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SmartWaste: Sustainable Waste Management with Robotic Automation

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ABSTRACT

With the growing demand for efficient waste management, automation has become essential in maintaining cleanliness across both public and private spaces. The Smart Dustbin and Auto Cleaning System is developed to streamline waste collection and disposal by leveraging smart technologies. This system comprises a smart dustbin integrated with sensors that monitor waste levels and an autonomous cleaning robot that activates once the bin is full. The smart dustbin employs IoT-enabled sensors to track the waste level in real time and relay data to a centralized system. When the waste reaches a specified threshold, the auto-cleaning robot is triggered. Equipped with advanced navigation and obstacle detection capabilities, the robot navigates toward the dustbin, collects the waste, and transports it to a designated disposal site. An additional feature of the system is a waste detection mechanism that identifies whether the deposited material is wet or dry via a sensing plate positioned above the bin. Based on this classification, the system segregates the waste accordingly to ensure proper disposal. The system incorporates various hardware components including servo motors, IR and ultrasonic sensors, wet and dry waste sensors, ESP32 modules, GPS for robot navigation, Arduino, RBS (robotic base systems), switches, and LCD screens. These components operate in coordination to facilitate real-time monitoring, waste sorting, and automated cleaning. By integrating IoT, intelligent navigation, waste segregation, and a comprehensive set of electronic and robotic components, the Smart Dustbin and Auto Cleaning System significantly enhances urban waste management, minimizes manual labor, and contributes to a cleaner, more sustainable environment.

Keywords: Servomotor, Smart Dustbin, Waste Segregation System, LCD, Ultrasonic.

1. INTRODUCTION

In recent years, urbanization has drastically increased, resulting in growing challenges for city planners and waste management authorities. The surge in population, coupled with an increase in consumerism, has led to the production of large amounts of waste, which puts immense pressure on existing waste management systems. Traditional waste collection methods, which often rely on manual labor and periodic collections, have proven to be inefficient and inadequate in addressing these challenges. Overflowing bins, poor waste segregation, and delayed waste disposal have become frequent issues in urban areas, contributing to environmental degradation and posing a threat to public health. The integration of advanced technologies, such as robotics, the Internet of Things (IoT), and smart sensors, into waste management systems has shown promising potential for addressing these issues. The Smart Bin Management and Response Robot system is a cutting-edge solution designed to automate the waste sorting process, monitor bin status in real-time, and optimize waste collection operations. By leveraging robotic technology and IoT connectivity, the system aims to streamline waste disposal, reduce human intervention, and improve efficiency in urban waste management.

2. LITERATURE SURVEY

Pollak, et al explored the MARBLE project use of autonomous robots for smart waste management in urban areas. We identified that the lack of data on litter bin (LB) fill levels hindered efficient services.

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To address this, we implemented machine learning-based predictions for LB filling levels, achieving 82% accuracy with the XGBoost binary classifier. By incorporating these predictions into a Simulated Rebalancing approach for route planning, combined with the Knapsack algorithm, we reduced operational time by 26% and energy consumption by 31% in our simulations for the James-Simon-Monbijoupark in Berlin. **[1]**

Abdullahi, et al This paper, "Development of a Smart Waste Management System with Automatic Bin Lid Control," presented a solution for optimizing waste collection in smart cities using the Internet of Things (IoT). The system featured intelligent waste bins with automatic lid control that opened only when the bin was not full, ensuring efficient waste disposal. By prioritizing bins based on real-time waste levels, it reduced unnecessary collection trips and improved operational efficiency. This approach provided city authorities with valuable insights for data-driven waste management, contributing to a cleaner and more sustainable urban environment. **[2]**

Zoumpoulis, et al In the past, early smart waste collection systems focused on basic features like fill-level monitoring and IoT connectivity for more efficient collection. However, they lacked advanced automation and material separation capabilities. Research highlighted varied approaches to waste sorting, with no standardized solutions. These early efforts laid the groundwork but revealed significant gaps in optimizing resource recovery and advancing sustainability in urban waste management. **[3]**

Oguejiofor, et al smart waste management systems have been developed to improve efficiency and reduce human intervention. Early prototypes incorporated sensors like ultrasonic devices to monitor waste levels, and microcontroller-based systems such as Arduino were used to automate the opening and closing of bin lids. These systems also included features like GSM communication to notify waste collectors when bins were full, reducing unnecessary collection trips. Such innovations aimed to optimize waste collection, minimize pollution, and improve environmental cleanliness by ensuring timely disposal without frequent manual checks.**[4]**

Bithi, et al smart waste management systems were developed to tackle waste disposal challenges and align with sustainability goals. Researchers used platforms like Arduino Uno and ultrasonic sensors to design prototypes that could detect objects and automate the opening of bin lids. These early systems aimed to improve hygiene and efficiency by reducing human intervention. By creating hardware prototypes and testing their functionality, previous work laid the foundation for further enhancements in smart bins, offering solutions to waste management while contributing to health and sustainability goals.**[5]**

Shan, et al explored the potential of smart bins to promote waste reduction, particularly through systems like PAYT. Researchers surveyed populations, such as in Japan, to gauge public response to smart bin features like automated waste separation and unscheduled pickups. Findings revealed that younger individuals were more receptive to these technologies, while older generations showed less interest. Additionally, those who didn't engage in waste separation were less likely to support the idea of reducing plastic waste, even with smart bin assistance. This highlights that, alongside technological advancements, strategies to encourage behavioural changes are necessary for successful waste reduction.**[6]**

