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IOT-Based Garbage Management Systems: A Survey of Sensing, Control and Cloud Monitoring Approaches for Smart Dustbins

Aditya Mohan Rathod[1], Vivek Prashant Koli[2], Sushant Sukhadev Lohar[3], Ashish Shivaji Waghmare[4], Ranjit Suryakant Akiwate[5], Sushant Sopan Jadhav[6].

[1,2,3,4]Student, Department of Mechanical Engineering, , Sanjay Bhokare Group of Institute, Miraj, Maharashtra, India

[5]HOD ,Department of Mechanical Engineering, , Sanjay Bhokare Group of Institute, Miraj, Maharashtra, India

[6]Lecturer, Department of Mechanical Engineering, , Sanjay Bhokare Group of Institute, Miraj, Maharashtra, India

ABSTRACT

Rapid urbanization, population growth and changing consumption patterns have increased the quantity of solid waste generated every day. Conventional collection relies on fixed schedules and manual inspection, which leads to overflowing bins, unpleasant odors, wasted fuel and labor, and unhygienic surroundings. The Internet of Things (IoT) offers a practical alternative: a dustbin fitted with a sensor, a microcontroller and a communication module becomes a data-generating node that reports its own fill level. This paper surveys recent work on IoT-based smart garbage bins, with emphasis on five representative studies published between 2017 and 2024. The surveyed systems are compared on four dimensions: level-sensing method, controller, communication technology and cloud or application layer. The review shows that ultrasonic distance sensing, Arduino or ESP8266-class controllers and free cloud dashboards such as Thing Speak form the most common low-cost design, while GSM/GPRS, GPS and mobile applications are added for city-scale deployment. Two gaps are identified: limited attention to the mechanical support structure, and dependence on the network for alerting. A low-cost reference prototype based on an ultrasonic sensor, Node MCU (ESP8266), red LED, buzzer, 16×2 LCD and Thing Speak, mounted on a metal frame, is described as a design that addresses these gaps, together with a proposed evaluation plan. Open challenges and future directions are also discussed.

Keywords: IoT, Garbage Management, Smart Dustbin, Ultrasonic Sensor, NodeMCU, Thing Speak, Waste Monitoring, Smart City

I. INTRODUCTION

Solid waste management is one of the most important civic problems of growing towns and cities. The quantity of waste rises every year with population growth, urbanization and changing lifestyles. When garbage is not collected and disposed of on time, it overflows from bins, spreads onto roads, attracts stray animals, insects and rodents, produces foul smell, and becomes a source of disease and environmental pollution. Clean public places are especially important in educational institutions, hospitals and residential colonies, where many people are present every day.

Traditional waste collection follows rigid, manual routines in which vehicles visit predefined routes at fixed times. Bins that are nearly empty are visited unnecessarily, wasting fuel and labor, while bins that fill early are left overflowing until the next round. Manual inspection of every bin is time-consuming, and there is usually no automatic warning to cleaning staff when a bin becomes full.

The Internet of Things (IoT) is a network of physical objects fitted with sensors, processing units and communication modules that collect data and exchange it over the internet with little or no human intervention. Applied to sanitation, IoT allows standard waste receptacles to be retrofitted with sensors and microcontrollers so that each bin reports its fill level to a central platform. Operators can then move from static schedules to an on-demand, dynamic collection model in which bins are emptied when needed. Low-cost sensors, Wi-Fi-enabled microcontrollers such as the NodeMCU (ESP8266) and free cloud platforms such as ThingSpeak have made it possible to build such systems even at student-project level.

II. Background: Architecture of an IoT Garbage Monitoring System

Most smart-bin systems in the literature follow a layered architecture. The layers and their typical implementations are described below.

Sensing layer. A sensor measures how full the bin is. The ultrasonic distance sensor (for example HC-SR04) is the most widely used because of its low cost and simple interface. It is mounted under the lid, emits ultrasonic pulses towards the garbage and measures the time taken by the echo to return. The distance between lid and garbage surface decreases as the bin fills, and this distance is converted into a fill percentage. Some systems add a load cell to measure weight.

Processing layer. A microcontroller reads the sensor, compares the fill level with a threshold, classifies the bin state (empty, partly filled, full) and drives the output devices. Arduino boards and ESP8266-based boards such as the NodeMCU are common because they are inexpensive, easily programmable and well supported.

