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Smart Waste Management System

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ABSTRACT

Manual inspection of dustbins and fixed collection schedules lead to overflowing bins, unnecessary collection trips and unhygienic surroundings. This paper proposes the Smart Waste Management System, a low-cost IoT-based system that monitors the waste level of dustbins and makes the information available through a web platform.

An HC-SR04 ultrasonic sensor measures the distance between the sensor and the waste surface, and an ESP32 microcontroller converts the reading into a waste level and a status (Empty, Medium, Almost Full or Full) and transmits it over Wi-Fi to a MySQL database that stores the Bin ID, location, waste level, status, date and time. A web application built with HTML5, CSS3 and JavaScript displays bin details, alerts and collection history, and Power BI is used to analyze the stored data through charts and reports that support collection planning.

The system is organized into six modules: smart dustbin, ESP32 controller, database management, web application, data analysis and waste collection management. This paper presents the architecture, methodology and planned evaluation of the system; the system is at the design stage, and no experimental results are claimed.

Index Terms - Smart Waste Management, Internet of Things (IoT), ESP32, Ultrasonic Sensor, HC-SR04, MySQL, Web Development, Data Analytics, Power BI, Waste Level Monitoring

I. INTRODUCTION

Proper waste management is an important requirement for clean, healthy and sustainable surroundings. Traditional waste management depends mainly on manual inspection and fixed collection schedules. As a result, some dustbins overflow before they are collected, while others are collected even when they are not full. This causes unnecessary collection trips, wastage of time and resources, and unhygienic conditions.

The Internet of Things (IoT) offers a practical way to reduce this problem. Sensors and microcontrollers can measure the waste level automatically, and Wi-Fi allows the readings to be sent to a remote system. Ultrasonic sensors are well suited to this task because they measure the distance between the top of a dustbin and the waste surface, and microcontrollers such as the ESP32 can process the readings and transmit them over Wi-Fi. Recent studies on smart bins combine sensors, IoT communication, databases, web applications and data analytics to monitor waste levels remotely and to support collection planning [1]–[4].

This paper proposes the Smart Waste Management System. An HC-SR04 ultrasonic sensor mounted in a dustbin detects the amount of waste present, and an ESP32 processes the reading and transmits it through Wi-Fi. The information is stored in a MySQL database and displayed in a web application developed with HTML5, CSS3 and JavaScript. The system identifies four waste-level conditions (Empty, Medium, Almost Full and Full) and indicates when a bin needs collection. Power BI is used to analyze the collected data and to understand collection patterns.

The main contributions of this work are: (i) a proposed modular pipeline from waste-level sensing to collection planning, built from low-cost components; (ii) a design that joins ultrasonic sensing, ESP32 processing and status classification with a MySQL database that keeps collection history, a web monitoring interface and Power BI analytics; and (iii)

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a planned evaluation covering waste-level accuracy, data transmission, response time, alert generation, reliability and error rate. The scope is a prototype smart dustbin with web monitoring; mobile applications, GPS-based route planning and predictive analytics are left for future work.

The rest of the paper is organized as follows. Section II reviews the literature. Section III describes the methodology as six modules. Section IV discusses the expected benefits, planned evaluation and feasibility. Section V concludes.

II. LITERATURE REVIEW

Zoumpoulis et al. [1] presented a systematic literature review of smart bins and their role in sustainable waste management in smart cities. The reviewed work covers sensing, actuation, IoT connectivity, waste-level monitoring, waste separation and automation. The review concludes that smart bins can give real-time information about waste levels, improve collection efficiency, reduce unnecessary collection activities and support recycling and resource recovery.

Snigdha et al. [2] proposed an IoT-based smart waste management system to reduce overflowing garbage bins. An ultrasonic sensor detects the garbage level at periodic intervals, the data is updated to the cloud for analysis, and an ESP32 Wi-Fi component sends a notification to the concerned authorities when the dustbin becomes full. The study shows that real-time monitoring reduces continuous manual monitoring and helps workers act in time. Its sensor and ESP32 combination is the closest to our proposed system.

Ahmed et al. [3] reviewed AI and IoT based waste management systems and proposed an updated architecture for municipal waste management in smart cities. Smart sensors monitor the status of bins and generate notifications when bins are full or empty, which are sent to the municipality office and to collection vehicle drivers. The authors report that IoT-based monitoring can reduce unnecessary collection, fuel consumption and operating cost, and that route optimization can further improve collection efficiency.

Abba and Light [4] presented an IoT-based framework for smart waste monitoring and control in smart cities. Waste levels in bins are monitored with IoT sensors and transmitted for remote monitoring, which identifies the status of bins, supports timely collection and reduces the need for continuous manual checking.

Cerchecci et al. [5] proposed a low-power IoT sensor node architecture for monitoring waste containers. Because such nodes may be deployed in large numbers, the work stresses energy-efficient operation to support continuous monitoring.