Dimailig, et al Focused on creating contactless, motion-activated trash bins to reduce the risk of indirect virus transmission through contaminated surfaces. Studies incorporated ultrasonic sensors for motion detection, demonstrating the feasibility of such systems. Prototypes were developed that could detect motion up to 60 cm with a response time of less than half a second, and self-dispose waste effectively with a capacity of 1 to 3 kg. These innovations addressed the need for hygienic, efficient waste disposal,

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emphasizing the potential of sensor-driven solutions. Recommendations for future improvements included using higher-quality materials for better performance.**[7]**

Rahman, et al researchers tackled inefficiencies in waste management by integrating IoT technologies like LoRa to improve coordination among garbage collection trucks. They focused on addressing fairness issues in transportation units, which often led to varying active times. By designing a network for reliable data exchange, they framed the problem as a capacitated vehicle routing issue and proposed an objective function that balanced total distance with fairness. Simulations showed that this approach effectively minimized travel distances while ensuring fairness across the waste collection process.**[8]**

3. PROPOSED SYSTEM

The Smart Bin Management system comprises two primary sections: the Transmitting Section and the Receiving Section. Each section plays a vital role in the efficient handling, sorting, and collection of waste. The Transmitting Section is responsible for detecting and classifying the waste as it enters the bin. The Receiving Section focuses on waste sorting, collection, and transportation through an autonomous cleaning robot. This system integrates various components, including sensors, microcontrollers, robotic systems, and IoT connectivity, to provide a comprehensive and intelligent waste management solution.

Fig. 1: Block diagram of proposed system transmitting section

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Fig. 2: Block diagram of proposed system receiving section

The Smart Bin Management and Response Robot system utilizes ESP32 and Arduino to automate waste management and robotic assistance. The ESP32 processes data from multiple sensors, including ultrasonic, IR, and wet/dry sensors, to monitor bin fill levels, detect objects, and determine waste type. It communicates with an IoT module for real-time data updates and activates outputs like LCD, buzzer and servomotor to indicate bin status or operate mechanical components. A GPS module helps track bin locations. Meanwhile, the Arduino-controlled response robot receives commands, powered by a battery, and connected via a router for network communication. A switch initiates the robot's movement, enabling it to perform tasks such as waste collection or navigation to designated bins. The system ensures efficient waste disposal, remote monitoring, and automated robotic intervention, enhancing smart city waste management.

Fig. 3: Schematic diagram of transmitting section

The smart waste bin system integrates multiple sensors for efficient monitoring and classification of waste. An ultrasonic sensor measures the fill level of the bin and triggers an alert when it is full, while

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an infrared (IR) sensor detects the presence of newly deposited waste. A newly added soil moisture sensor helps classify waste based on its moisture content—high moisture indicates wet waste, and low moisture indicates dry waste. All sensor data is processed by an ESP32 microcontroller, which determines the bin's status and takes appropriate actions. If the bin is full, it activates a buzzer alert and displays the status on an LCD screen. Additionally, the ESP32 uses Wi-Fi connectivity to send real-time data to a cloud-based IoT platform. A GPS module is included to track the bin's location, and the current bin status along with its location is sent to a response robot via Bluetooth for timely waste collection and management.

4. RESULTS AND DISCUSSION

This image shows the transmitting section of your smart bin project, featuring sensor-based waste segregation with an ESP32 controller, ultrasonic and IR sensors, an LCD display, and GPS for IoT-based monitoring.

Fig. 4: smart bin setup

Fig. 5: Title Display in LCD

This image displays the control circuit of the IoT Smart Bin Management system, featuring an ESP32 microcontroller, LCD display, power regulation module, and connected sensors for waste monitoring and segregation.

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S.No	Wet_Level	Dry_Level	Status	Location	Date	
1	0	0	Dry	Location	Location	2025-03-20 12:23:56
2	0	0	Dry	Location	Location	2025-03-20 12:22:42
3	0	0	Dry	Location	Location	2025-03-20 12:21:21
4	100	0	Dry	Location	Location	2025-03-20 12:20:21
5	0	100	Dry	Location	Location	2025-03-20 12:16:40
6	0	0	Dry	Location	Location	2025-03-20 12:15:20
7	0	0	Dry	Location	Location	2025-03-20 12:11:09
8	0	0	Dry	Location	Location	2025-03-20 12:10:33
9	91	0	Dry	Location	Location	2025-03-20 12:10:02
10	94	97	Dry	Location	Location	2025-03-20 12:08:14
11	94	0	Dry	Location	Location	2025-03-20 12:08:09
12	0	100	Dry	Location	Location	2025-03-20 12:08:01
13	0	9	Dry	Location	Location	2025-03-20 11:46:14
14	0	0	Dry	Location	Location	2025-03-20 11:43:48
15	0	0	Dry	Location	Location	2025-03-20 11:42:44
16	0	0	Dry	Location	Location	2025-03-20 11:42:18
17	0	0	Dry	Location	Location	2025-03-20 11:41:48
18	0	0	Dry	Location	Location	2025-03-20 11:41:24

Fig. 6: Real time monitoring data

This image shows a real-time IoT dashboard for the Smart Bin system, displaying wet and dry waste levels, bin status, location links, and timestamped data for monitoring waste segregation.

Fig. 7: Robot i.e receiving section

This image shows the receiving section of the Smart Bin system, featuring a robotic vehicle with an Arduino-based control circuit, LCD display, motor drivers, and a Bluetooth module for remote operation and waste collection.

5. CONCLUSION

The Smart Dustbin and Auto Cleaning System represents a significant step toward modernized waste management solutions. By integrating smart technology, real-time waste level monitoring, automated waste collection, and waste segregation, this system provides a sustainable and efficient approach to maintaining cleanliness. As cities and communities continue to embrace smart solutions, this system has the potential to play a crucial role in shaping the future of waste management, promoting environmental conservation, and ensuring healthier living conditions for all.

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