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Smart Bin and IoT: A Sustainable Future for Waste Management System in Nigeria

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Highlights

- A web-based application for an Internet of Things-based waste management system is developed.
- Waste bins are tracked in real time using a unique internet protocol address.
- To facilitate data sensing and monitoring, the system model employs a four-layer IoT architecture.
- A system that uses disruptive technology to improve waste disposal efficiency.
- The potential for municipal solid waste-to-energy conversion technology is discussed.

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Keywords

Smart Bin
Internet-of-Things (IoT)
Waste System
Atduino Uno
Bioenergy

Abstract

As waste production is becoming more widely recognized as a significant issue, particularly in developing nations, rising food consumption and population growth have caused environmental degradation and health crises. Nigeria's waste collection and disposal problems are commonly associated with environmental pollution and health crises. Consequently, throwing garbage on roads during environmental sanitation, is a typical method of waste disposal, leading to large piles of refuse along the roadside, which hinders the nation's beauty. Therefore, for Nigeria's waste management system to be effective, sustainable smart bins with efficient Internet of Things (IoT) applications must be quickly adopted to create a green, clean atmosphere within cities. Smart bins with integrated IoT can provide a sustainable future for cities' waste management. This model seeks to develop a low-cost, intelligent waste bin system with IoT technology. Sensors and data sharing over a Wi-Fi network, allow for remote control of the waste bin, leading to improved optimization of the bin's level of waste. The economic benefits of this IoT-based system include remote access for efficient level control, lower labour costs, improved time and energy efficiency, and reduced congestion in waste bins.

1. INTRODUCTION

The economy plays a significant role in municipal waste generation (MWG) in cities around the world [1]–[3]. Global waste generation is increasing rapidly as a result of population growth [4], urbanization [5], rising food consumption rates [6], and industrial growth [7]. These factors contribute significantly to the global waste problem in cities. To address this issue, countries have begun to focus on strategies such as Waste Efficiency (WE) and Waste Management (WM), with particular emphasis being placed on African nations. The main goal of these strategies is to bridge the gap between MWG and disposal, thus making cities more conservative when it comes to solid waste disposal. This includes initiatives such as a smart waste management system, which reduces landfills while also providing economic benefits such as cost savings associated with landfill management. Furthermore, education campaigns are frequently implemented alongside WE/WM efforts to inform people about proper trash disposal methods. Inefficient waste disposal has been viewed as a potential factor contributing to environmental and health-related issues threatening sustainable development in developing countries. Improper management of solid waste can lead to water pollution, air pollution, land degradation, climate change, and even the spread of diseases [8].

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In addition, improper waste management also leads to economic losses due to the loss of resources from the environment or damage caused by floods or fires as a result of poor waste management practices [9]. These problems require a multi-pronged approach that includes both technological solutions such as efficient Internet of Thing (IoT) applications for smart bins and changes in public attitudes towards proper disposal methods for different types of waste. There is a growing emphasis on the use of sustainable smart bins with efficient IoT applications that have been specifically designed for urban areas where space is limited yet, large amounts of trash are generated daily. This technology enables municipalities and other stakeholders responsible for managing a city's garbage collection system to track their progress more precisely while minimizing waste [10]. Moreover, its effective implementation can help reduce flooding damages through better control over storm water run-off, [11] and limit health crises related with exposure to hazardous materials from open dumping sites [12]. Although a growing number of urban areas remain heavily congested with heaps of refuse, as shown in Figure 1, resulting in environmental degradation and health issues, appropriate measures must be taken to ensure that all citizens have access to safe sanitary facilities and dispose-off their garbage properly without putting local ecosystems under strain. Therefore, governments should continue to invest in research into new technologies to provide a viable solution to the global waste problem and unsustainable practices associated with inadequate management of municipal solid waste (MSW).

(a)

(b)

Figure 1. *(a) Heaps of refuse, emitting an unpleasant smell and obstructing vehicular traffic in the Ijebu Ode area of Ogun State* [13] *(b) A typical waste collection situation in a Nigerian city during a monthly environmental sanitation inspection* [14]

