

IoT Based Automated Waste Management System for Sustainable Cities

Michael Franklin N.^{1*}, Jenish J.², Abinanthu R.³, Rexlin Nayagam P.⁴, Aathira S.P.⁵, Aswathy G.⁶ & Anila T.⁷

¹Assistant Professor, ²⁻⁷UG Student, ¹⁻⁴Department of Electronics and Communication Engineering, ⁵⁻⁷Department of Computer Science and Engineering, ¹⁻⁷Stella Mary's College of Engineering, Kanyakumari, Tamilnadu, India.
Corresponding Author (Michael Franklin N.) Email: franklin4u@gmail.com*



DOI: <https://doi.org/10.46759/IIJSR.2024.8216>

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Article Received: 22 March 2024

Article Accepted: 26 May 2024

Article Published: 30 May 2024

ABSTRACT

Innovative approaches are required to effectively manage waste disposal and recycling in light of the growing global waste crisis. Conventional waste management systems frequently require real-time data and inefficiencies to be addressed, which results in inefficient use of resources and damage to the environment. In order to assess waste management, this paper suggests utilizing data analytics and Internet of Things (IoT) technology advancements along with the integration of smart bins. Installing compactors to optimize space usage, sensors to detect fill levels, and connectivity to send real-time data to a central management system are all features of smart bins. This makes it possible for waste management firms and municipalities to keep an eye on waste generation trends, improve collection routes, and more efficiently allocate resources. Furthermore, by adding features like gamification and reward programs, smart bins can encourage recycling and promote public engagement in sustainable waste management practices. Comparing smart bins to conventional waste management techniques reveals a number of benefits. Municipalities that offer actionable insights into waste generation and disposal behaviors can lower operating costs, minimize their impact on the environment, and improve overall service quality. Additionally, incorporating smart bins improves the quality of life for locals and promotes sustainability in line with larger smart city initiatives. This study looks at the technical aspects of smart bin systems, looks at case studies of effective installations, and talks about possible obstacles and factors to take into account before broad adoption. Communities can set the path for a future that is more effective, sustainable, and environmentally conscious by reevaluating waste management with smart bins.

Keywords: Smart bin; Waste management; Internet of Things (IoT); Automation; Central management system.

1. Introduction

The introduction of intelligent technology has brought about a period of unparalleled creativity in different sectors, including waste management [1]. By incorporating sensors to monitor waste levels, optimize collection routes, and encourage recycling, the introduction of smart bins in waste management has the capacity to transform the industry. These advancements offer the potential to decrease operational expenses and minimize environmental harm while improving the effectiveness of collection processes. This comprehensive introduction explores the various advantages and possibilities of smart bins, demonstrating how they can revolutionize waste management by making it more effective, environmentally friendly, and reliant on data. Smart bins are waste containers that are equipped with sophisticated sensors and communication technology. The sensors continuously monitor the levels of the bins and transmit this information to a central system in real-time [2]. Smart bins utilize the Internet of Things (IoT) to constantly provide updates on their status, enabling waste management companies to optimize their operations. A smart bin system consists of sensors, communication modules, data analytics software, and a central management platform [3].

Smart bins offer a notable benefit by efficiently optimizing waste collection routes. Traditionally, waste collection adheres to a predetermined schedule without considering the actual amount of waste in the bins. This results in inefficiencies, such as collecting bins that are only partially filled or failing to collect bins that are overflowing. Smart bins, on the other hand, facilitate flexible scheduling. Waste management companies can optimize their collection routes by using real-time data to determine the fill levels of bins, allowing them to prioritize bins that are

either full or close to being full. This optimization decreases superfluous collections, diminishes fuel consumption, and minimizes greenhouse gas emissions, thereby contributing to more sustainable waste management practices [4]. Smart bins have the potential to greatly decrease operational expenses for waste management companies. Companies can reduce fuel and labor costs by minimizing the number of collections required and optimizing routes. In addition, the capability to monitor the levels of bins in real-time aids in preventing overflows thereby decreases the necessity for emergency collections and the accompanying costs. Over time, the accumulated cost savings can be significant, rendering smart bins a financially feasible choice for both municipalities and private waste management companies.