Research Gap: The reviewed studies show that IoT-based waste-level monitoring is feasible, but they emphasize different parts of the problem: smart-bin technologies and automation [1], sensing with notification [2], system architecture and routing [3], a monitoring framework [4] and low-power hardware [5]. The proposed work does not claim a new sensing technique. Its aim is a simple, practical and low-cost prototype that joins ultrasonic sensing, ESP32 processing, Wi-Fi transmission, a MySQL database with collection history, a web interface with alerts and Power BI analytics, and that is planned to be tested for accuracy, transmission, response time and reliability.

III. METHODOLOGY

The proposed system follows a modular pipeline in which each stage passes its output to the next (Figure 1): ultrasonic sensor, ESP32, Wi-Fi, server-side application, MySQL database, web application and Power BI analytics. It combines IoT sensing, embedded processing, database management, web development and data analytics, and is organized into four modules (Table 1).

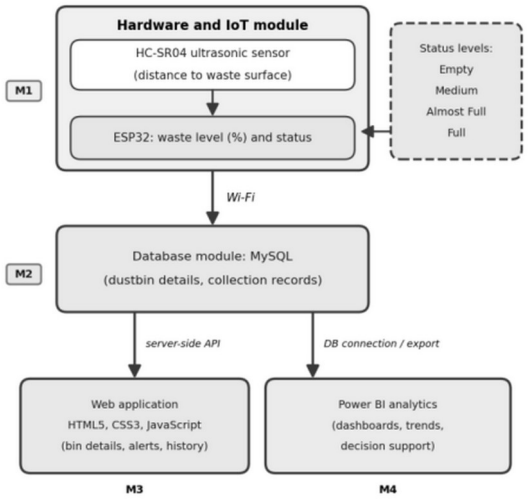


Figure 1. Block diagram of the proposed Smart Waste Management System and its four modules (M1–M4). The ESP32 assigns one of four status levels to each reading before sending it over Wi-Fi.

Table 1. Summary of the six modules

Module	Function	Key tools
1. Hardware and IoT	Sensing, waste-level calculation, status classification, Wi-Fi transmission	HC-SR04, ESP32, Arduino IDE
2. Database	Storage of current bin data and collection history	MySQL
3. Web application	Bin monitoring, alerts, collection history	HTML5, CSS3, JavaScript, server-side API
4. Analytics	Dashboards, trend analysis, decision support	Power BI

3.1 Module 1: Hardware and IoT Module

A. Smart Dustbin Prototype: An HC-SR04 ultrasonic sensor is mounted at the top of the dustbin,

facing the waste surface. It emits ultrasonic pulses and measures the time t taken by the echo to return, from which the distance d between the sensor and the waste is obtained as

$$d = v \times t / 2 \quad (1)$$

where v is the speed of sound.

B. Circuit Connections: The sensor VCC pin is connected to the ESP32 5V/VIN pin and GND to the common ground. TRIG is connected to GPIO 5 and ECHO to GPIO 18. Because the HC-SR04 ECHO output is 5 V while the ESP32 GPIO pins operate at 3.3 V, the ECHO line passes through a voltage divider of 10 kΩ and 20 kΩ resistors, which reduces the signal to about 3.3 V (Figure 2).

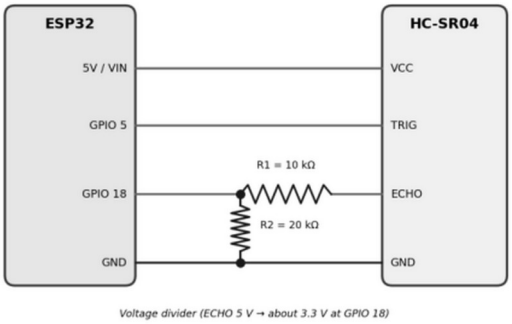


Figure 2. Circuit diagram of the smart dustbin: the HC-SR04 sensor is connected to the ESP32, with a 10 kΩ and 20 kΩ voltage divider on the ECHO line.

C. Waste-Level Calculation: If H is the bin height (the distance from the sensor to the bottom of the empty bin) and d is the measured distance, the waste level is calculated as

$$\text{Waste Level (\%)} = [(H - d) / H] \times 100 \quad (2)$$

D. ESP32 Processing: The ESP32 reads the sensor at periodic intervals, calculates the waste percentage and classifies the bin as Empty, Medium, Almost Full or Full according to predefined thresholds. The limits between the status levels are fixed during calibration and testing.

E. Wi-Fi Communication: The ESP32 sends the processed readings through its built-in Wi-Fi to a server-side application, which stores them in the MySQL database. A reliable Wi-Fi connection is therefore required at the place of installation.

3.2 Module 2: Database Module

A. Database Design: MySQL is used to store the current dustbin information and the historical collection records in two separate tables.