Local alert layer. Visual and audible indicators, such as LEDs, buzzers and character LCDs, inform people near the bin and the cleaning staff immediately and do not depend on any network.

Communication layer. Wi-Fi is suitable for indoor and campus deployments where a network is available. GSM/GPRS, with GPS for location, is used where bins are spread over a wide area.

Cloud and application layer. The data are stored and displayed graphically on a cloud platform such as ThingSpeak, or on a dedicated server with a mobile application. Collectors and administrators can view bin status remotely and plan collection.

The overall data flow can be summarized as:

Garbage level → Ultrasonic sensor → Microcontroller → (LED / Buzzer / LCD) and Wi-Fi / GSM → Cloud platform → User (mobile / PC)

III. Review of Literature

This section summarizes five representative studies on smart garbage bins, presented in reverse chronological order.

A. Paul et al. (2024) [1]

Paul et al. present an IoT-based smart waste management system for municipalities and city corporations. Ultrasonic sensors measure the height of waste, and an Arduino Uno with GSM/GPRS and GPS modules handles communication and location. A central data center and a mobile application alert waste collectors when a bin must be emptied. A survey of 150 people suggested good community acceptance of the system. The study shows that the basic smart-bin concept can be scaled from a single bin to a city-wide network.

B. Tashi et al. (2021) [2]

Tashi et al. propose an IoT garbage monitoring system to address overflowing bins caused by population growth and rising consumption. They observe that waste managers often lack information about bin levels and collection schedules. Their system uses an Arduino UNO with an ultrasonic sensor to give authorized personnel real-time bin-level data, so that bins can be emptied on time instead of on a fixed routine. The authors conclude that this approach reduces energy use and improves waste-collection operations.

C. Bhuvaneswari et al. (2020) [3]

Bhuvaneswari et al. developed a smart garbage monitoring prototype for remote tracking of bins. An Arduino reads an ultrasonic sensor that measures garbage depth and a load cell that measures the weight of the bin. The data are sent over Wi-Fi to the ThingSpeak IoT platform, where administrators can view the status of each bin. Collection could therefore be planned more efficiently, and the prototype performed satisfactorily in testing. This study directly supports the combination of ultrasonic sensing, Wi-Fi and ThingSpeak.

D. Rishan (2018) [4]

Rishan proposed a low-cost IoT system for smart garbage and waste collection bins in public places. Ultrasonic sensors connected to a microcontroller measure how full each bin is, and the readings are sent to a central server so that municipal staff can view bin levels online and dispatch vehicles only when required. The study showed that level-based collection can reduce labour and improve urban waste management compared with fixed-schedule collection, and it stressed that such systems must be low-cost to be widely adopted.

E. Mustafa and Ku Azir (2017) [5]

Mustafa and Ku Azir developed a smart bin that monitors garbage levels in real time and alerts the municipality when bins are nearly full. Ultrasonic sensors measure fill depth and an ARM microcontroller controls the operation. Data are sent to the ThingSpeak cloud, and the status of four waste categories (domestic, paper, glass and plastic) is also shown on an LCD. The stored data could later be used for analysis such as predicting when bins become full. The authors suggest that the system can support greener cities by making collection more efficient.

IV. Comparative Analysis

A. Comparison of Surveyed Systems

Table I compares the surveyed systems with the reference prototype described in Section VI. Entries marked "Not stated" were not reported in the summaries of the studies reviewed here.

Table I. Comparison of IoT-based smart garbage bin systems

Ref.	Year	Sensing	Controller	Communication	Cloud / Application	Local alert
[1] Paul et al.	2024	Ultrasonic	Arduino Uno	GSM/GPRS, GPS	Data center, mobile app	Not stated
[2] Tashi et al.	2021	Ultrasonic	Arduino UNO	Not stated	Real-time data for authorized staff	Not stated
[3] Bhuvaneswari et al.	2020	Ultrasonic, load cell	Arduino	Wi-Fi	ThingSpeak	Not stated
[4] Rishan	2018	Ultrasonic	Microcontroller	Not stated	Central server (online view)	Not stated
[5] Mustafa and Ku Azir	2017	Ultrasonic	ARM	Not stated	ThingSpeak	LCD (four waste categories)
Reference prototype	2026	Ultrasonic	NodeMCU (ESP8266)	Wi-Fi	ThingSpeak	Red LED, buzzer, 16×2 LCD

B. Observations

1. **Sensing.** Ultrasonic distance measurement is the most common and lowest-cost method of detecting garbage level. All five studies use it, and some add a load cell, temperature sensor or camera.
2. **Controller.** Arduino and ESP8266-based boards dominate because they are cheap, easily programmable and well supported.