The environmental consequences of waste management can have a significant impact, especially in terms of the amount of fuel consumed and the emissions produced by the vehicles used for waste collection [5]. Smart bins can decrease the carbon footprint of waste management operations by optimizing collection routes and reducing collection frequency. In addition, by preventing bin overflows, we can minimize littering and the risk of waste entering natural ecosystems, thereby safeguarding wildlife and mitigating pollution. Smart bins are essential for advancing environmental sustainability. Promoting recycling is an essential element of contemporary waste management strategies. Smart bins can play a crucial role in this matter by providing incentives for recycling [6]. For instance, bins that are equipped with RFID scanners have the capability to monitor and record the quantity and nature of recyclable material that is placed inside them. Users can receive points, discounts, or other incentives as a reward for their recycling efforts. This approach not only encourages the practice of recycling but also nurtures a culture of sustainability within communities. Analyzing the data gathered from smart bins allows for the identification of trends and patterns in waste generation and disposal [7]. This information is extremely valuable for waste management companies and municipalities as it allows for decision-making based on data. By comprehending the regions that produce the highest amount of waste, the predominant types of waste and the fluctuations in waste levels over time, authorities can make well-informed choices regarding the allocation of resources, planning of infrastructure, and implementation of public awareness campaigns. By adopting a data-centric approach, waste management strategies can be optimized for maximum efficiency and effectiveness [8]. Efficient waste management is intricately connected to the well-being of the general population. Inadequate waste management can result in the proliferation of pests, noxious smells, and the transmission of illnesses. Smart bins can mitigate these health risks by effectively managing waste collection and preventing overflowing. Furthermore, the decrease in littering and waste leakage contributes to cleaner and more sanitary urban environments. The integration of smart bins into waste management systems is crucial for achieving significant advancements in public health [9].

Smart bins can be easily incorporated into wider smart city projects, improving overall urban sustainability and quality of life. As urban areas become more interconnected, the information produced by intelligent waste bins can be merged with other data streams related to urban activities, such as traffic flow, weather conditions, and energy consumption [10]. This integration allows for a comprehensive understanding of how cities function. This integration enables synchronized reactions to urban challenges, encompassing waste management, energy conservation, and more. Smart bins play a role in advancing smart cities by enhancing efficiency, sustainability,

and livability [11]. Smart bin technology has been successfully implemented in various cities around the world. For instance, in Singapore, intelligent bins have been implemented in public areas to monitor the amount of waste and optimize the timing of waste collection. This initiative has resulted in decreased collection frequencies and reduced operational costs, all while upholding high cleanliness standards. Similarly, in Barcelona, intelligent waste containers are integrated into a wider smart city strategy, aiding the city's objectives of sustainability and effective resource management. These case studies demonstrate the tangible advantages and expandability of smart bin technology in various urban environments [12].

Although smart bins offer numerous advantages, their implementation is not without difficulties. The initial expenses associated with setting up waste management systems can be substantial, and stakeholders who are used to conventional waste management methods may express opposition [13]. Moreover, the dependability of sensor technology and communication networks is essential for the efficient functioning of smart bins. Factors such as sensor malfunctions, failures in data transmission, or cybersecurity threats have the potential to diminish the effectiveness of the system [14]. Hence, it is imperative to tackle these challenges by implementing thorough planning, involving all relevant parties, and continuously maintaining and enhancing the system. The future holds immense potential for smart bins to revolutionize waste management. The continuous development of sensor technology, data analytics, and integration with the Internet of Things (IoT) will significantly improve the functionality of smart bins, resulting in increased efficiency and cost-effectiveness [15].

Furthermore, as intelligent urban areas progress, the function of intelligent waste bins will increase, making a significant contribution to various urban sustainability endeavors. By adopting this technology, waste management companies and municipalities can establish themselves as leaders in innovation, advancing towards a more environmentally friendly future [16]. The incorporation of intelligent bins into waste management systems signifies a substantial advancement for the industry. These cutting-edge devices provide a wide range of advantages, such as improved collection routes, decreased operational expenses, ecological sustainability, incentivized recycling, and enhanced public health. Smart bins utilize real-time data and advanced analytics to facilitate a proactive and efficient waste management strategy. As a component of wider smart city initiatives, they contribute to the overall sustainability and quality of life in urban environments. Implementing smart bins is an essential measure towards achieving a more effective, environmentally friendly and information-based future in waste management.