The Internet of Things (IoT) is a disruptive technology that has transformed the way humans interact with devices and systems. IoT enables machines, objects, and people to communicate in real time over the internet. This connection allows for new opportunities in a plethora of applications, including healthcare [15], home automation [16], smart cities [17], disaster management [9, 18], smart parking [19], smart learning [20], and smart library management [21]. The potential uses of this technology are vast; from improving energy efficiency to providing better medical care. IoT provides numerous benefits to both individuals and organizations by making processes more efficient through increased connectivity between devices and systems. Smart cities use sensors embedded in everyday items li ke bins or trash cans to collect data on how citizens manage their waste, allowing city officials to make informed decisions based on this information. Additionally, it can be used for monitoring traffic flow or managing water resources efficiently, improving citizens' quality of life within those areas. Furthermore, IoT also helps businesses increase productivity while reducing costs associated with manual labour, thereby driving economic growth across industries. IoT is digitally transforming our lives across various application domains, creating more innovative solutions that benefit us all. It has enabled unprecedented levels of automation, thus increasing convenience while optimizing resource utilization at an individual and organizational level. With its wide range of capabilities ranging from helping governments improve public safety and security measures or aiding scientists to explore uncharted territories such possibilities are endless when leveraging the power offered by the IoTs.

Recently, there has been a significant interest in applying IoT technology in waste management systems and the quest for new development continues. Lazaro et al. [22], used a magnetic scanner to create an improved solar-powered trash can. A global system for mobile communication (GSM)-based garbage-bin was implemented in [23]. Sai [24], proposed an IoT-based liquefied waste bin, whereas [25] presented a real-time smart garbage-based IoT integrated with an Android application. Lokuliyana [26], developed a waste management system that is integrated with IoT and Raspberry Pi. The use of infrared sensors [27], [28], weight sensors [29], ultrasonic sensors [30], waterproof sensors [31], gas sensors [32], and load cell sensors [33] with IoT technology was reported. Shaikh [34], implemented an intelligent waste bin with a temperature sensor to detect bin surrounding temperature and air pollution. The author further used light-dependent resistors to reduce electrical waste. Monika [35], designed a smart bin with a microcontroller, a GSM module, and an ultrasonic sensor. The GSM module acts as a communication gateway to raise bin level awareness. Chandra used voice recognition biometrics to control waste opening and closing, and to monitor waste levels. The model has a passive infrared (PIR) sensor, an ultrasonic sensor, and an Arduino Uno. Pavithra [36], used a radio frequency identification (RFID)-enabled waste bin to keep track of the trash level. Infrared and gas sensors are used in the design primarily to detect trash levels and toxic gases. An alert system is also integrated into the design to communicate the trash level and location to the respective area truck driver in charge of trash collection. Suvarnamma [37], reported using RFID and IoT technologies in smart bins for waste tracking and sorting. The author used capacitive and inductive proximity sensors to separate waste made of plastic and metal. To identify the location of each bin, the author assigned each bin a unique RFID tag. Although a similar strategy is reported in [38], the proper waste authorities are informed of the location and status of the garbage using a GSM module as a short message service.

Several works have examined waste disposal issues and proposed solutions to this societal problem. Contrary to previous research, this study aims to improve waste disposal efficiency through a disruptive Internet of Things system. The novel contribution of this paper is as follows:

1. Developing a waste management system based on IoT technology and a web-based application.
2. Real-time waste bin tracking via a unique internet protocol (IP) address.
3. Reduced costs associated with manual labour involved in garbage collection from homes and businesses.
4. Improved transparency in reporting the environmental impact of improper disposal practices.
5. Improved city hygiene and sanitation.

2 TOOLS AND METHOD USED

2.1. Arduino Microcontroller

The Arduino Uno as shown in Figure 2a is the most well-known Arduino series microcontroller. It is used in this study as a main controller that controls the entire system including data communication flow and transmission. Furthermore, the Arduino Uno reduces power consumption by allowing current to flow through the sensor and servo motor on demand. It coordinates and controls the Wi-Fi module used for internet connectivity. The Arduino Uno is a free computing platform that enables the communication of various modules. It makes use of the ATmega3289P microchip controller.

2.2. ESP8226 Wi-Fi Module

The Wi-Fi ESP8266 module is a 32-bit Tensilica controller-integrated wireless enable system on-chip (SOC). The Wi-Fi module sends waste bin status information to the web server regularly. This allows the waste collector authority to keep track of waste collection and bin reuse. It offers Wi-Fi networking solutions for various Internet of Things (IoT) applications. It uses the full TC/IP protocol stack and supports the 802.11/b/g/n, 2.4 GHz, WI-Fi, P2P, and WPA/WPA2 protocols. The Wi-Fi module now features a GIPO pin to interface with various sensing devices. Figure 2b depicts the ESP866-12F used in this study.

2.3. Ultrasonic Sensor

The ultrasonic sensor, as shown in Figure 2c, is a contactless proximity measurement device that uses high-frequency sound waves to detect people or objects. This sensor functions as a position and level identification measurement in various IoT-based applications. It offers an excellent non-contact range detection of 2 cm to 400 cm. Two HC-SR04 sensors are used in this design. The first sensor detects an object or people within a 20cm range while the other sensor senses the level of waste in the waste bin. The Arduino controller establishes communication between these sensors to automate the lid system and display the waste level status via a liquid crystal display.

