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Development of Internet of Things (IoT) Based Waste Management System

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ABSTRACT

In response to the global challenge of improper waste disposal and solid waste management an Internet of Things (IoT)-based waste management system was developed to address the challenge of inappropriate garbage disposal. Three systems were designed using ultrasonic sensors connected to NodeMCU to measure garbage levels in bins. Data was transmitted to an online database via Firebase and an Android app was developed to display real-time information on a Google Map. Bins exceeding 70% capacity were highlighted in red color and green color otherwise. The system provided efficient, real-time waste management, allowing users to access information remotely, locate nearby bins, and contribute to improved cleanliness and sanitation in urban areas.

INTRODUCTION

The Internet of Things (IoT) has become an essential tool in today's human lifestyle, offering advanced connectivity of devices, systems, and services beyond machine-to-machine communications. IoT devices include heart monitoring implants, biochip transponders, electric clams, automobiles, and field operation devices. Current market examples include smart homes and cities (Chowdhury *et al*., 2007). As urbanization increases, waste production has increased, making waste management services crucial in Nigeria.

Waste management involves collection, transport, treatment, disposal, monitoring, and regulation, as well as legal and regulatory frameworks. Waste management deals with all types of waste, including industrial, biological, household, and special cases that threaten human health. The traditional manual waste collection process is complex and time-consuming, making it unsuitable for modern technologies. A waste management system uses an IoT Garbage Monitoring System to monitor and manage waste with minimal human interaction. The system uses sensors to categorize garbage and detect levels using ultrasonic sensors. It operates on solar energy and sends records to higher authorities if dustbins are not cleaned within a specified time. This system also helps reduce corruption and overflow of dustbins, reducing filling and cleaning time (Bashir *et al*.,2013).

In this paper, IoT-based waste management addresses environmental concerns, optimizes resource allocation, improves service delivery, ensures public health, aligns with smart city initiatives, and enables data-driven decision-making for sustainable communities. (Chowdhury and Chowdhury 2007) proposed "pay as you throw" weight-based billing for waste collection to encourage waste reduction. This system integrates load sensors and RFID technology in smart waste management. Load sensors measure bin weight, enabling accurate tracking of waste generation by associating sensor data with residents' RFID tags.

Bashir *et al*. (2013) introduced a system incorporating load sensors, an infrared proximity sensor, and an RF transmitter in a Smart Trash Bin. This system enables automatic garbage detection, real-time monitoring, and communication, addressing overflow issues. Folianto *et al*. (2015) utilized ultrasonic sensors and a wireless mesh network for data collection in their Smart Bin system. They highlighted operational insights and power efficiency but noted connectivity risks and scalability challenges with mesh networks.

Nataraj and Meghana (2016) introduced a system using infrared and gas sensors for waste level monitoring and toxic gas detection, aiming for cleaner environments but emphasizing the importance of sensor maintenance. This innovation enhances data collection efficiency through a dedicated mobile app, facilitating the real-time acquisition of crucial information. The app enables seamless communication between sensors and the central repository, improving understanding of waste bin utilization patterns. Its user-friendly interface empowers personnel to efficiently manage and monitor data, expediting decision-making on collection schedules and resource allocation.

METHODOLOGY

Hardware Design

The IoT-based waste management system incorporates three smart bins equipped with ultrasonic sensors to monitor waste levels. These sensors measure the distance to the waste and relay the data to a NodeMCU microcontroller. The NodeMCU connects to the internet through the ESP8266 WiFi module, enabling real-time data transmission to an online Firebase database. This system architecture seamlessly combines both hardware and software components to create an efficient and intelligent waste management framework. Figure 1 illustrates the generalized block diagram of the IoT-based smart bin. The system incorporates the following hardware components:

Ultrasonic Sensor

This was utilized for measuring garbage levels within the waste bins. Ultrasonic waves emitted by the sensor bounce off the surface of the garbage, and the time taken for the waves to return is analyzed to determine the garbage level accurately. The sensor is connected to the NodeMCU microcontroller for data acquisition and processing.