2. Related works

IoT-based waste management systems refer to research and initiatives that investigate the benefits of using IoT technology for managing trash. These systems may consist of bins equipped with sensors, advanced collection vehicles, and centralized monitoring services. The primary objective of waste collection research is to enhance garbage collection routes by utilizing real-time data such as garbage generation rates, traffic patterns, and bin fill levels in optimization algorithms. The literature on sustainable waste management practices seeks to minimize waste production and encourage responsible disposal through initiatives such as recycling and composting, as well as community engagement strategies. Publications focusing on smart city initiatives and broader endeavors to enhance urban sustainability, particularly highlighting the role of advanced technology such as smart pins in enhancing the

quality of urban life. Researchers in waste management utilize data analytics techniques such as machine learning and predictive modeling to analyze data from waste management systems, with the aim of optimizing operations and resource allocation. Subsequently, this data is utilized to enhance the accuracy and effectiveness of decision-making procedures. Assessments and analyses of experimental initiatives and real-life examples that implement innovative methods for waste management are accessible. These documents provide comprehensive information on the achievements and shortcomings of these projects, as well as the knowledge gained from them. Environmental impact assessments (EIAs) are comprehensive evaluations that analyze the advantages and disadvantages of implementing novel technologies to mitigate environmental degradation and enhance sustainability. Additionally, they examine the ecological consequences of outdated waste management practices. The policy and regulatory frameworks section includes an analysis of the national, regional, and municipal waste management policies, regulations, and governance structures, and how these factors influence the implementation of innovative waste management practices. Through the analysis and synthesis of these interconnected studies, researchers can enhance their comprehension of the present trends in the field, identify areas where knowledge is lacking, and expand upon prior research to expedite the incorporation of intelligent bins into waste management.

The smart bin waste management project typically employs conventional methods for garbage collection. Typically, determining the appropriate time to empty bins relies on either predetermined schedules or physical inspections. Typically, these methods constitute the existing system in this project. Waste management workers consistently adhere to their predetermined schedules when collecting trash cans, regardless of their level of fullness. Possible consequences of employing this method include inefficiencies such as the collection of trash from bins that are not yet full and the neglect of overflowing bins that require immediate attention. Both of these scenarios are suboptimal. Moreover, it is possible that recycling and waste sorting initiatives are lacking or severely insufficient, leading to the deposition of valuable recyclable materials in landfills. Efficiently addressing issues such as overflowing bins or illegal dumping can be difficult if there is a lack of effective communication between the public and the responsible waste management authorities. Possible improvements to the current system may involve the implementation of real-time monitoring, data-driven decision-making, and efficient resource allocation strategies. This could result in suboptimal waste management strategies and subsequent environmental repercussions. In order to address these limitations, intelligent waste bin systems are being deployed. These systems employ technology to automate the monitoring of waste, optimize the routes for waste collection, promote recycling, and enhance communication with individuals or groups with an interest in the process.

3. Proposed system

The proposed system in the smart bin waste management project involves the utilization of smart bin technology that is equipped with advanced sensors, microcontrollers, and communication modules. The proposed system presents various significant improvements compared to the current system, which depends on manual inspections and fixed collection schedules.

Intelligent bins equipped with sensors constantly monitor the levels of waste fill. Once a bin reaches a predetermined threshold, the system promptly notifies waste management authorities through Wi-Fi or other

communication channels. The system employs data analytics and machine learning algorithms to optimize waste collection routes by using real-time fill-level data from smart bins. This proactive strategy minimizes superfluous acquisitions and diminishes fuel consumption and emissions. Advanced sensors and AI algorithms facilitate the automatic sorting of recyclable materials in smart bins, enhancing waste sorting and recycling processes. This practice facilitates recycling by segregating recyclable materials from regular waste at the point of origin, thereby minimizing pollution and optimizing the retrieval of valuable resources.

