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# A Distributed Sensing Framework for Continuous Waste Status Analysis and Location-Guided Collection

P. Hussain[1*], S.Swapna[1], Sugu Bhargavi[1], Penta Uday Sagar[1], B. Prashanth[1], D. Hari Rohith[1]

[1]Department of Electronics and Communication Engineering, Kommuri Pratap Reddy Institute of Technology, Ghanpur, Ghatkesar, 501301, Telangana, India.

*Correspondence: P. Hussain

## Abstract

Urban waste mismanagement remains a critical public health concern, particularly in densely populated market areas where delayed garbage collection can increase the risk of disease outbreaks such as cholera, especially during the rainy season. This issue is largely attributed to the absence of an efficient monitoring mechanism that informs municipal authorities about the real-time status of waste bins. To address this challenge, this project presents an intelligent waste monitoring and collection system that integrates Internet of Things (IoT) technology with Global Positioning System (GPS) capabilities. The proposed system continuously tracks the fill level of garbage bins using embedded sensors and transmits this information to a centralized IoT server. Alongside fill-level data, the system also provides precise geographic location details of each bin through GPS integration. This enables waste management personnel to identify which bins require immediate attention without the need for manual inspection. Automated alerts are generated when bins reach critical capacity, ensuring that collection activities are carried out in a timely manner. Furthermore, the availability of real-time data supports route optimization for garbage collection vehicles, thereby reducing fuel consumption, operational costs, and environmental impact. By enabling data-driven decision-making, the system enhances overall efficiency in municipal waste management operations. Ultimately, this solution not only minimizes the risk of overflow and associated health hazards but also contributes to cleaner and more sustainable urban environments through improved waste collection practices.

**Keywords:** Waste monitoring, IoT, GPS tracking, smart waste management, real-time data acquisition, sensor-based systems.

## 1. Introduction

In recent years, the rapid advancement of the Internet of Things (IoT) has transformed conventional systems into intelligent and interconnected solutions capable of performing tasks with greater efficiency and minimal human intervention. IoT enables seamless communication between devices, allowing real-time data collection, analysis, and decision-making across a wide range of applications, as shown in figure 1. One of the most pressing challenges faced by modern urban environments is effective solid waste management, which directly impacts public health, environmental sustainability, and overall quality of life. Traditional waste collection methods rely heavily on manual monitoring, where authorities inspect garbage bins periodically. This approach is time-consuming, labour-intensive, and often inefficient, leading to issues such as garbage overflow, foul Odors, and the spread of harmful diseases. These problems become more severe in densely populated areas, where timely waste collection is critical to maintaining hygiene and preventing environmental hazards. To overcome these limitations, this project introduces an IoT-based smart waste management system designed to automate the monitoring and handling of garbage bins. The system employs sensors to continuously measure the fill level and weight of waste within each bin, enabling accurate tracking of its status. Each bin is uniquely identifiable,

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allowing authorities to pinpoint its location and condition through a centralized monitoring platform. When predefined threshold levels are reached, the system automatically generates alerts, ensuring prompt collection and reducing the risk of overflow.

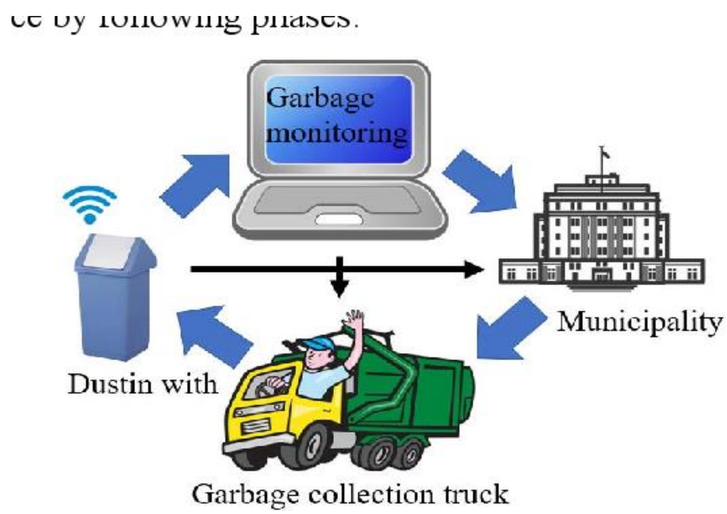


Figure. 1: Garbage bin monitoring.