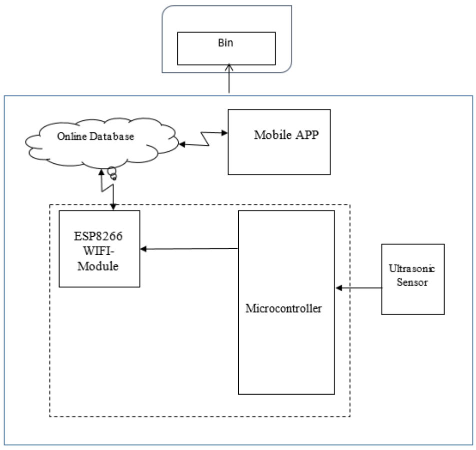

Figure 1: The Generalized Block Diagram of Iot Based Smart Bin

NodeMCU Microcontroller

This is an open-source firmware and development board designed for IoT applications. It collects garbage-level data from the ultrasonic sensor and transmits it to an online database. Equipped with an ESP8266 WiFi module, the NodeMCU facilitates wireless communication. The microcontroller offers various features such as GPIO pins, analog inputs, UART, I2C, SPI interfaces, and USB for power supply and programming. Programming is done using the Arduino IDE. The hardware and software components were harmoniously integrated to establish a framework for efficient waste management. The system design ensures seamless communication between the ultrasonic sensors, NodeMCU microcontroller, internet gateway, online database, and mobile application. The waste management system's circuit diagram in Figure 2 illustrates the Circuit Diagram of Iot Based Smart Bin showing the connections between all components. It depicts how the ultrasonic sensor, NodeMCU microcontroller, and WiFi module are interconnected to monitor garbage levels, process data, and transmit it to the online database.

The hardware implementation of the project involves four stages: Implementation on Solder-less Board: The initial phase involves setting up the system on a solder-less experimental board. Components including the NodeMCU, ultrasonic sensor, and WiFi module are interconnected on the breadboard. The ultrasonic sensor is connected to the NodeMCU's digital I/O pins, while the NodeMCU is linked to the WiFi module for internet connectivity. Resistors, capacitors, and power sources are integrated to ensure voltage regulation and stability. Once the functionality is confirmed on the solder-less board, components are soldered onto Vero boards for permanent connection as in Figure 3 showing the Breadboard connection of the IoT-Based Waste Management System. Key components like the ultrasonic sensor and NodeMCU are securely soldered to ensure proper functionality. The NodeMCU facilitates distance measurements and data transmission to the online Firebase database. Extensive testing and adjustment are conducted to ensure optimal functionality and performance. Various sections of the system are tested to guarantee seamless operation.

Software Design

The software components of the system include:

Online Database (Firebase)

This was utilized for storing waste management data. Firebase serves as a centralized repository for garbage-level information, enabling real-time monitoring and efficient waste management. The NodeMCU sends data to Firebase for storage, retrieval, and analysis.

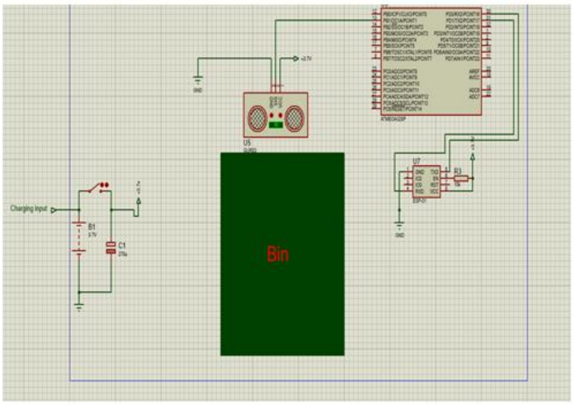

Figure 2: Circuit Diagram of IoT Based Smart Bin

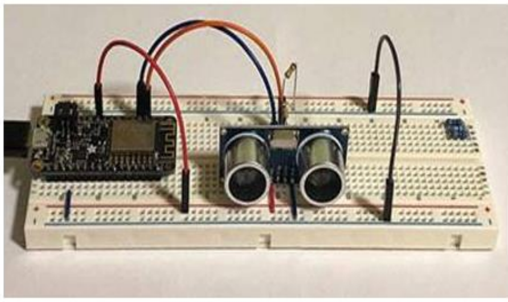

Figure 3: Breadboard connection of the IoT-Based Waste Management System

Mobile Application (Flutter)

This was developed to provide a user-friendly interface for managing the waste management system. The application retrieves garbage-level data from Firebase and presents it on Google Maps. It enables users to tap on bins for detailed information and employs dynamic color coding to indicate garbage levels.

The development of the mobile application involves utilizing the Flutter framework for compatibility with Android devices. The application integrates with other system components and employs the Google Maps API to display waste bin locations as in Figure 4 showing the Map page of the app. It implements dynamic color coding to indicate garbage levels and offers features for efficient waste management. Data collection involves monitoring garbage levels using ultrasonic sensors and transmitting the data to the online Firebase database. The data is then analyzed to identify trends and patterns in waste generation and disposal.

RESULTS AND DISCUSSION

In the IoT-based waste management system, successful implementation of data collection and visualization was achieved. The mobile application, developed using Flutter, retrieved data from Firebase and presented it on the Google Maps interface. Each waste bin was depicted as an icon on the map, indicating its location. Users could tap on a bin icon to view its garbage level. The system included a color indication feature, changing the color of bins nearing 70% capacity from green to red as shown in Figure 4, aiding in identifying bins requiring attention. The system's data collection and visualization modules provided real-time updates on the fill levels of waste bins, enabling users to make informed decisions regarding waste collection and management. Through a map-based interface, users could quickly identify bins that required emptying, ensuring prompt and efficient waste disposal.