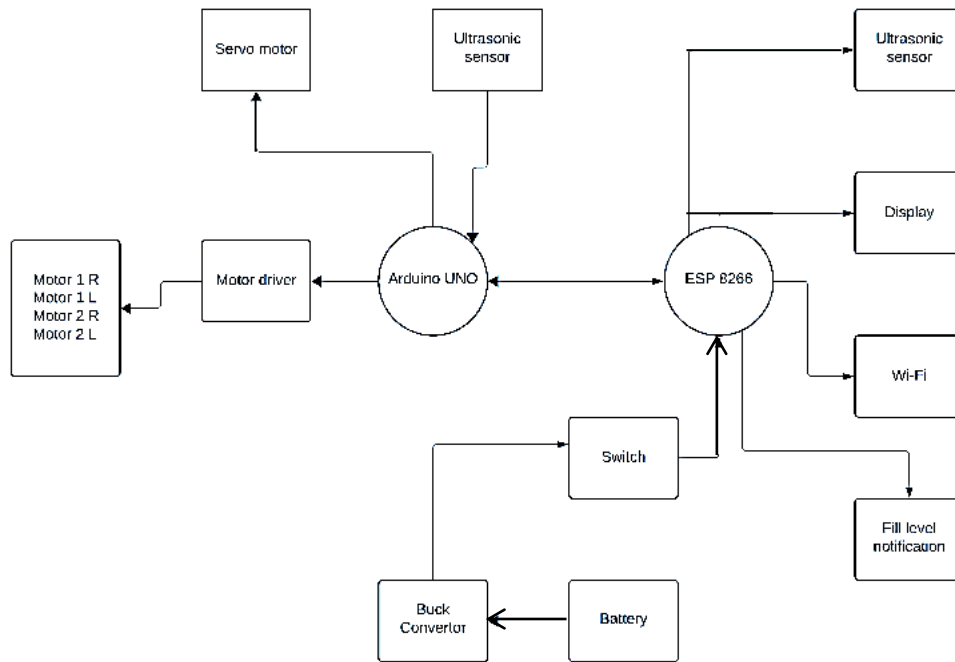


Figure 1. Block Diagram of the Proposed System

User Interaction and Feedback: The system features user interfaces like mobile apps or web portals, enabling residents and businesses to engage with the waste management system. Users can get notifications about bin status, report problems such as overflowing bins, and access educational materials on correct waste disposal methods.

Data-Driven Decision Making: The system collects and analyzes data on waste generation patterns, fill levels, and recycling rates. This data enables waste management authorities to make informed decisions regarding route optimization, resource allocation, and policy development.

Environmental Impact Reduction: By promoting recycling, optimizing collection routes, and reducing overflow and littering, the proposed system contributes to a cleaner environment and reduced ecological footprint. This proposed system significantly advances the existing waste management system, offering real-time monitoring, optimization, and automation capabilities to improve efficiency, sustainability, and user engagement in waste management practices.

The primary objective of this image preprocessing project is to improve the quality and appropriateness of images for further analysis and interpretation in different image processing and computer vision tasks. The project endeavors to tackle prevalent issues such as noise reduction, image denoising, and image enhancement by utilizing a variety of techniques. By utilizing Gaussian blur, median filtering, and histogram equalization techniques, the presence of noise in the image is effectively reduced, leading to an enhancement in image sharpness and clarity.

Moreover, sophisticated denoising algorithms and conversions of color spaces are employed to maintain crucial image details and rectify color distortions. Image segmentation and feature extraction methods are used to simplify intricate scenes and extract pertinent information for subsequent analysis. In summary, this project is crucial in preparing images for a wide range of applications, including object recognition, classification, medical image analysis, and remote sensing. Image segmentation plays a vital role in simplifying intricate visual data for further analysis and interpretation in this project focused on image preprocessing. The project's objective is to streamline the process of identifying, categorizing, and monitoring objects by dividing images into distinct and significant regions or objects.

Multiple segmentation techniques, such as thresholding, edge detection, and clustering, are used to divide images based on pixel intensity, color, texture, or spatial proximity. These techniques allow for the differentiation of foreground objects from background noise, making it easier to visualize and analyze target characteristics with greater accuracy. Furthermore, image segmentation facilitates the extraction of pertinent data for subsequent analysis, such as the identification of specific areas of interest within medical images or the isolation of objects of interest in satellite imagery. Image segmentation is a crucial initial step in this project, allowing for effective and precise analysis of visual data in various applications within image processing and computer vision.

Feature extraction plays a crucial role in this image preprocessing project by identifying and locating pertinent information within images for further analysis and interpretation. The project seeks to capture the fundamental attributes of objects or regions of interest by extracting unique features such as edges, corners, textures, or critical points. Diverse feature extraction techniques, such as edge detection, corner detection, and scale-invariant feature transform (SIFT), are used to emphasize important aspects of the image data. The extracted features function as descriptors that facilitate subsequent tasks such as object recognition, classification, and tracking. Moreover, feature extraction is crucial in decreasing the number of dimensions in the data while retaining important information and enabling efficient processing and analysis. In the future, improvements in feature extraction methodologies, particularly those based on deep learning, have the potential to significantly improve the accuracy and reliability of image analysis techniques in various fields such as medical imaging, remote sensing, and autonomous navigation.