Additional intelligent features enhance user interaction and environmental safety. The system can guide users to nearby available bins when a particular bin is full, while integrated odor-control mechanisms help maintain cleanliness by minimizing unpleasant smells. This smart solution leverages IoT technology to improve operational efficiency, reduce costs, and promote cleaner, healthier urban spaces.

## 2. Literature Survey

Nathanson [1] described solid waste management as a structured and continuous process that involves the collection, transportation, processing, and disposal of waste materials in a controlled manner. The explanation focuses on how traditional systems are designed to handle increasing waste generation in urban areas. In many cities, these systems depend heavily on fixed schedules and manual inspections to determine when bins should be emptied. Such an approach often leads to inefficiencies, especially when waste levels fluctuate unpredictably. Overflowing bins and underutilized collection trips are common outcomes of this method. The absence of real-time monitoring makes it difficult for authorities to respond dynamically to changing conditions. This also results in higher operational costs due to unnecessary fuel consumption and labor usage. Furthermore, delays in waste collection can create unhygienic environments that affect public health. The description highlights the need for more responsive and data-driven solutions. It clearly brings attention to the limitations of conventional waste management practices in modern urban settings. Manaf, et al. [2] examined municipal solid waste management by focusing on the categorization of waste into different types such as organic, recyclable, and hazardous materials. Their discussion emphasizes how proper classification plays a crucial role in improving the efficiency of waste handling processes. Without effective segregation, waste processing becomes complicated and less environmentally friendly. The explanation also reflects the challenges faced by municipalities in implementing structured waste separation at the source level. Public awareness and participation are identified as important factors in achieving successful segregation. In many regions, mixed waste collection leads to difficulties in recycling and disposal. By introducing organized classification systems, the efficiency of recycling operations can be significantly improved. This also helps in reducing the burden on landfills and minimizing environmental

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damage. The discussion underlines the importance of systematic waste categorization in achieving sustainable waste management. It also supports the idea that better organization leads to better resource utilization.

Mi, et al. [3] explored methods of improving waste handling through classification-based disposal strategies. The concept of using color-coded bins for different types of waste is explained as an effective way to encourage segregation at the source. Each color represents a specific category such as biodegradable, non-biodegradable, or hazardous waste. This visual identification system makes it easier for users to dispose of waste correctly without confusion. As a result, the overall waste collection process becomes more organized and efficient. Proper segregation reduces contamination between waste types, which improves recycling outcomes. It also lowers the environmental risks associated with improper disposal. The explanation highlights how simple design interventions can have a significant impact on waste management efficiency. By promoting user participation, such systems enhance the effectiveness of waste handling practices. The approach contributes to cleaner surroundings and more sustainable urban environments.

Pardini, et al. [4] discussed the integration of modern technologies into waste management systems through the use of IoT-enabled devices. The explanation focuses on how smart bins equipped with sensors can monitor waste levels in real time. These bins communicate data to centralized platforms, enabling authorities to track the status of multiple locations simultaneously. This continuous flow of information allows for better planning and scheduling of waste collection activities. Instead of relying on fixed routes, collection can be performed based on actual need. This reduces unnecessary trips and improves overall efficiency. The use of connected systems also enhances transparency and accountability in waste management operations. By leveraging sensor data, municipalities can make informed decisions quickly. The approach demonstrates how technology can transform traditional waste handling into a more intelligent and adaptive system. It highlights the growing importance of digital solutions in urban infrastructure. Bacot, et al. [5] discussed municipal commercial recycling practices with a focus on improving waste recovery from business sectors. The explanation highlights how organized recycling programs can significantly reduce the volume of waste sent to landfills. It emphasizes the role of policy frameworks and administrative strategies in encouraging participation from commercial establishments. The discussion also reflects challenges such as lack of awareness and inconsistent implementation across regions. Efficient recycling systems require coordination between local authorities and private entities. The explanation points out that structured collection mechanisms improve material recovery rates. It also stresses the importance of economic incentives in promoting recycling behavior. By strengthening municipal recycling initiatives, waste management efficiency can be improved. The approach contributes to sustainable resource utilization. It highlights the importance of organized waste handling systems in urban environments.

