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An IoT-Based Smart Garbage Monitoring System for Solid Waste Management in Urban Environments

Tushar Garg, Vivek Anand, Aditya Kumar, Anand Krishna
Ms. Ritu Juneja, Ms. Gaganpreet Kaur
Ganga Institute of Technology & Management, Kablana

Abstract: *Rapid urbanization and high housing demands have led to significant challenges in municipal solid waste management, resulting in overflowing public dustbins, environmental pollution, and heightened health risks from vector-borne diseases. This paper presents an automated, Internet of Things (IoT)-based* ***Garbage Monitoring System*** *designed to replace traditional static waste collection bins with intelligent, real-time tracking nodes. Built upon the open-source* ***ESP8266 NodeMCU*** *microcontroller framework, the system incorporates an* ***HC-SR04 ultrasonic sensor*** *mounted beneath the bin lid to measure garbage volume percentages continuously. When the waste depth crosses a predefined threshold, telemetry data is localized on a 16x2 character Liquid Crystal Display (LCD) and transmitted via HTTP POST requests over Wi-Fi to a remote web server. Prototype testing validates the system's capacity to optimize collection routes, reduce human resource overhead, and prevent roadside accumulation, directly contributing to "Smart Cities" initiatives and public health frameworks.*

Keywords: *Rapid urbanization*

I. INTRODUCTION

With modern migration patterns shifting heavily from rural sectors to urban apartment complexes, municipal infrastructure frequently struggles under the weight of accelerated domestic waste generation. In many developing nations, the infrastructure supporting solid waste management remains unoptimized, characterized by overflowing public bins that sit untreated for extended periods due to lack of municipal oversight [1-3]. This unchecked piling up of organic and industrial wastes produces severe environmental crises: noxious odors, groundwater contamination via untreated landfill leachate, and ideal breeding conditions for disease vectors carrying dengue, cholera, or malaria.

To modernize waste networks, this project introduces a real-time, independent waste tracking framework. The primary objectives are:

Automate level tracking within individual public bins to facilitate an on-demand collection schedule rather than relying on fixed, inefficient collection routes.

Minimize labor overhead and route logistics costs while driving architectural models designed for clean, responsive municipal environments.

The primary objective is to automate level tracking within individual public waste bins using sensors and IoT connectivity. This enables **on-demand waste collection scheduling**, replacing traditional fixed-route systems that are often inefficient and resource-intensive [4-5].

II. THEORETICAL BACKGROUND AND RELATED LITERATURE

Solid waste routing represents a major public expenditure that historically receives scant analytical attention. Amponsah and Salhi [2004] examined these operations through a class of capacitated arc routing heuristics tailored for

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developing regions, confirming that hot weather conditions worsen the environmental hazards of delayed trash collection [6].

Recent electronic frameworks have shifted toward microcontrollers to address these issues. Abdurahman et al. [2018] designed an automated waste monitor using an Arduino processor paired with a GSM communication shield. That implementation focused on a local Graphic User Interface (GUI) to alert drivers when a bin reached capacity, combined with a Passive Infrared (PIR) sensor and audio speaker to physically block citizens from throwing garbage into an already overflowing bin [7].

This project expands on these methods by using an integrated Wi-Fi System-on-a-Chip (SoC) to upload operational telemetry directly to web dashboards, creating a compact, solar-adaptable system architecture.

III. SYSTEM ARCHITECTURE AND HARDWARE SPECIFICATIONS

The smart bin hardware matrix is divided into three processing modules: the core computation block, the telemetry acquisition block, and the local/cloud user interfaces.

3.1 Control and Compute Engine

NodeMCU ESP8266 SoC: The core processor is an open-source hardware-software development unit built on the low-cost ESP8266 core. It includes a Tensilica CPU running at a clock speed of 80 MHz, 64 KB of SRAM, 4 MB of flash memory, and an onboard CP2102 USB-TTL interface for quick plug-and-play prototyping. It processes physical calculations while managing network handshakes over standard Wi-Fi protocols.

3.2 Telemetry Acquisition Unit

HC-SR04 Ultrasonic Module: This sensor contains an ultrasonic transmitter and receiver working at 40kHz. It has an effective sensing range from 2 cm to 450cmwith an accuracy profile down to 3 mm. The module is mounted at the highest nterior point of the bin lid, pointing downward toward the accumulation zone.

3.3 Power and Interface Modules

Power Optimization Group: Features dual 3.7V Lithium-Ion storage batteries matched with a TP4056 protective charging board, a solar collection panel, and a 7805 voltage regulation IC to provide a steady +5VDC bus across the peripherals.

