

AI And IOT Based Smart Waste Management System

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Abstract— The rapid growth of urban populations has placed significant pressure on traditional waste management systems, leading to inefficiencies such as premature waste collection, overflowing bins, and environmental hazards. This paper presents a smart waste management system leveraging Internet of Things (IoT) and Artificial Intelligence (AI) technologies to optimize waste collection. The system integrates ultrasonic sensors for real-time waste level monitoring, load cells for weight measurement, and gas sensors (MQ-2) for hazardous gas detection. Data from these sensors are transmitted via Wi-Fi to cloud platforms (ThingSpeak and Blynk) for remote monitoring and decision-making. An AI model hosted on a FastAPI server analyzes the data to predict optimal collection times, reducing unnecessary pickups. Experimental results demonstrate the system's reliability in real-time monitoring, with accurate sensor measurements and timely notifications. The proposed solution enhances operational efficiency, reduces costs, and supports sustainable urban development.

Keywords— Smart waste management, IoT, AI, real-time monitoring, sustainability, Arduino MKR 1000, Sensors, Blynk App, Thingspeak

I. INTRODUCTION

With the rapid growth of urban populations, managing municipal waste efficiently has become increasingly complex. Traditional systems, often based on fixed schedules, frequently result in premature or delayed collections, leading to overflowing bins, fuel wastage, and health hazards. Emerging technologies such as IoT and AI offer promising solutions by enabling real-time monitoring and intelligent decision-making.

This research focuses on building a prototype smart waste management system designed to automate and optimize waste collection operations using real-time sensor data and AI algorithms. The system aims to improve operational efficiency, reduce environmental impact, and align with smart city goals.

II. RELATED WORK

The increasing challenges of urban waste management have prompted significant research into IoT-based and AI-enhanced solutions. This section surveys six key studies that inform and contextualize the development of our system.

Beena et al. [1] proposed an IoT-based waste management and segregation system where smart bins are equipped with ultrasonic sensors and ESP32 microcontrollers. Their model integrates machine learning algorithms to classify waste into categories such as dry, wet, and metallic, in addition to real-time bin monitoring. Alerts are generated automatically once predefined thresholds are exceeded, enabling responsive waste collection. The

inclusion of AI for segregation enhances operational precision and promotes environmental sustainability.

Tanveer et al. [2] developed a smart waste management framework using ESP8266 microcontrollers, moisture sensors, and IR sensors. Their system distinguishes between wet and dry waste and communicates bin status to waste management authorities via GSM modules. Real-time alerts and an LCD interface allow for streamlined monitoring and quicker response times. The focus of this work is on improving operational efficiency while minimizing manual supervision.

Manasa et al. [3] addressed disorganized garbage collection in urban environments through an IoT-enabled system that employs IR sensors, soil moisture sensors, and ultrasonic distance sensors to monitor and categorize waste. Data is transmitted to the ThingSpeak cloud platform and alert notifications are sent via IFTTT. This project emphasizes decentralized data collection and multi-sensor waste differentiation, offering a low-cost, scalable approach.

Tejashree et al. [4] introduced the concept of the “Smart Netbin,” which rewards users with limited-time internet access for proper waste disposal. This innovation leverages Wi-Fi integration and sensor technologies to incentivize cleanliness in public spaces. It adds a behavioral component to technical monitoring, contributing to public hygiene and pollution reduction, particularly in developing nations.

Nitin Kumar [5] proposed a comprehensive system combining real-time monitoring with data analytics. This model uses sensors for fill-level detection and automated waste classification. Through the application of cloud-based communication and microcontrollers, the system aims to optimize waste pickup schedules, reduce operational costs, and improve service delivery. It demonstrates a full lifecycle approach to waste monitoring and intervention.

Srikanth et al. [6] designed a system using LoRa and MQTT communication protocols to connect smart bins to a cloud platform. The bins are equipped with weight sensors and the data collected informs predictive routing and timely collection. Although the system requires robust connectivity infrastructure, it successfully minimizes manual oversight and supports environmentally conscious urban planning.