Babu, et al. [6] addressed the growing issue of electrical and electronic waste as a global environmental concern. The explanation focuses on the rapid increase in e-waste generation due to technological advancements and shorter product life cycles. Improper disposal of electronic waste leads to the release of hazardous substances into the environment. This creates serious risks to human health and ecological systems. The discussion emphasizes the need for specialized handling and recycling processes for electronic waste. It also highlights the lack of proper infrastructure in many developing regions. Effective management requires strict regulations and public awareness. The explanation shows how improper waste segregation complicates disposal processes. It underlines the importance of adopting safe and sustainable e-waste management practices. This contributes to reducing environmental pollution and health hazards. Ali, et al. [7] examined hospital waste management practices, particularly in developing countries. The explanation highlights the risks associated with improper handling of biomedical waste. Such waste often contains infectious and hazardous materials that can pose serious health threats. The discussion emphasizes the importance of segregation, treatment, and safe disposal methods. Inadequate management systems can lead to contamination and disease spread. The explanation also reflects the challenges faced due to limited resources and lack of proper infrastructure. Training and awareness among healthcare workers are identified as critical factors. The study stresses the need for strict regulatory frameworks. Proper waste handling practices can significantly reduce health risks. This approach improves safety and environmental protection in healthcare settings.

Zobel [8] explored the relationship between environmental management standards and industrial waste generation. The explanation focuses on how the adoption of ISO 14001 influences waste reduction practices in manufacturing sectors. Organizations implementing such standards tend to improve their environmental performance. The discussion highlights how structured environmental policies lead to better waste control and minimization. It also emphasizes the role of continuous monitoring and improvement processes. Industries adopting these standards show more responsibility toward sustainable practices. The explanation reflects how regulatory frameworks encourage efficient waste management. It also demonstrates the importance of compliance in reducing industrial waste output. This approach contributes to cleaner production processes. It supports the integration of environmental responsibility into industrial operations. Gan and Yang [9] discussed the legal and regulatory aspects of high-level radioactive waste disposal. The explanation highlights the complexity involved in managing hazardous waste that requires long-term containment. Strict legal frameworks are essential to ensure safe handling and disposal. The discussion emphasizes the importance of policy development in addressing environmental and safety concerns. It also reflects the challenges associated with implementing effective disposal strategies. Regulatory systems must ensure accountability and risk management. The explanation shows how legal structures guide waste management practices. It also stresses the importance of continuous improvement in policies. Proper governance plays a key role in ensuring environmental safety. This approach supports sustainable and secure waste disposal systems.

Kawai and Huong [10] analysed factors influencing household waste segregation behaviour, particularly for organic waste. The explanation focuses on how public awareness and attitudes impact waste separation practices. Proper segregation at the source is essential for efficient waste processing. The discussion highlights behavioural and social factors that affect participation. Lack of awareness often leads to mixed waste disposal, reducing recycling efficiency. The explanation emphasizes the importance of education and community involvement. It also reflects the need for convenient and accessible waste collection systems. Encouraging proper habits can significantly improve waste management outcomes. This approach supports sustainable environmental practices. It contributes to reducing the burden on waste processing facilities. Seyring, et al. [11] assessed different collection schemes for recyclable waste across European regions. The explanation highlights how structured collection systems improve recycling efficiency. Various approaches such as door-to-door collection and centralized drop-off points are analysed. The discussion emphasizes the importance of system design in achieving high recovery rates. Efficient collection methods reduce waste loss and improve material reuse. The explanation also reflects differences in implementation across regions. It highlights the role of policy and infrastructure in shaping collection systems. Well-designed schemes encourage public participation in recycling activities. This approach enhances sustainability in waste management. It supports the development of efficient and organized waste collection frameworks.