2.4. Servomotor

A servomotor is a rotary actuator with negative feedback that allows for precise position control. It only rotates up to 180 degrees and not continuously. It is a motor with an embedded position feedback sensor. In this study, the servomotor (SG90) is used to automate the bin cover. When a person enters the sensing area, the lid automatically opens and remains open until the person moves away from the waste bin. The lid system is designed to close temporarily when the waste level reaches the threshold level. The SG90 servomotor is shown in Figure 2d.

2.5. Liquid Crystal Display

LCD, as shown in Figure 2e, is a data and message display technology. It is a 32-character output unit. In this study, a 16 X 2 LCD is used as a multifunctional device to display the IP address of each waste bin as well as to indicate the status of the waste bin. It is a suitable replacement for a light-emitting diode (LED).

2.6. Buzzer Chip and DC Power Cable

A buzzer is a sound notification alarm system activated when the waste bin is full. This enables quick squashing and waste bin reuse. The buzzer is shown in Figure 2f. While the waste bin system is powered by a direct current (DC) adapter, which converts power from the network (mains electricity) to low-voltage DC. A DC-AC power source is a voltage-controlled power supply that includes a transformer, a rectifier, and an electronic filter. The study utilized a 5V, 2A, power adapter.

2.7. Waste Bin Container

A waste bin is a receptacle made of metal or plastic that is used to store waste temporarily. The curbside waste bins are of different types such as wheelie bins, dumpsters, and trash cans. The waste bin, as depicted in Figure 2g, has a unique identifier, IP address, which enables information on the waste bin's fill level to be transmitted via a network's Wi-Fi module. The hardware design is presented in Figure 3. Furthermore, the system design is classified based on the system hardware and software as shown in Figure 4.

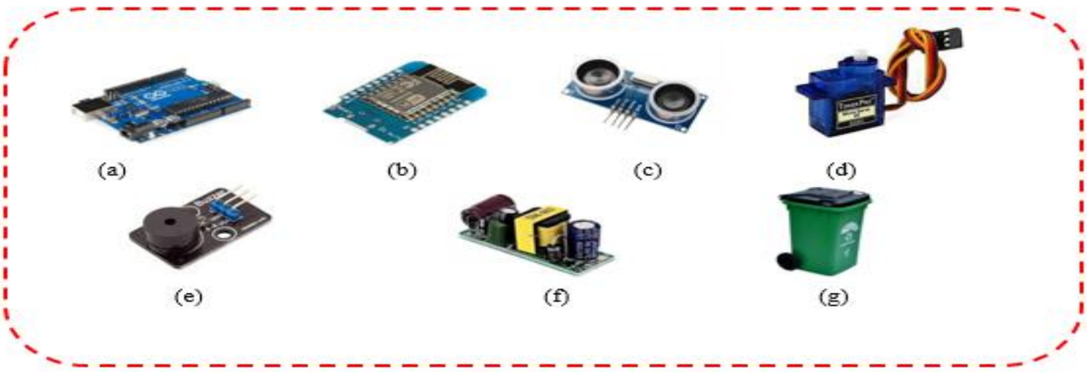

Figure 2. *System hardware components (a) Arduino Uno, (b) Wi-Fi module, (c) Ultrasonic sensor, (d) Servomotor, (e) Buzzer chip, (f) DC power cable, and (g) Waste bin container*