All the referenced works focus on improving waste collection efficiency through IoT-based sensing and alert mechanisms. However, only a few integrate AI for decision-making, and fewer still implement a combination of gas, weight, and ultrasonic sensors. Our system distinguishes itself by integrating all three sensor types and leveraging AI via cloud-based FastAPI models for predictive analysis.

III. SYSTEM DESIGN

The proposed smart waste management system is architected around an integration of hardware sensors, microcontroller platforms, cloud communication services, and artificial intelligence algorithms to create a responsive and intelligent solution for waste monitoring. At the core of the system is the Arduino MKR WiFi 1000 board, selected for its compact form factor and built-in Wi-Fi capabilities, which enable seamless data transmission without additional communication modules. The sensing subsystem comprises three key components: an ultrasonic sensor for measuring the fill level of waste bins, a load cell coupled with the HX711 amplifier for accurate weight measurement, and an MQ-2 gas sensor for detecting the presence of hazardous gases such as methane or carbon monoxide, which are often emitted by decomposing organic waste.

Data collected by these sensors is sampled at five-second intervals and processed locally by the Arduino. The processed data is then transmitted to two cloud platforms—Blynk and ThingSpeak—for real-time monitoring and visualization. Blynk provides mobile app-based notifications and interactive dashboards, allowing waste management personnel to receive immediate alerts based on sensor thresholds. ThingSpeak serves as a data analytics and visualization platform, storing historical sensor readings and enabling long-term trend analysis.

To enhance the decision-making process, the system also interfaces with a FastAPI-based AI server hosted in the cloud. The sensor data is serialized into JSON format and securely transmitted via HTTPS to the API endpoint. The server runs Support Vector Machine (SVM) models trained to evaluate bin conditions and classify the required action as either "Take" (indicating the bin should be emptied) or "Keep" (indicating it is not yet necessary). Additionally, the AI model includes a gas toxicity classifier that labels the environmental condition as "Normal," "Full," or "Toxic." These models consider combined sensor inputs such as gas concentration (ppm), fill level (distance in cm), and weight (grams) to make context-aware predictions.

The operational workflow of the system begins with initialization and Wi-Fi connection, followed by periodic data acquisition and condition evaluation. When sensor thresholds are exceeded—e.g., gas level above 400 ppm, fill distance below 6 cm, or weight over 1500 grams—the system triggers alerts via Blynk and sends the data to the AI model for verification. Based on the AI response, appropriate actions are logged and visualized in the user interface. The system's design emphasizes modularity, low power consumption, and scalability, making it suitable for deployment in university campuses, residential areas, or as a foundational prototype for city-wide smart waste management networks.

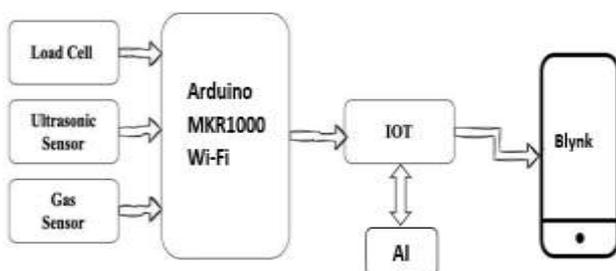


Fig. 1. Block diagram of Domotics using Google Assistant



Fig. 2. Hardware setup

IV. IMPLEMENTATION AND RESULTS

The prototype smart waste management system underwent rigorous testing to evaluate its effectiveness, responsiveness, and overall performance across various operational parameters. Each component—sensors, microcontroller, cloud platforms, and AI model—was individually validated and assessed in integrated operation.

The ultrasonic sensor consistently provided accurate fill-level readings within a 1–2 cm margin of error, effectively detecting distance variations that indicate the trash level inside a bin.

The load cell, interfaced via the HX711 module, demonstrated reliable weight measurement capabilities across a range of simulated waste conditions. After initial calibration, the system could detect even small changes in load, with readings stable under repeated trials.

The MQ-2 gas sensor successfully identified elevated concentrations of gases such as methane and smoke, triggering alerts when values exceeded 400 parts per million (ppm), the defined threshold for potential hazard.

