulse is actually for the to-and-from journey of ultrasonic waves, which we only require half of. As a result, time is divided by two.

$$Distance = Speed * Time/2$$

Speed of sound at sea level

$$Speed = 343 \text{ m/s}$$

Or

$$Speed = 34300 \text{ cm/s}$$

$$Distance = 17150 * Time \text{ (unit cm)}$$

Distance in cm, $Distance = Time/58$
 Distance in inches, $Distance = Time/148$

Clearly there is an approximation going on here i.e., $148/58 = 2.5517\text{cm/inch}$ and we know that there are exactly 2.54cm to the inch.

If the speed is 340 m/sec that's 34,000 cm per second or 0.034 cm per microsecond but, it's the return journey that is measured in microseconds so the result was divided by 2 and therefore 0.017cm is the distance that the object is away when the echo is received in 1 microsecond and the reciprocal of 0.017 is 58.823. (Close to 58)

$$Distance = Time * 17000$$

Therefore, this was half the speed of sound. For accurate distance reading, the output was calibrated using a ruler to monitor a particular range.

C. Bin Lid Control Mechanism

A Servo Motor was employed for the lid control mechanism that opens and closes the lid based on sensor inputs. It is an electromechanical device that is designed to provide precise control of angular or linear position, acceleration, and velocity in various applications.



Figure 6 Servo Motor

Servo motors are actuators that enable for accurate position (angle) control. The angle of the motor is typically between

0 and 180 degrees. In this research the servo was configured to operate between 0 and 90 degrees.

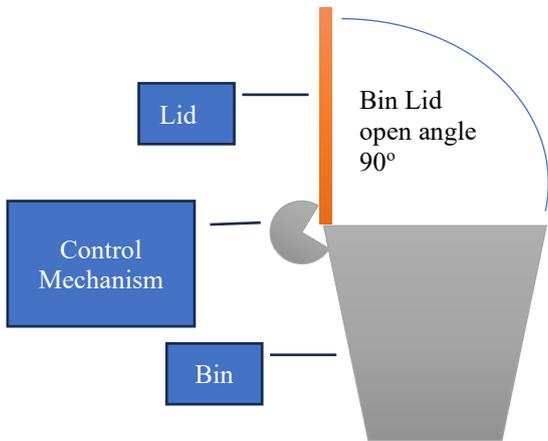


Figure 7 Open lid angle

Servo motors are widely used in robotics, industrial automation, and other systems where accurate and controlled motion is required.

D. IoT Communication Gateway

The bin’s communication to the server uses SIM800L GSM/GPRS module for communication Gateway to offer a compact and versatile solution for alert notification. The module offers a wide range of functionalities including HTTP protocol. It operates at a low voltage range of 3.4V to 4.4V, which makes it well-suited for lithium battery-powered applications. See Figure 9.

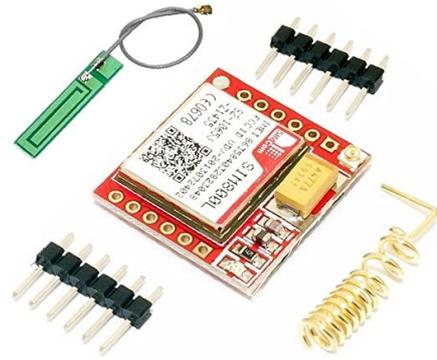


Figure 8 SIM800L module by SIMCOM

The SIM800 module serves as the IoT communication gateway, facilitating communication between the smart bin and the cloud server using the HTTP protocol. This module plays a crucial role in establishing internet connectivity for the smart bin, enabling it to transmit the bin's state to the cloud server through HTTP requests (using the GET method). The server validates the data to ensure its integrity. This validation process was essential to maintain data accuracy and reliability.

The cloud server stored the bin's data in a dedicated database for historical records, allowing for in-depth analysis of bin usage over time. It also plays a vital role in alert notifications, particularly when the bin's status indicated that it was full. These notifications were triggered based on the data stored in the database, ensuring timely and efficient waste management. Figure 9 shows the schematic diagram of the hardware circuitry for the system, using the components listed in Table 2