Sharmin and Al-Amin [12] presented a cloud-based waste management approach that utilizes IoT sensors for monitoring bin conditions. The explanation emphasizes how data collected from sensors is transmitted to a centralized cloud platform for processing and analysis. This enables real-time visibility of waste levels across different locations. With this information, authorities can prioritize collection tasks based on urgency rather than following rigid schedules. The system supports dynamic decision-making, which improves operational efficiency. It also reduces the chances of bin overflow by ensuring timely intervention. The use of cloud technology allows data to be accessed remotely, making monitoring more convenient. Additionally, it supports scalability, enabling the system to expand across larger areas. The approach highlights how combining IoT and cloud computing enhances the responsiveness of waste management systems. It demonstrates a shift toward more flexible and data-driven urban services.

Al-Fuqaha, et al. [13] explained the fundamental concepts of IoT by outlining its key components, including sensing devices, communication networks, data processing units, and service layers. The explanation focuses on how these components work together to transform ordinary objects into smart entities capable of interaction. Sensors collect data from the environment, which is then transmitted through communication networks for processing. The processed data is used to make intelligent decisions or trigger automated actions. This interconnected structure enables systems to operate with minimal human intervention. In the context of waste management, IoT allows continuous monitoring and automated reporting of bin status. The explanation highlights how IoT supports efficiency, accuracy, and real-time responsiveness. It also emphasizes the role of IoT in enabling smart applications across various domains. The concept provides a strong foundation for developing intelligent monitoring systems. It reflects the growing significance of connectivity in modern technological solutions. Shahabdeen [14] introduced a smart garbage bin concept that incorporates embedded systems for monitoring waste levels. The explanation describes how sensors are used to detect the amount of waste inside the bin. Once a certain threshold is reached, the system automatically sends a notification to the concerned authorities. This eliminates the need for manual checking and ensures timely waste collection. The embedded system acts as a control unit that processes sensor data and manages communication. Such automation improves the reliability of waste management operations. It also reduces human effort and increases efficiency. The design demonstrates how simple electronic components can be combined to create an intelligent system. By enabling real-time updates, the system helps prevent overflow situations. The explanation highlights the practical benefits of integrating sensing and communication technologies. It reflects a step toward smarter and more responsive waste handling solutions.

Bigbelly [15] demonstrated the real-world application of smart waste management systems in urban environments. The explanation focuses on how sensor-enabled bins can significantly reduce the frequency of waste collection trips. These bins monitor their fill levels and notify collection teams only when necessary. This results in optimized routing and reduced fuel consumption. The system also lowers operational costs by minimizing unnecessary labor and transportation. In addition, it helps maintain cleaner public spaces by preventing bin overflow. The use of data-driven approaches improves overall efficiency and service quality. The explanation highlights the practical advantages of adopting smart technologies in city management. It also shows how innovation can lead to more sustainable waste handling practices. The implementation serves as an example of successful smart city integration. It demonstrates the effectiveness of intelligent waste monitoring solutions. Dorsemaine, et al. [16] described IoT as a network of interconnected objects capable of sensing, processing, and exchanging data. The explanation outlines how these objects communicate through various technologies to create a unified system. Each component plays a specific role, from data collection to service delivery. This interconnected framework enables automation and intelligent control across different applications. In waste management, IoT allows bins to act as smart devices that can report their status in real time. The system can then analyze this data to optimize operations. This reduces delays and improves efficiency in waste collection. The explanation highlights the importance of integration between hardware and software components. It also emphasizes the role of IoT in enabling scalable and flexible solutions. The concept supports the development of advanced monitoring systems. It reflects the transformation of traditional infrastructure into smart ecosystems.