Figure 3. *Waste bin system design*

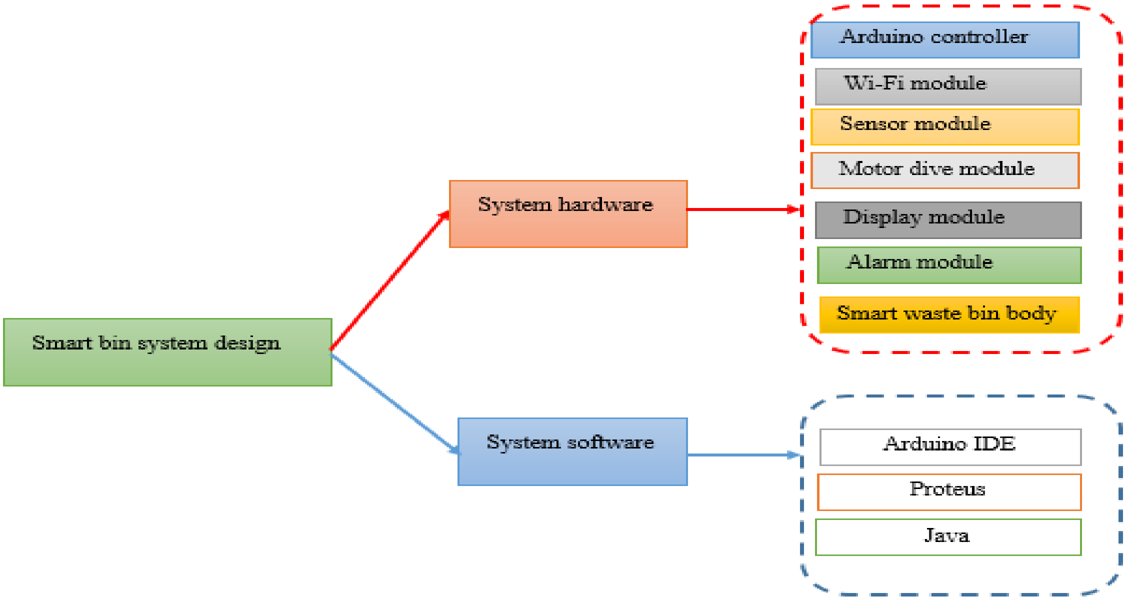

Figure 4. *System hardware design*

2.8. Software Development

An Arduino C language is written in the Arduino integrated development environment (IDE) for the proposed smart waste bin management system (SWBMS). The Arduino software is compatible with Windows, Mac OS X, and Linux. The Arduino code is designed to carry out the following instructions: (a) create an Arduino C code for the position identification module, (b) automate the opening and closing of the lid system, (c) create Arduino C code for the level identification module, (d) create an Arduino C code for the alarm notification system, (e) assign a unique IP address to each waste bin, (f) display waste level and the waste bin IP address, and (g) create a communication link between the Wi-Fi module and the waste bin. The system's code is written in Arduino C and runs on the Arduino IDE. Proteus software is also used for circuit design and simulation. The web user interface (Web UI) is written in the Java programming language.

2.9. Method

The SWBMS is designed to provide a sustainable green solution for disposing municipal solid waste (MSW), as well as to reduce the negative effects of trash mounds impeding vehicular traffic in Nigerian cities. The SWBMS is made up of ultrasonic sensors, HC-SR04 (for person/level identification), a WI-Fi ESP8266 module (for internet connectivity), an Arduino Uno, 16 X2 LCD, a servo motor (for lid system control), a buzzer (for alarm notification), and a waste bin (for waste storage). To accomplish these goals, each waste bin is assigned a unique IP address via a Wi-Fi module, and data is transmitted wirelessly. The HC-SR04 ultrasonic sensor is mounted in front of the waste bin to detect an object or a person within a 20cm range. When a person (waste producer) enters the detection zone, the lid automatically opens with the help of a servo motor attached to the lid system and remains open until the person discards the waste and exits the waste bin detection zone. After the person has left, the lid system waits three seconds before closing the lid. However, the second ultrasonic sensor ensures proper waste bin level monitoring; once the waste reaches the 80% threshold, the Arduino sends this information to the web server via a Wi-Fi module, and the web interface displays that the waste bin is full. The buzzer will continue to sound until the waste bin is crushed. In addition, the waste collection authority uses the web to access information to facilitate waste data analysis and prompt waste bin collection. The bin system is powered by a 5 DC power supply. The waste bin IP address and level are displayed on the LCD. Figure 5 depicts the SWBMS schematic diagram. To validate the model in this study, a comparison between the proposed system (SWBMS) and the manual waste bin management system (MWBMS) currently in use in a typical Nigerian waste management institute is done through the use of a questionnaire with a 5-point Likert scale rating on a scale from 1 to 5 where 5, denotes “Excellent” and 2 denotes “very poor”.