I2C Liquid Crystal Display: A 16x2 pixel-grid visual display paired with a serial I2C adapter to compress data connections down to four structural paths (`Vcc`, `Gnd`, `SDA`, and `SCL`).

IV. SYSTEM METHODOLOGY AND WORKING MECHANISM

4.1 Ultrasonic Volumetric Calculation

The distance calculation is governed by the time of flight of an ultrasonic pulse. The NodeMCU initializes measurement by bringing the `Trig` pin high for 10s, driving an eight-cycle sonic burst through the air. When this wave encounters an obstruction, it bounces back toward the receiver module, forcing the `Echo` output pin high for a duration corresponding directly to the wave's round-trip travel time. The target distance is modeled using the equation:

$$\text{Distance} = \frac{\text{Time} \times \text{Speed of Sound}}{2}$$

Given that the speed of sound is approximately 340 m/s (or $0.034\text{ cm/}\mu\text{s}$), the absolute depth is extracted via:

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$$\text{Distance (cm)} = \frac{\text{Duration } (\mu s) \times 0.034}{2}$$

4.2 Local and Cloud Data Processing

The system uses the calculated distance d against the known total bin height (H_total = 27cm to scale the remaining capacity into an accumulation percentage:

Garbage Level (%) =Map}(d, H_{total}, 0, 0, 100

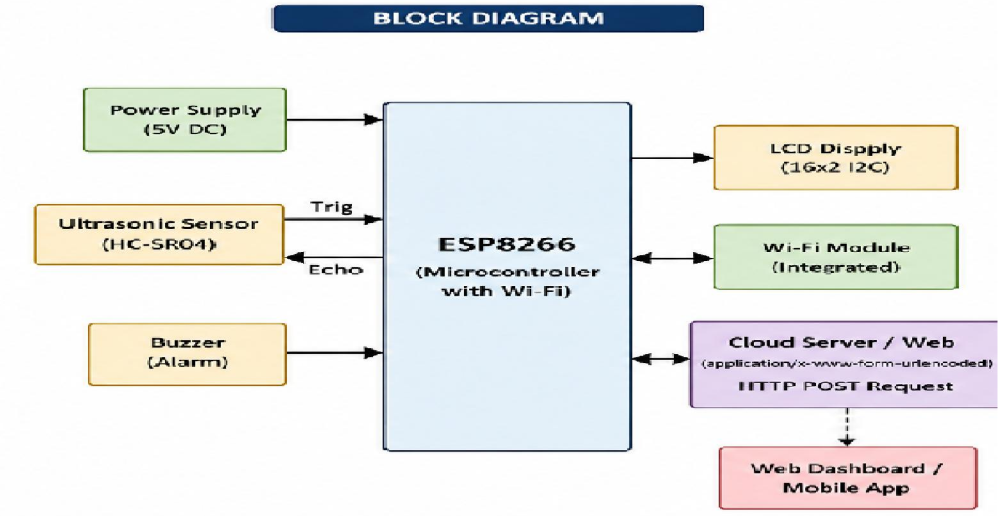
If the remaining headroom distance falls below a set threshold, the microcontroller confirms the bin is full, prints a local alert message across the LCD module, and activates an acoustic buzzer warning node.

Concurrently, the NodeMCU packages this accumulation data into an structured HTTP POST body payload:

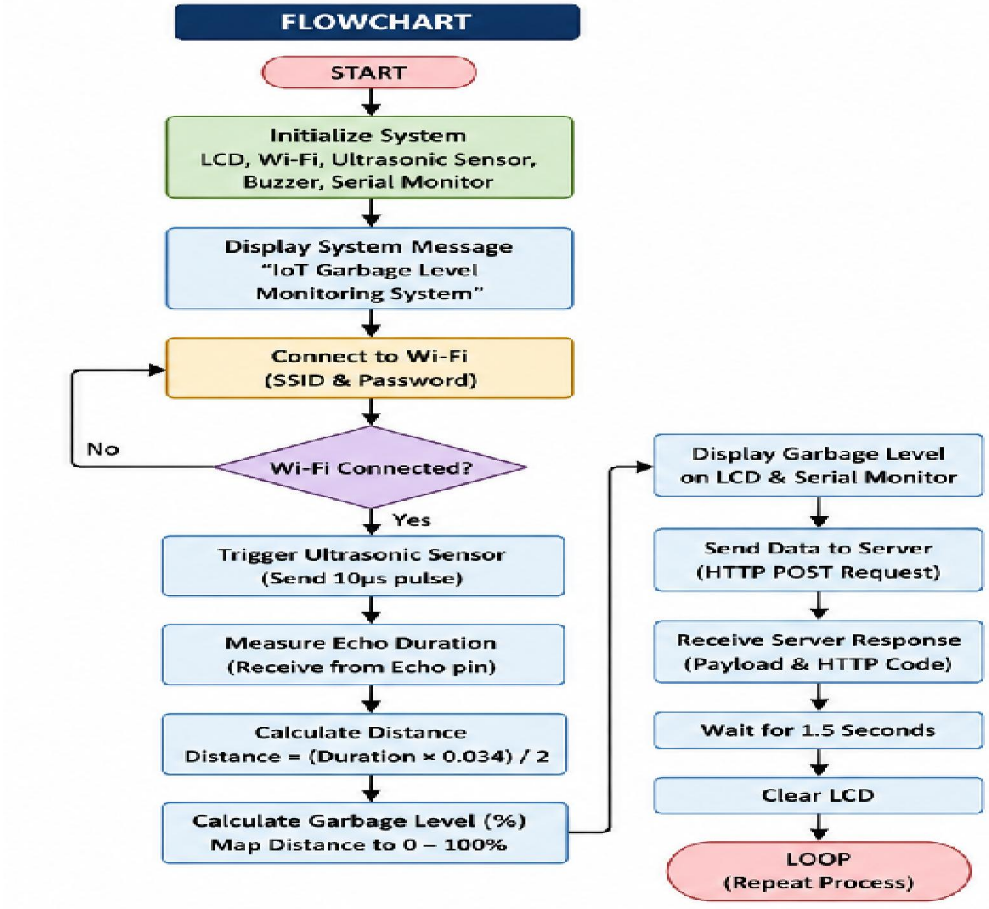
`id=garbagelvl%`

V. PROPOSED ALGORITHM

The system logic was engineered using the Arduino IDE environment. The proposed algorithm, handling data capture and network execution loops is detailed below:



The proposed IoT-based garbage monitoring system is designed to enable **real-time, automated waste level detection and remote monitoring**, thereby improving the efficiency of municipal waste collection. The system integrates an ultrasonic sensor to continuously measure the fill level of the bin, while the ESP8266 microcontroller processes this data and enables wireless communication. The inclusion of a Wi-Fi module allows transmission of data to a cloud server, where it can be visualized through a web dashboard or mobile application for decision-making. Additionally, the LCD display provides local status updates, and a buzzer offers an alert mechanism when the bin reaches a critical level. This architecture ensures reduced manual intervention, optimized collection scheduling, and supports the development of smart and sustainable urban waste management systems.



The flowchart represents the systematic working of the IoT-based garbage monitoring system, illustrating how real-time sensing, processing, and communication are integrated into a continuous operational cycle. The process begins with system initialization, where all hardware components such as the ultrasonic sensor, LCD display, Wi-Fi module, and buzzer are configured. Once connected to the network, the system periodically measures the garbage level using ultrasonic sensing, computes the fill percentage, and displays it locally. Simultaneously, the processed data is transmitted to a remote server using HTTP protocols for cloud-based monitoring. The inclusion of response handling and delay ensures stable communication, while the looped execution enables continuous, real-time tracking. This structured workflow ensures reliable data acquisition, efficient monitoring, and timely decision-making for smart waste management.

VI. TESTING, RESULTS, AND DISCUSSION

6.1 Testing Environment and Results

System verification proceeded across software compilation validation and hardware test vectors. Sensor calibration parameters were cross-checked using manual tape measurements to verify data accuracy.

Target Accumulation Metric Verified during Loop Cycles	
Distance to Object (cm)	Computed Garbage Volume Level (%)
27CM	0%
14CM	48%

2CM	92% (Alert level)

6.2 Key Structural Advantages

Resource and Fuel Optimization: Minimizes structural transit runs to distant municipal zones by steering collectors exclusively toward active filled nodes.

Hygiene and Public Health Preservation: Prevents trash overflows, helping mitigate urban odor issues and insect-borne disease vector pools.

Cost-Efficient, Scalable Build: Relies on affordable, standard electronics components, making it accessible for deployment across university campuses, public parks, and hospitals.

VII. CONCLUSION AND FUTURE SCOPE

7.1 Conclusion

The developed IoT-based Garbage Monitoring System provides an effective, automated alternative to traditional, static waste collection frameworks. By enabling remote monitoring of fill levels, the system cuts down municipal inefficiencies, prevents roadside dumping, and advances smart-city infrastructure goals. However, broad public deployment requires community education to protect these delicate sensor modules from physical damage or vandalism during daily use.

7.2 Future Scope

Future improvements can expand on this foundation by deploying multiple networked bins tracked via a centralized GPS-mapped dashboard. To improve material recycling workflows, the system can integrate capacitive and inductive sensors at the bin openings to automatically segregate waste streams into dry, wet, or metallic categories at the point of disposal.

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