3. **Communication.** Wi-Fi suits indoor and campus use, whereas GSM/GPRS and GPS are used where bins are spread over a wide area.
4. **Cloud and application.** Free cloud platforms such as ThingSpeak give quick graphical monitoring; larger systems use their own servers and mobile applications.
5. **Benefits.** All the studies report that level-based collection saves labour, time and fuel and reduces overflow.
6. **Cost.** Low cost is repeatedly identified as a condition for wide adoption [4].
7. **Scalability.** The same design pattern scales from a single bin to a city-wide network when communication and a central platform are added [1].

V. Problem Analysis and Research Gap

A. Problem Analysis

The literature and field observation point to the following problems:

- Bins in public places, colleges, hospitals and residential areas often overflow before they are emptied, causing foul smell and unhygienic conditions.
- Collection is done on a fixed schedule without knowledge of the actual fill level, so time, fuel and manpower are spent on nearly empty bins.
- Manual inspection of every bin is time-consuming, and no automatic warning reaches the cleaning staff when a bin is full.
- Overflowing garbage attracts stray animals, insects and rodents and raises the risk of disease and environmental pollution.
- Existing commercial smart-bin systems are costly and not easily available to small institutions.

The core problem is therefore to develop a low-cost system that monitors the garbage level automatically, gives an immediate local warning, and reports the status remotely so that the bin is emptied at the right time.

B. Research Gap

Most of the reviewed systems concentrate on electronics and software and depend on the network to inform the user. Two gaps follow from this:

1. **Network-independent alerting.** When the internet connection fails, a bin that relies only on cloud notification gives no warning to people nearby. Local indicators (LED, buzzer, LCD) keep the bin useful during outages.
2. **Mechanical design.** The supporting structure, sensor mounting and protection of electronics receive little attention in the reviewed studies, although they affect sensor alignment, durability and stability in public use.

VI. Reference Prototype

To address these gaps, a low-cost prototype is proposed. It integrates mechanical fabrication (bin and sensor-mounting frame), basic electronics, embedded programming and IoT communication, and is intended for colleges, hospitals, residential areas, markets and other public places.

A. System Design

Table II. Modules and components of the reference prototype

Module	Components	Function
Mechanical structure	MS angle / sheet frame, dustbin, sensor mount	Gives strength, stability and protection; houses electronics
Sensing	Ultrasonic sensor HC-SR04 (5 V)	Measures distance from lid to garbage surface
Processing and control	NodeMCU (ESP8266), Arduino IDE program	Computes level, compares with limit, controls outputs
Alert	Red LED (with 220 Ω resistor), piezo buzzer	Visual and audible warning when bin is full
Display	16×2 LCD with I2C module	Shows level and status (“BIN EMPTY” / “BIN FULL”)
Communication	Built-in Wi-Fi of NodeMCU	Sends data to the internet at regular intervals
IoT monitoring	ThingSpeak channel, mobile / PC	Stores and graphs level data for remote monitoring
Power supply	5 V adapter / USB supply, wiring	Regulated power for sensor, controller and outputs

B. Working Principle

1. **Level detection.** The ultrasonic sensor under the lid sends waves towards the garbage and receives the echo. The distance shrinks as the bin fills, and the reading is passed to the NodeMCU.
2. **Processing.** The NodeMCU converts the distance to a percentage of bin height and classifies the bin as empty, partially filled or full against a preset limit (for example 80–90% of bin height).
3. **Local alerts.** At the full limit, the red LED glows, the buzzer sounds and the LCD shows “BIN FULL”. Below the limit the LED and buzzer remain off.
4. **Cloud update.** The level is uploaded over Wi-Fi to ThingSpeak at regular intervals, where it is stored and shown graphically. A working internet connection is needed for this step only.
5. **Collection.** The cleaning person empties the bin; the sensor detects the new level and the status updates automatically.