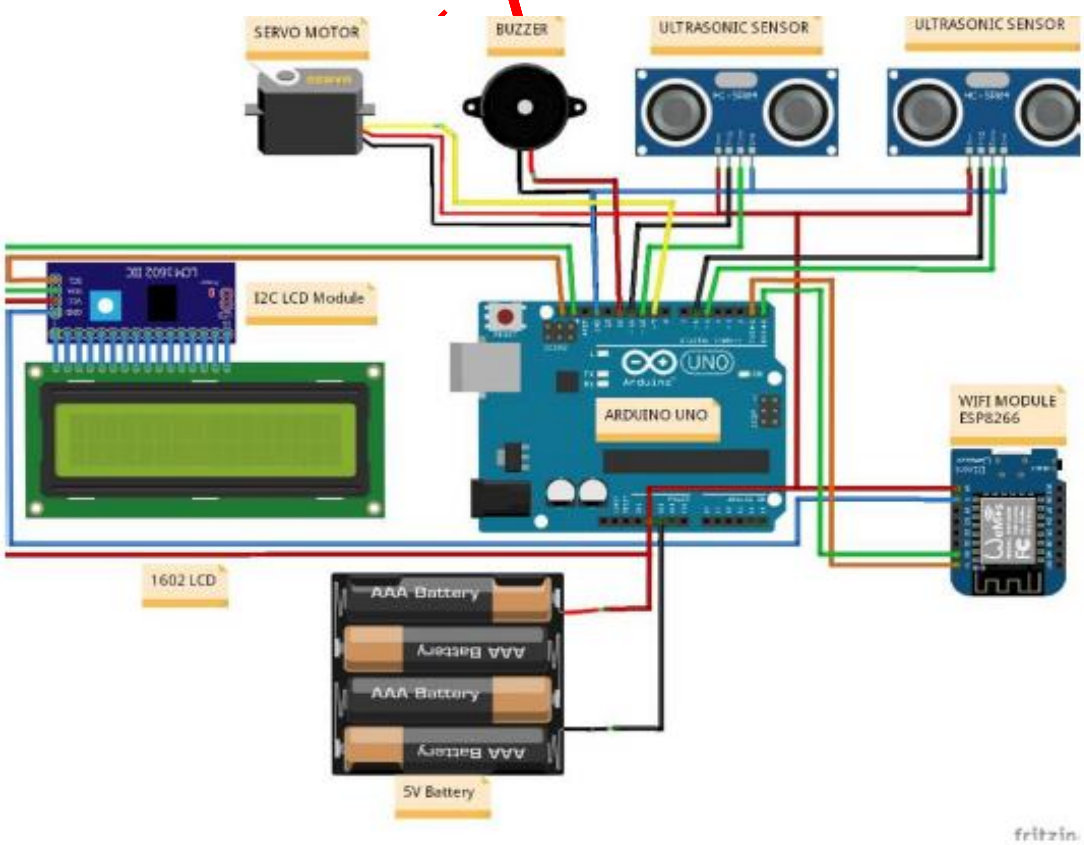

Figure 5. *Schematic diagram of the proposed smart waste bin management system (SWBMS)*

3. PROPOSED SOLUTION

3.1. System Architecture

The system architecture is based on a four-layer Internet of Things architecture, as shown in Figure 6. The sensing layer is responsible for the detection and collection of information. In this layer, the microcontroller interacts with sensors and actuators to collect, process, and transmit data through a wireless communication module. The network layer creates wireless connections between the microcontroller and the web application interface using Wi-Fi communication technology. The application layer manages data analysis, and visualization of waste collectors. This layer is responsible for monitoring the level of waste bins, maintaining waste data updates, and implementing efficient waste collection systems.