## 3. Proposed System

The proposed methodology defines a structured technological framework for intelligent waste monitoring and management using IoT-enabled sensing and communication techniques. The analytical workflow begins with real-time data acquisition from smart waste bins equipped with sensors, followed by data processing, transmission, and remote monitoring. Ultrasonic sensors are utilized to measure the fill level of bins, while additional sensing mechanisms detect user interaction and bin status. The collected data is transmitted through a wireless communication network to a centralized server for analysis and storage. Location information is integrated using positioning techniques to uniquely identify each bin within the monitoring network. The system

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incorporates automated decision-making logic to trigger alerts when bins reach predefined threshold levels, ensuring timely waste collection. A user interface enables authorities to monitor bin status, visualize data, and manage operations efficiently. The architecture also supports remote access, allowing monitoring and control from any location. A lightweight storage mechanism maintains system data, while continuous updates improve operational reliability. The overall framework enhances efficiency, reduces manual effort, and supports sustainable urban waste management practices, as illustrated in Figure 2.

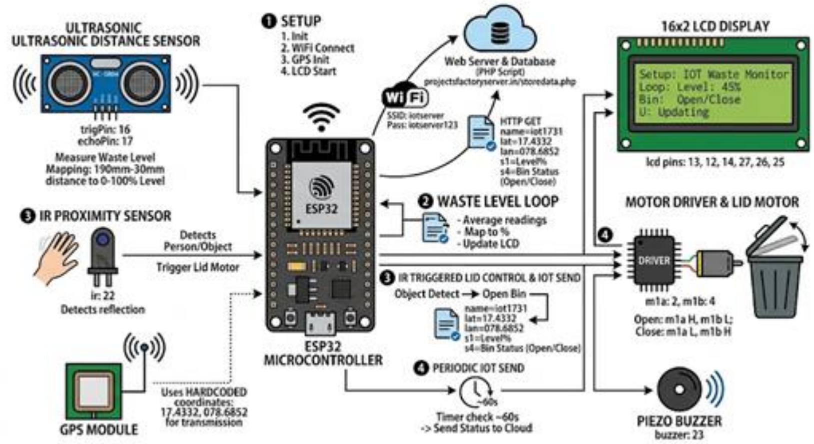


Figure. 2: System architecture.

**User Interface (Monitoring Application)**

- The system provides a graphical interface for interaction with waste monitoring operations.
- It enables functionalities such as login, real-time bin monitoring, data visualization, and status tracking.
- Users can observe bin fill levels, location details, and operational alerts through the interface.
- All user actions are processed and communicated to the backend system for further execution.

**IoT Embedded Device (Smart Bin Unit)**

- Each waste bin is integrated with an embedded controller and multiple sensors.
- Ultrasonic sensors measure the distance between waste and bin lid to estimate fill level.
- IR sensors detect user interaction and bin usage activity.
- Motor drivers control automatic opening and closing of the bin lid.
- The embedded unit continuously collects and processes sensor data.

**Wireless Communication Module (WiFi/IoT Connectivity)**

- The communication module connects the embedded device to the internet using WiFi technology.
- It transmits real-time sensor data to the remote server using HTTP protocols.
- The module ensures continuous data flow between physical devices and cloud infrastructure.
- It supports reliable communication for real-time monitoring applications.

**Central Server (IoT Data Processing Unit)**

- The server acts as the core processing component of the system.
- It receives sensor data including bin level, status, and location information.
- The server processes incoming data and stores it for monitoring and analysis.
- It generates alerts when bins exceed threshold levels.

**Database (Data Storage System)**

- A lightweight storage system is used to maintain bin-related information.
- It stores historical data such as fill levels, timestamps, and bin status.
- The database supports efficient retrieval and analysis of waste management data.
- It enables long-term monitoring and performance evaluation.

**Sensor Data Acquisition and Processing**

- Sensors continuously collect real-time data from waste bins.
- Ultrasonic sensors calculate bin fill percentage based on distance measurement.
- Data is filtered and averaged to reduce noise and improve accuracy.
- Processed data is converted into meaningful parameters for monitoring.