C. Software Flow

1. Start and initialize the sensor, LCD, LED, buzzer and Wi-Fi connection.
2. Trigger the ultrasonic sensor and measure the distance to the garbage.
3. Convert the distance into garbage level (percentage of bin height).
4. If the level is above the set limit, switch on the LED and buzzer and display “BIN FULL”; otherwise keep them off and display “BIN EMPTY” or the current level.
5. Send the level to ThingSpeak at regular intervals and repeat the cycle.

VII. Evaluation Plan and Feasibility

The prototype has not yet been evaluated; the results below are the planned measurements and expected outcomes.

A. Hypothesis

A properly calibrated ultrasonic sensor with a NodeMCU controller can detect the garbage level with sufficient accuracy to generate a timely "bin full" alert both locally (LED, buzzer, LCD) and remotely (ThingSpeak). Actual accuracy will depend on sensor mounting, the type and surface of the garbage, and Wi-Fi signal strength.

B. Performance Measures

Table III. Proposed performance measures

Aspect	Measure
Sensor accuracy	Measured versus actual distance at different garbage levels
Response time	Time from reaching the full level to LED / buzzer / LCD alert
IoT performance	Delay between sensor reading and ThingSpeak update; any data loss
Reliability	Repeated tests with different waste types and Wi-Fi conditions
Mechanical	Strength and stability of the frame; security of component mounting

C. Expected Outcomes

- A functional smart dustbin integrating a metal frame, sensor, controller, alert devices and cloud monitoring.
- Correct "BIN EMPTY" and "BIN FULL" indication at the set levels.
- LED and buzzer activation when the garbage reaches the set limit.
- Level data uploaded to ThingSpeak at regular intervals and viewable on a phone or computer.
- Reduced overflow and manual inspection effort during the test period.

D. Feasibility

- **Technical:** All components are easily available and the technology is simple and proven. Fabrication can be done in the college workshop.
- **Economic:** The estimated prototype cost is approximately Rs. 2,500 to Rs. 4,000, to be confirmed after finalizing components. Running cost is negligible because power consumption is very low.
- **Environmental:** Overflow and unnecessary collection trips are reduced, which lowers pollution. Electronic waste must be disposed of properly at end of life.
- **Operational:** The system is easy to install, operate and maintain; only basic training of cleaning staff is required.

The design is therefore feasible as an educational prototype and for small-scale application.

VIII. Challenges and Future Directions

Challenges.

- *Sensor accuracy:* ultrasonic readings depend on mounting angle and on the shape and surface of the waste, so calibration is needed.
- *Connectivity:* Wi-Fi-based reporting needs network coverage, and cloud data can be delayed or lost; local alerts reduce this risk but do not remove it.
- *Cost versus scale:* commercial systems are costly, while low-cost prototypes must still remain reliable across many bins [4].
- *Maintenance:* sensors and electronics must be protected from dirt, moisture and misuse in public places.
- *Electronic waste:* the devices themselves must be disposed of responsibly.

Future directions. The reference design can be extended with:

- multiple bins reporting to one dashboard, with data used for route planning so bins are emptied precisely when needed;
- GPS-based location and GSM/GPRS communication for wide-area deployment [1];
- weight sensing [3] and gas sensing for odour monitoring;
- a mobile application with notifications;
- analysis of stored data to predict when bins will become full [5].

IX. Conclusion

This survey reviewed five studies on IoT-based garbage monitoring and found a consistent design pattern: ultrasonic level sensing, a low-cost Arduino or ESP8266-class controller, wireless communication and a cloud dashboard. All the reviewed work reports that level-based collection reduces overflow, labour, time and fuel compared with fixed schedules. The review also showed that mechanical design and network-independent local alerting receive limited attention. A low-cost reference prototype using an ultrasonic sensor, NodeMCU, red LED, buzzer, 16×2 LCD and ThingSpeak on a metal frame was described to address these gaps, along with a plan for evaluating sensor accuracy, alert response time and data-update performance. Such systems are a simple, practical step towards cleaner, healthier surroundings and the wider smart-city and cleanliness goals of the country.

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