B. Dustbin Details Table: This table stores the Bin ID, location, bin height, measured distance, waste level (%), bin status and the date and time of the last update.

C. Collection Records Table: This table stores the record ID, Bin ID, location, the waste level before and after collection, the collection date and time, and the collection status.

D. Relationship Between Tables: The Bin ID links each collection record to the corresponding dustbin. One dustbin can have many collection records (a one-to-many relationship).

E. Data Management: The server-side application updates the current readings and stores the collection history. This data is used by the web application and by Power BI.

3.3 Module 3: Web Application Module

A. Website Development: The website is developed with HTML5 for the page structure, CSS3 for the design and JavaScript for user interaction and data presentation.

B. Dustbin Monitoring: The website displays the Bin ID, location, waste level and current status of each dustbin.

C. Alert Management: Alerts are displayed when a dustbin reaches predefined thresholds, such as 80% or 90% full, to indicate that collection is required.

D. Collection History: Users can view previous collection dates, the waste levels before and after collection, and the collection status, so that staff can check when a bin was last emptied.

E. Database Connectivity: A server-side API connects the website to the MySQL database, so that database credentials are not exposed in client-side JavaScript.

3.4 Module 4: Data Analytics and Power BI Module

A. Data Integration: The dustbin details and collection records are provided to Power BI through a supported database connection or a data-export process.

B. Dashboard Development: Power BI is used to create charts and dashboards that show current bin statuses, waste levels and collection activities.

C. Data Analysis: The historical data is analyzed to identify high-waste locations, collection frequency and waste-level trends.

D. Decision Support: The analysis helps to prioritize full dustbins, improve collection schedules and reduce unnecessary collection trips, so that collection is planned according to the actual waste level instead of a fixed schedule.

The prototype is planned with an ESP32 development board, an HC-SR04 sensor, a breadboard, jumper wires, 10 kΩ and 20 kΩ resistors for the voltage divider, a USB cable, a power supply and a small dustbin model. Software tools are the Arduino IDE for ESP32 programming, Visual Studio Code for web and server-side development, MySQL and Power BI. Testing uses web browsers, the Arduino Serial

Monitor and MySQL tools. The work is divided into hardware development, database development, website development, data analysis and system testing, and is carried out in the college computer and project laboratories.

IV. EXPECTED BENEFITS AND EVALUATION PLAN

4.1 Expected Benefits

Based on the design and the literature, the system is expected to: provide real-time information about the waste level of dustbins; reduce manual inspection of bins; reduce overflowing waste by giving timely alerts for full and almost-full bins; allow collection to be planned according to the actual status of the bins, which reduces unnecessary trips and saves time, fuel and manpower; support data-based planning through stored history and Power BI analysis; and contribute to cleaner surroundings in smart-city waste management. These are design goals, not measured results.

The system can be useful wherever waste collection is required: colleges and schools, hospitals, residential societies, public places such as parks, markets, bus stands and railway stations, offices and commercial areas, and municipal waste management.

4.2 Planned Evaluation

After implementation, the system will be evaluated on the following measures:

- Waste-level accuracy of the HC-SR04 sensor.
- Successful transmission of sensor data from the ESP32 to the database.
- Response time from sensor reading to display in the web application.
- Loading and response time of the web application and storage and retrieval time of the database.
- Correct generation of alerts when the waste level reaches a high or critical level.
- Reliability during continuous operation and the error rate of sensor, communication, database and website operations.
- Clarity of the Power BI charts and reports, and the ability of the system to identify bins that require collection.

4.3 Feasibility and Scope

The project is technically feasible because it uses commonly available technologies: ESP32, the HC-SR04 sensor, Wi-Fi, MySQL, HTML, CSS, JavaScript and Power BI. It is economically feasible because the prototype needs only low-cost hardware, and operationally feasible because the web application shows waste-level information without continuous manual inspection. The required computers, software, hardware and laboratory facilities are available, and the work can be completed in the available time by dividing it into hardware, database, website, analysis and testing tasks. The system also supports environmental cleanliness by enabling timely collection. Its limitations are that the prototype uses a small dustbin model, depends on a Wi-Fi connection, and does not yet include mobile applications, GPS-based collection planning or predictive analytics.

V. CONCLUSION

This paper proposed the Smart Waste Management System, an IoT-based system that measures the waste level of dustbins with an HC-SR04 ultrasonic sensor, processes it on an ESP32, sends it over Wi-Fi to a MySQL database, displays bin details, alerts and collection history in a web application, and analyzes the data with Power BI. The six-module design lets each stage be developed, tested and improved independently and uses low-cost hardware and widely available software, so it can serve as a practical and scalable prototype for waste monitoring.

Future work includes completing the implementation, evaluating the system as planned in Section IV, and adding mobile applications, GPS-based collection planning, automated notifications and predictive data analytics.

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