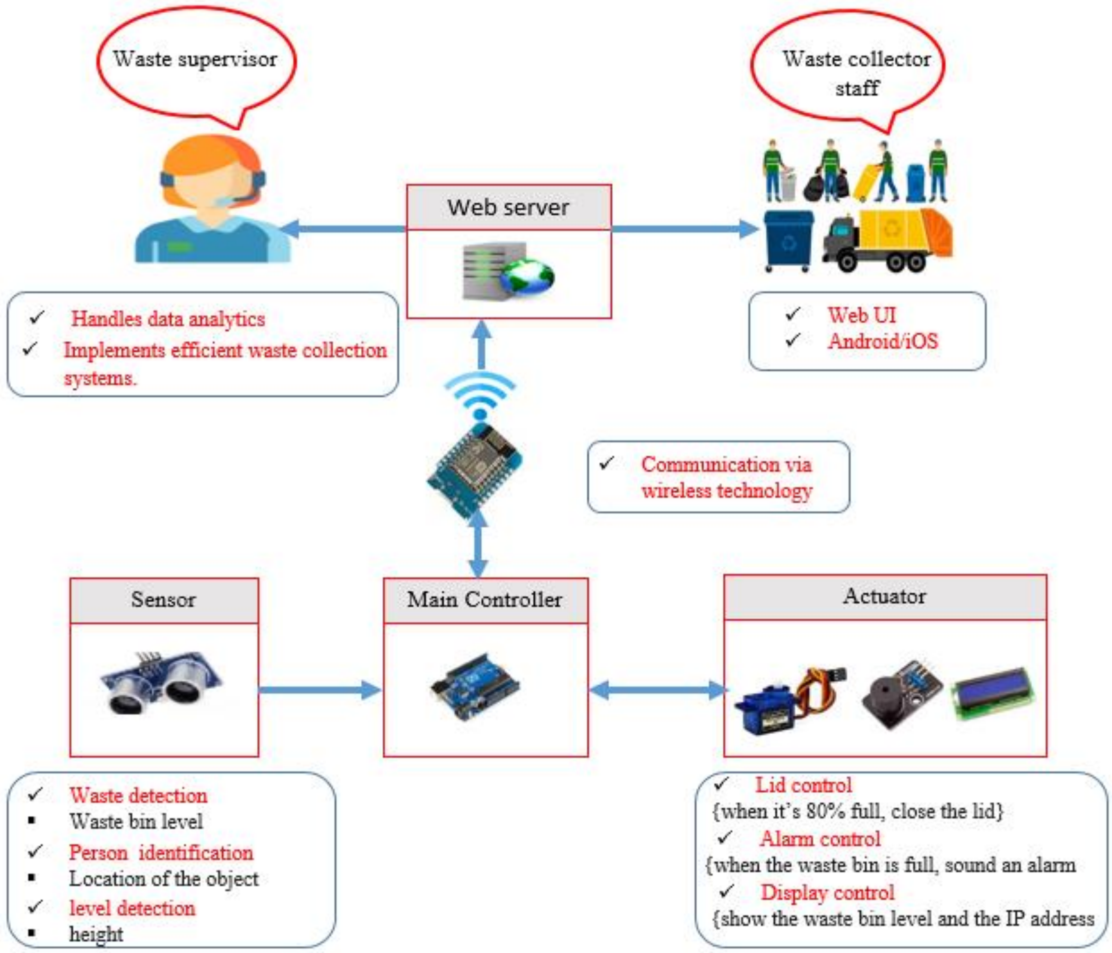

Figure 6. *System Architecture*

4. RESULTS AND DISCUSSION

As shown in Figure 7, various hardware components were integrated and tested, and the Arduino Uno serves as the primary controller for the system. The ultrasonic sensor is positioned in the waste bin at a predetermined height. When the waste reaches the threshold level, the lever sensor alerts the main controller. Each waste bin has a unique IP address that communicates the waste bin status to the web server via the internet module, as shown in Figure 8. The web server monitors the amount of waste in each waste bin. The level sensor is used to measure the waste bin level. The information of the waste level is transmitted wirelessly to the web server via the Wi-Fi module.

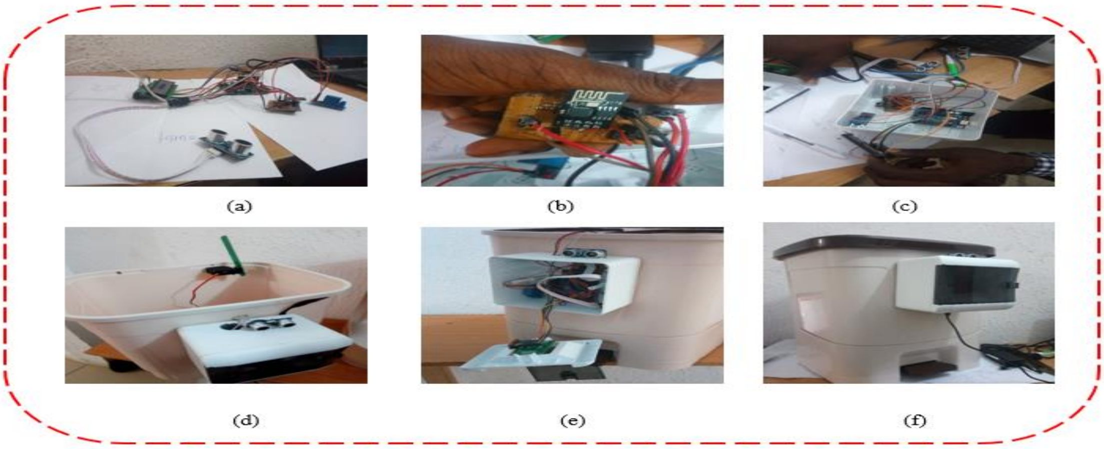

Figure 7. *(a) Arduino and sensors set up (b) set up of Wi-Fi module (c) components mounted on the vivo casing (d) servo motor set up (e) components setup (f) Prototype of the waste bin system*