**Alert and Notification Module**

- The system generates alerts when bin levels reach predefined thresholds.
- Notifications are sent to authorities through the IoT server.
- Alerts include bin status, location, and urgency level.
- This ensures timely waste collection and prevents overflow conditions.

**Location Tracking Module**

- Each bin is associated with location information using GPS or predefined coordinates.
- The system identifies the exact position of bins requiring attention.
- Location data supports efficient route planning for waste collection vehicles.
- It enhances operational efficiency and reduces unnecessary travel.

**Automated Bin Control Mechanism**

- The system includes an automated mechanism for opening and closing the bin lid.
- IR sensors trigger the motor when user interaction is detected.
- The motor driver controls lid movement for hygienic waste disposal.
- This feature minimizes human contact and improves usability.

**Remote Monitoring and Control Workflow**

- The architecture supports remote monitoring through internet connectivity.

- Authorities can access system data from any location using connected devices.
- Real-time updates allow quick decision-making and response.
- The system ensures continuous supervision without physical inspection.

**System Evaluation and Improvement**

- The system performance is evaluated based on accuracy, response time, and reliability.
- Data trends are analyzed to improve waste collection efficiency.
- Periodic updates enhance system performance and adaptability.
- Continuous monitoring ensures long-term sustainability and effectiveness.

## 4. Results And Discussion

The results and discussion section presents the performance evaluation of the developed waste monitoring system under real-time operating conditions. The system was tested to analyze its ability to accurately measure bin fill levels, detect user interaction, and transmit data to the server without delay. Observations indicate that the sensor-based measurements provide reliable and consistent outputs, enabling effective monitoring of waste accumulation. The integration of wireless communication ensures timely data transfer and alert generation for critical conditions. The system also demonstrates improved operational efficiency by reducing the need for manual inspection and unnecessary collection trips. Additionally, location-based information supports better decision-making for waste collection planning.

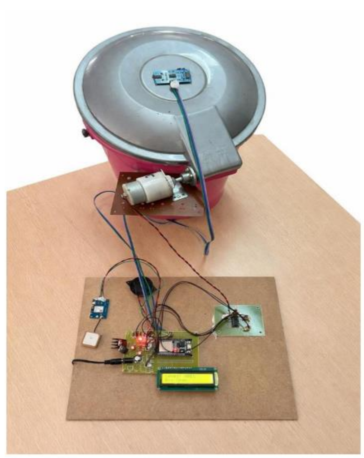

Figure. 3: Prototype implementation of IoT-Based smart waste monitoring system.

Figure 3 illustrates the hardware prototype of the developed smart waste monitoring system integrated with sensing, control, and communication components. The setup demonstrates the practical implementation of an automated waste bin equipped with an ultrasonic sensor for level detection and an embedded control unit for data processing. The system incorporates a motor-driven mechanism to enable automated lid operation based on user interaction. Sensor data is continuously acquired and transmitted to the processing unit, where it is analyzed for monitoring and alert generation. The inclusion of a display module provides real-time visualization of system parameters, enhancing user awareness. The figure also depicts the interconnection of various electronic modules that collectively enable intelligent waste management functionality.

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## 5. Conclusion

This research presents an intelligent IoT-enabled waste monitoring framework that significantly improves the efficiency and reliability of urban waste management systems. By integrating ultrasonic sensing, IR-based interaction detection, and wireless communication, the system enables real-time monitoring of bin fill levels and operational status. The incorporation of location awareness further enhances the ability to identify and service bins that require immediate attention. Compared to conventional manual methods, the approach reduces unnecessary collection trips, lowers operational costs, and minimizes human effort. Performance improvements are achieved through accurate sensor data acquisition, noise reduction using averaging techniques, and timely alert generation. The automated lid mechanism also enhances hygiene and user convenience. Real-time data transmission ensures faster decision-making and improved responsiveness. The system contributes to cleaner environments, reduced overflow incidents, and better resource utilization. The framework demonstrates a scalable and efficient solution suitable for modern smart city applications.

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