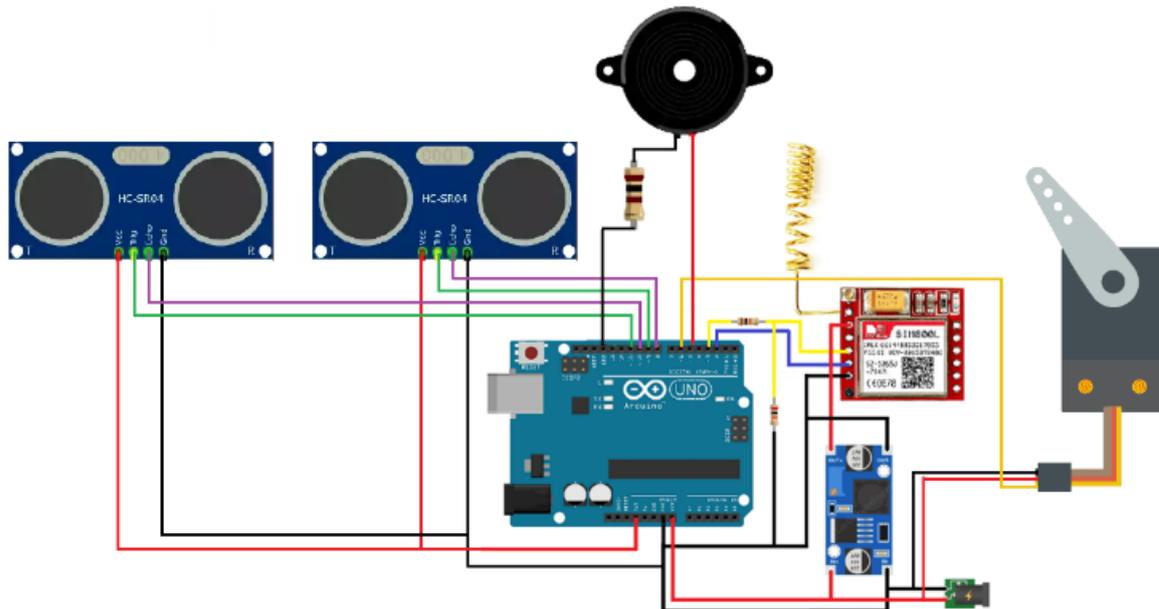


Figure 9 Schematic diagram with all the components

5. Testing and Result

The waste level sensor was calibrated meticulously to precisely measure waste levels in the bin, and a 20cm threshold was established to indicate when a bin reached its full state. This calibration ensured accurate and reliable waste level measurements.

Additionally, the proximity sensor, designed to detect objects approaching the bin, was calibrated with a detection distance of 12cm. It was programmed to trigger the bin's lid to open when a user or object approached it. Importantly, the system was designed with a condition to open the lid only if the bin was not full, ensuring efficient waste collection. The servo motor responsible for controlling the bin lid underwent comprehensive testing to validate its ability to effectively and consistently open and close the lid as required. To enhance the system's efficiency and conserve energy, power-saving mechanisms were thoughtfully implemented. These mechanisms were particularly crucial when the system operated in a battery-powered state, helping to extend battery life and reduce maintenance requirements.

Finally, real-world testing was conducted using actual waste materials to thoroughly validate the accuracy and efficiency of the lid control system. This testing phase simulated practical waste disposal scenarios, confirming that the system's responses met the operational requirements effectively and reliably.



Figure 10 A Prototype of the system

Benefits of this System:

- Reduced operational costs through optimized waste collection.
- Improved waste management efficiency by reducing unnecessary bin emptying.
- Minimized overflow and littering around bins.
- Remote monitoring and control for real-time decision-making.
- Enhanced environmental sustainability by reducing unnecessary waste collection trips.
- Overall reduction in environmental pollution and enhanced city cleanliness and population health status.

This experiment provides a foundation for the development of a Smart Waste Management System with Automatic Bin Lid Control, offering a more efficient and sustainable approach to waste collection and management.

Conclusion

In developing and evaluating the prototype for a Smart Waste Management System with Automatic Bin Lid Control, several key findings and insights have emerged. The following conclusions highlight the system's performance, efficiency, and the benefits it offers for optimized waste management in urban centers. The prototype demonstrates the ability to control bin lids effectively based on waste levels. Lid opening and closing events are closely aligned with the actual filling of bins, reducing the need for manual inspections. The system's data-driven approach optimizes the waste collection schedules, significantly reducing the frequency of collection trips. This not only saves operational costs but also contributes to environmental sustainability by minimizing vehicle pollutant emissions. The prototype proved successful in reducing waste overflow and littering around bins in their designated locations. Instances of waste overflow were observed to have decreased, leading to cleaner and more aesthetically pleasing surroundings. Remote monitoring and real-time decision-making capabilities enabled quick issue identification and resolution. This feature enhances the overall efficiency and responsiveness of waste management operations. In conclusion, the prototype for a Smart Waste Management System with Automatic Bin Lid Control has demonstrated its potential as an efficient and sustainable solution for waste management. It offers cost savings, environmental benefits, and user satisfaction, making it a valuable asset in optimizing waste collection operations. Further development and scalability will continue to enhance its impact on waste management and environmental sustainability.

Looking towards the future, further development of the Smart Waste Management System with Automatic Bin Lid Control holds promising avenues for advancement.

Integration with advanced sensor technologies, such as IoT devices and AI-powered analytics, can enhance the system's capabilities for more precise waste monitoring and predictive maintenance. Additionally, incorporating unsupervised machine learning algorithms can enable the system to adapt and optimize its operations dynamically based on evolving waste patterns and environmental factors. Scalability efforts can focus on expanding the system's deployment to broader urban areas, fostering collaboration with municipal authorities and waste management agencies. Continued research and innovation will drive the evolution of this technology, ensuring its continued relevance and effectiveness in addressing the challenges of modern waste management and sustainability.

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