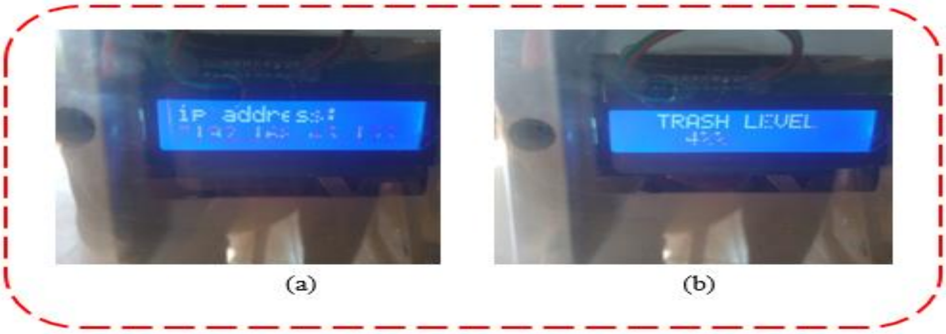

Figure 8. *(a) Waste bin IP address (b) The waste bin's percentage filled level*

Once the waste level is 80% filled, the main controller will relay the information to the web server through the Wi-Fi module. The waste supervisor will receive the sent information, analyze it, and designate a waste collector staff in that location to pick up the bin and empty to allow for reuse.

4.1. Performance Evaluation

Table 1 compares the proposed system (SWBMS) to the manual waste bin management system (MWBMS) currently in use in a typical Nigerian waste management institute. Furthermore, a questionnaire with a 5-piont Likert scale rating on a scale from 1 to 5 as depicted in Table 2, where 5, denotes "Excellent" and 2 denotes "very poor" was used to further assess the performance of the proposed system. The assessment statement from the questionnaire as well as users rank distribution is shown in Table 3. The system evaluation statement received a score of "Excellent" from 85% of users and "Good" from 15%. Furthermore, the proposed system has a 4.5 average performance rating, indicating that it outperforms traditional waste bin systems. The evaluation found that implementing the designed system can be used to improve waste disposal and collection processes, as well as serve as a roadmap for the development of waste management systems that can improve city hygiene.

Table 1. *Performance evaluation of MWBMS and SWBMS*

Performance Metrics	MWBMS	SWBMS
Identification System ▪ Bin information	– Intelligent means for system identification are missing. – By physical inspection	– Smart-enable system identification

▪ Waste level information ▪ Position information	- It is identified by bin color and location.	- Utilizes various sensors and communication technologies - Uses position sensors to display information on position.
Costs ▪ Hardware cost ▪ Software cost	- When compared to manual waste disposal and collection process costs, SWBMS is more expensive. - It does not require any hardware or software.	- Relatively low cost - Additional web design costs are required.
IoT based application	- None	- Enhanced with a Wi-Fi Module
Web based application	- None	- It includes a web server and web user interface (Web UI)
System Efficiency ▪ Labour ▪ Collection (run)Time ▪ Waste collection response ▪ Waste bin status	- Costly - time consuming and - Inefficient - Slow - Slow	- High efficiency - time-saving, - fast response time - Enhanced collection run time - Enhanced collection response time
Mode of operation	- Manually operated	- Internet based.
Mode of Communication Waste Management process	- Human-to-human interaction - Collection and disposal by hand	- IoT, Wi-Fi, and wireless Technology - Real-time tracking of waste disposal, and collection
Environmental sustainability	- Ecologically hazardous - Promotes unhygienic cities. - Promotes the spread of malaria and others infected bacteria. - Causes the climate crisis	- Promotes smart cities. - Reduces carbon dioxide emissions. - Improves city air quality. - Improves the quality of life and the environment.

Table 2.*The scale index*

Scale	Range	Interpretation
5	4.5 - 5.0	Excellent
4	3.5 - 4.4	Good
3	2.6 - 3.4	Average
2	2.1 - 2.1	Fair
1	1.0 –2.0	Poor

Table 3. *Test data interpretation*

Design Assessment Statement	5	4	3	2	1	Total	Cumulative	Mean	Description
In comparison to the other waste bin fill-level monitoring system I have used, I found SWB to be more efficient, maintainable, and affordable	40	5	5	0	0	50	235	4.7	Excellent
The SWB system is simple to use	25	20	5	0	0	50	220	4.4	Good
The web user interface (Web UI) is user interactive and friendly	35	15	5	0	0	50	230	4.6	Excellent
Waste data is easily retrieved via web server without data loss	32	10	8	0	0	50	224	4.5	Excellent
The waste collectors' response time to waste disposal is excellent	30	15	5	0	0	50	222	4.5	excellent

4.2. Economic Assessment

The main purpose of this study is to develop a low-cost smart bin system for an academic community. The waste disposal and collection in this community is time-consuming and costly. Cleaners are responsible for waste disposal and collection on campus. These tasks are performed manually, and most waste bins are frequently overflowing. The University's management paid a high price for this process. Therefore, it is necessary to compare the proposed system of the waste disposal and collection practices currently used by the university community in order to assess the proposed system's economic viability and to provide a clear roadmap for adopting the designed system. The economic cost of the proposed system is presented in Table 4. The system prototype cost ($23.43) per unit, which is equivalent to N9, 372 Naira in Nigerian currency. However, the University community employs ten cleaning staff members, each of whom earns $32.59 per month. University administration spent $391.08 per year on each cleaning staff member. The proposed system is budget – friendly and waste-conserving than the current practice. The proposed system will also save money on the workforce (cleaning staff) and fuel because the vehicle only needs to be available once it is notified via the internet.