Image classification plays a crucial role in organizing and categorizing visual data according to predefined criteria in this image preprocessing project. Images are analyzed and categorized into specific classes or categories using machine learning algorithms and advanced learning models like convolutional neural networks (CNNs). The process entails instructing the model using a dataset that has been labeled, enabling it to acquire the ability to identify patterns and characteristics that are indicative of each category. After undergoing training, the model is capable of precisely categorizing unfamiliar images into their respective categories. This capability is highly significant in various applications, ranging from identifying objects in photographs to classifying medical images for diagnostic purposes. Furthermore, image classification plays a crucial role in automating tasks such as content moderation on social media platforms or quality control in manufacturing processes. In the future, the ongoing improvement and progress of image classification algorithms hold the potential to increase the precision and effectiveness of automated image analysis in different fields.

3.1. Methodology

The smart bin will immediately notify the appropriate office or waste management authority if it senses that its capacity has been exceeded. They are hereby notified of the urgent need for garbage collection. Also, the smart bin has sensors that track when garbage is disposed of. Instantaneous insights into garbage production patterns are provided by the data transmission to the central system. Through effective communication and automated procedures, the system ensures timely interventions for garbage collection and enables proactive waste management strategies. Upon reaching its full capacity, the smart bin will communicate with the designated office or waste management authorities through Wi-Fi to convey a message. The need for garbage collection is promptly communicated to them through this notice. Also, the smart bin has sensors that track when garbage is disposed of. The data is transmitted to the central system through the Wi-Fi connection, enabling real-time analysis of patterns in waste generation. Efficient waste management is made possible by the system's ability to facilitate seamless communication via Wi-Fi. This communication enables proactive strategies and timely interventions.

Smart bins provide numerous benefits that fundamentally transform waste management practices. Firstly, they enhance efficiency by automating the monitoring and collection of waste, thus optimizing the allocation of resources and decreasing operational expenses. Prompt notifications guarantee that bins are emptied at the appropriate time, thereby reducing the risk of overflow and potential environmental dangers. Furthermore, these systems facilitate resource conservation through the efficient collection and categorization of recyclable materials, thereby minimizing landfill waste and preserving precious resources.

4. Results and Discussion

The smart bin waste management project provides an innovative solution to conventional waste collection methods. The system improves operational efficiency, encourages recycling, and supports environmental sustainability by incorporating advanced technologies and real-time monitoring capabilities.



Figure 2. Hardware Prototype

The project aims to minimize environmental impact by optimizing collection routes, automated waste sorting, and user engagement initiatives while encouraging responsible waste disposal practices. Overall, implementing the

smart bin system represents a significant step forward in modernizing waste management practices and creating cleaner, more sustainable communities.



Figure 3. Bisecting View of the prototype

Furthermore, smart bin systems effectively mitigate environmental impact by effectively preventing bins from overflowing, minimizing instances of littering, and ensuring the maintenance of cleaner public spaces, thereby reducing pollution. In addition, they facilitate data-driven decision-making by gathering real-time data on patterns of waste generation, enhancing operational efficiency and optimizing resource utilization. Moreover, these systems actively involve communities in the implementation of sustainable waste management practices, promoting greater consciousness and involvement in recycling initiatives. Finally, the introduction of advanced bin systems promotes technological advancement in waste management methods, resulting in enhanced capabilities and increased functionalities over a period of time. In general, intelligent bins provide a sustainable, effective, and eco-friendly method for managing waste, benefiting both local communities and the wider ecosystem.

5. Conclusion

In conclusion, the incorporation of smart bin systems into waste management practices has a multitude of advantages, some of which include the enhancement of operational efficiency, the preservation of resources, the promotion of environmental sustainability, the engagement of the community, and the advancement of technology. By streamlining waste monitoring and collection procedures, smart bins reduce operational costs, improve resource distribution, and eliminate environmental hazards associated with overflowing bins. Smart bins also improve resource distribution. These systems also contribute to the preservation of resources by reducing the amount of waste that is sent to landfills and saving valuable resources. They do this by collecting and sorting recyclables in an efficient manner. Moreover, intelligent waste receptacle systems contribute to the reduction of environmental consequences by promoting the cleanliness of public areas, lowering the amount of littering that occurs, and encouraging environmentally conscious waste disposal practices among users. Additional advantages of real-time data collection include improved operational efficiency and resource utilization. This type of data collection also makes it possible to make decisions based on the data collected. The implementation of smart bin systems encourages both environmentally responsible waste management practices and technological advancements in the

field of waste management. This method's improved waste management practices, which are both more efficient and less harmful to the environment, will be beneficial to communities as well as ecosystems. These practices will be beneficial to both aspects of the environment.

Declarations

Source of Funding

This study did not receive any grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing Interests Statement

The authors declare no competing financial, professional, or personal interests.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

All the authors took part in literature review, analysis and manuscript writing equally.

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