To evaluate the system's performance, various test scenarios—including bin emptying simulations—were conducted. The user interface (UI) was designed for intuitive navigation and featured seamless integration with Firebase for real-time data retrieval.

Figure 4: Map page of the app

Google Maps integration allowed for a clear visual representation of bin locations, while dynamic color coding indicated each bin's current fill status.

Additional management functionalities were incorporated, such as the ability to add new bins (as shown in Figure 5) and remove existing ones (as shown in Figure 6) via the mobile application. These features contributed to a scalable, user-friendly, and efficient waste management system with enhanced accessibility and control.

Figure 5: Bin Adding Page

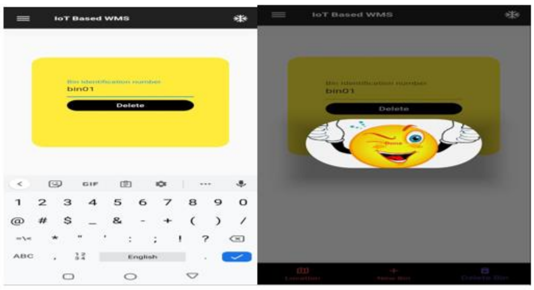

Figure 6: Bin Removal Page

All components of the IoT-Based Waste Management System were packaged and attached to the top of the waste bin for durability and integration as Figure 7 shows the installation of the Ultrasonic sensor in the bin. The hardware, including NodeMCU and the ultrasonic sensor, was mounted inside a sturdy, weather-resistant casing capable of withstanding environmental conditions. The casing was selected to provide ample space for components and easy access to ports. The ultrasonic sensor, vital for measuring garbage levels, was securely positioned for accurate readings and minimal risk of damage. The packaging process ensured the durability, protection, and seamless integration of hardware components with the waste bin. It played a vital role in facilitating accurate garbage level measurements, data transmission to the online database, and the overall efficiency of the waste management system.

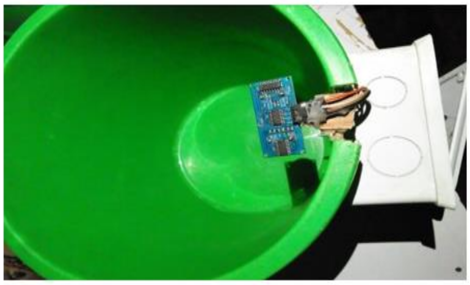

Figure 7: Installation of the Ultrasonic Sensor in the bin

By tapping on the bin icons, users can access detailed information about each bin. The system's performance was assessed through various test scenarios, such as emptying and filling the bins, with real-time updates accurately displayed on both the mobile app and the dashboard, as illustrated in Figures 8 and 9. Table 1 summarizes the bin status and the appearance of the bin on the mobile app.

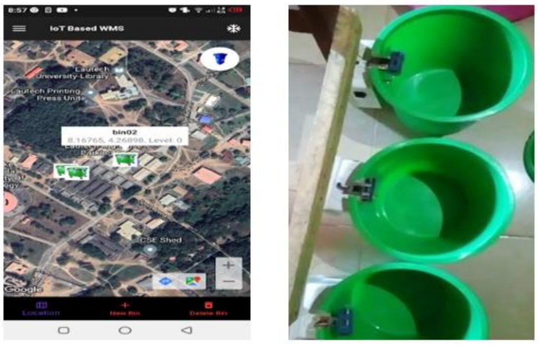

Figure 8: Empty bins and the result from the dashboard

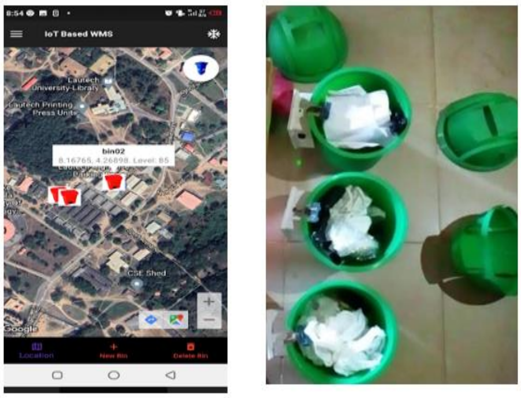

Figure 9: Filled bins and the result from the dashboard

Table 1: Status and the Appearance of the Bin

Status of the bin	Result	Appearance on the Bin
(0%-70%)	Not fill	Green
(70%-100%)	Fill	Red

CONCLUSION

The IoT-Based Waste Management System was developed to address urban waste accumulation issues by monitoring waste bin fill levels in real time. The system utilized an ultrasonic sensor connected to a NodeMCU microcontroller, which transmitted data to a Firebase online database via the internet. An Android application, built using Flutter, provided users with a user-friendly interface to access bin data displayed on Google Maps. The system's components were securely packaged to ensure durability and accurate readings. These enhancements aim to optimize waste management processes and foster cleaner urban environments.

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