Table 4. *Cost analysis of components*

Component Description	Unit price in USD ($)	Unit	Amount in USD ($)
Arduino Uno Rv3	8.72	1	8.72
ESP8266-12E Wi-Fi module	2.73	1	2.73
HC-RS04 Ultrasonic sensor	1.64	2	3.28
SG90 Servo motor	2.18	1	2.18
LCD 1802 chip	2.18	1	2.18
Buzzer chip	0.52	1	0.52
DC power adapter (5V,2A)	1.01	1	1.01
Plastic waste bin material	2.73	1	2.73
		Sum	**23.43**

4.3. LIMITATIONS OF THE STUDY

The study is limited majorly by the inability of funds and technological expertise to further improve the usefulness of the collected waste into possible conversion into biogradable products.

5. FUTURE OUTLOOK

Recent technological advancements in artificial intelligence (AI) powered robots have provided insight into the use of AI-powered robots to identify, monitor, and collect waste in each household. Such an AI system can be implemented in Nigerian cities, but it will require government financial support and resources. As a future outlook, the proposed system in this study can be enhanced with a global positioning system (GPS) device to track the coordinate of the waste bin, resulting in a shorter truck route, reduced fuel consumption, and increased efficiency during the waste collection process.

It is worth noting that the difficulty of sorting waste with an equally dielectric constant is a significant issue that can be addressed in future designs. In this regards, future designs can incorporate various sensors such as capacitive, inductive, photoelectric, and infrared sensors to detect and sort various waste materials. Several houses in Nigerian cities are poorly planned in terms of their location. As a result, proper housing numbering identification can promote the use of location-based smart bins in cities. A centralized waste collection database using blockchain technology could also be implemented in the future to improve waste data security and guide government policy decisions on waste collection practices.

The ultrasonic sensor of the system has a limited sensing range/detection zone. However, a laser (LiDAR) sensor can be used as a replacement for this sensor. A very interesting futuristic direction of this study can be seen in the conversion of waste into bio-energy products. Specifically, the various MSW constituents can be converted into beneficial bio-energy products using waste-to-energy conversion technologies. It has been viewed as a promising alternative to landfills or other forms of waste disposal. In particular, the biodegradable portions of municipal solid waste can be converted to bio-energy products such as bioethanol and biogas using waste-to-energy conversion technologies. Bioethanol derived from waste can be used as an alternative transportation fuel to gasoline.

Biogas is another form of bioenergy derived from MSW through the co-digestion process. The biogas can be compressed to fuel vehicles, improved to generate electricity, and can also be used as cooking fuel.
The biodegradable component of MSW can also be converted into bio-oil via a hydrothermal liquefaction process. Bio-oil can be used as a renewable fuel to power automobiles, and ships, and as an alternative source of power generation for mini-grids. Furthermore, instead of incineration, organic waste such as food, feedlots, and cooking oil waste can be converted into biodiesel via a transesterification reaction. Biodiesel can be used to power diesel engines, biodiesel generators, and electronic devices.

6. CONCLUSION

This study presents a smart waste bin management system (SWBMS) that integrates various sensors and internet-of-Things (IoT) technology to improve real-time tracking of waste bin information, which can optimize waste collection efficiency. The system model uses 4-layer IoT architecture to facilitate data sensing, sharing, processing, and monitoring. The whole system was controlled by the Arduino Uno and coded into the Arduino IDE platform with C. In addition, a Web User Interface (Web UI) has been developed to provide users and waste collection staff with real-time access to trash information via smartphones and Internet-enabled devices. The proposed design allows the user to access the waste bin IP address and percentage bin fill level from a remote location, resulting in timely waste collection. The identification system, costs, and efficiency were used as comparative metrics for system performance. Furthermore, the system comparison analysis reveals that the proposed system has advantages in terms of efficient waste control, improved time and energy efficiency, and lower costs than the existing method. Therefore, transitioning to an eco-friendly, sustainable smart bin system can assist the Nigerian government in revolutionizing the waste management industry.

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CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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