Connectivity was another critical area of assessment. The Arduino MKR WiFi 1000 ensured stable wireless communication throughout testing, successfully transmitting data to the Blynk and ThingSpeak platforms without significant packet loss or lag.

The ThingSpeak platform simultaneously logged all sensor data, facilitating visualization through time-series graphs and supporting historical trend analysis. This dual-platform integration enhanced redundancy and user accessibility.

On Blynk, sensor values were updated in near real-time and displayed on virtual pins, with event-based notifications being pushed instantly to registered mobile devices. These alerts included messages such as "Gas detected in the trash can! Immediate attention required" ensuring timely responses from waste collection personnel.

A key innovation of the system—the integration of an AI model hosted via FastAPI—was evaluated based on its classification accuracy and response time. The model was tested against multiple combinations of sensor readings to determine whether a bin required immediate servicing. It effectively categorized inputs into actionable outcomes such as "Take" or "Keep" for bin status, and "Toxic" or "Normal" for environmental assessment. Despite being

hosted on a free-tier cloud service with occasional startup delays, the AI server consistently responded to POST requests within 60–80 seconds, providing clear, interpretable predictions. For example, in a scenario with a gas level of 400 ppm, a distance of 5 cm, and a weight of 30 Kg, the AI correctly predicted a "Take" action and labelled the situation as "Toxic," aligning with pre-established rules.

Overall, the integrated system proved stable, reliable, and effective over extended operational periods. The embedded logic and AI model worked in harmony to assess sensor data, trigger alerts, and reduce false positives. Importantly, the automation reduced reliance on manual monitoring while ensuring environmental safety and collection efficiency. These outcomes support the system’s potential scalability for use in public infrastructure, aligning with broader smart city and sustainability goals.

The Figures below show the testing of each module:

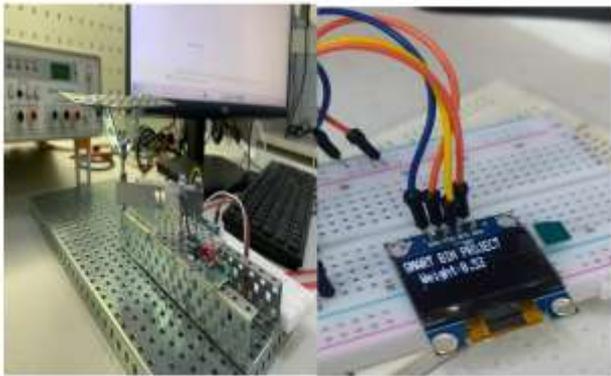


Fig. 3. Testing of Load Cell and OLED Display

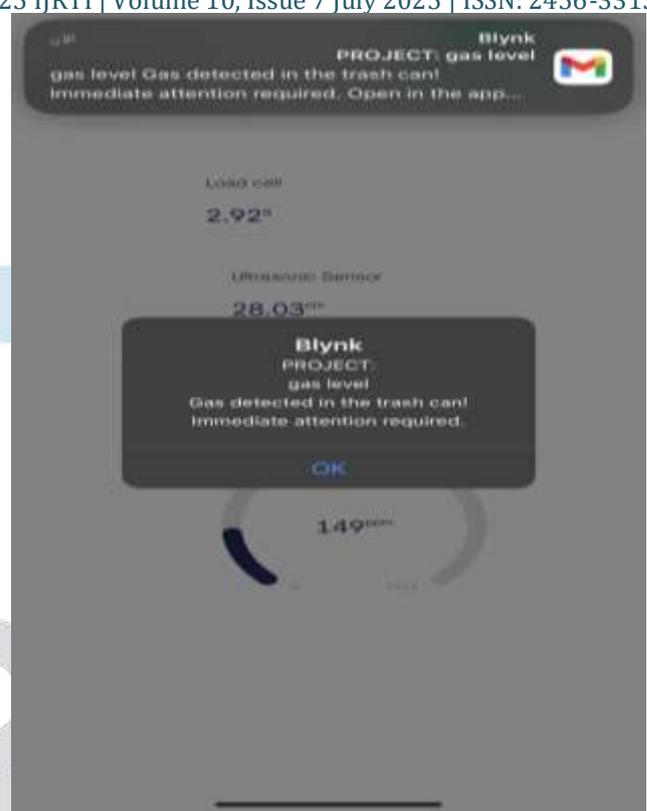


Fig. 5. Notification on Mobile from Blynk



Fig. 4. Results on ThingSpeak

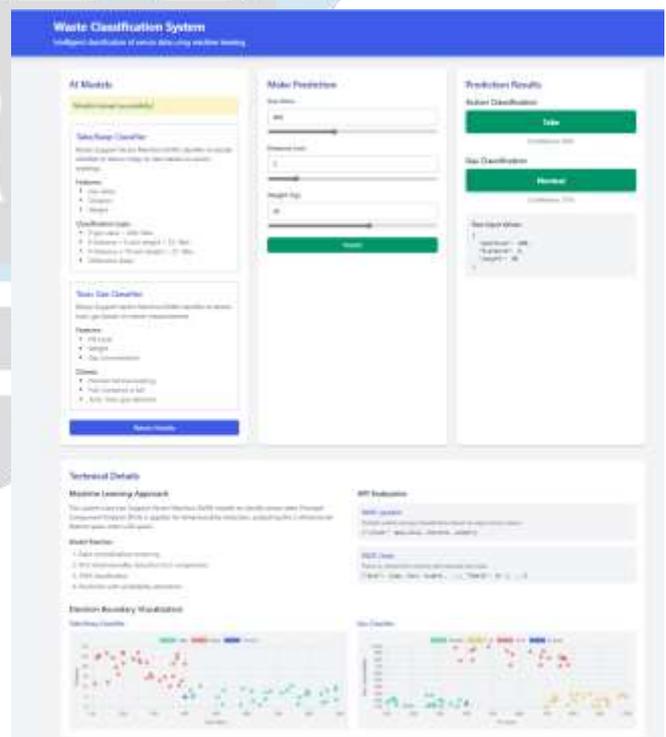


Fig. 6. AI Website

V. CONCLUSION AND FUTURE WORKS

This study presented the design, implementation, and evaluation of an AI- and IoT-based smart waste management system aimed at addressing the limitations of traditional waste collection methods. By integrating ultrasonic sensors, load cells, and gas sensors with the Arduino MKR WiFi 1000 microcontroller, the system successfully enabled real-time monitoring of trash bin status in terms of fill level, weight, and hazardous gas emissions. The incorporation of cloud platforms such as Blynk and

ThingSpeak facilitated seamless visualization and alert generation, while a FastAPI-based AI server provided intelligent classification of bin conditions to guide timely decision-making. The system demonstrated stable performance, accurate sensing, and effective communication, proving its viability as a scalable and cost-efficient solution for urban environments seeking to enhance waste management through automation and data-driven approaches.

The use of machine learning, specifically Support Vector Machines (SVM), added a predictive dimension that distinguished this system from earlier IoT-only implementations. It enabled the automatic classification of bins into categories such as “Take” or “Keep,” and environmental states like “Normal” or “Toxic,” based on real-time sensor inputs. These capabilities collectively reduce operational inefficiencies, lower environmental risks, and promote more sustainable urban living.

Looking ahead, several enhancements are proposed to further increase the system’s robustness and functionality. Firstly, integrating solar-powered modules would reduce dependency on external power sources and improve system sustainability. Secondly, deploying edge computing techniques could reduce latency and enable local AI inference, especially useful in areas with unreliable internet access. Thirdly, expanding the system to support mobile user interfaces for public engagement—such as enabling citizens to report bin tampering or illegal dumping—would enhance community involvement. Moreover, retraining the

AI models using deep learning techniques and a more extensive dataset could improve classification accuracy and enable the system to adapt to diverse waste environments. Lastly, large-scale field trials across different municipalities and smart city projects would validate the system’s scalability and long-term operational impact.

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