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Intelligent Recycling Facilities with IoT Sensors and Data Analytics for Environmental Justice and Sustainable Materials Processing in Low-Income Areas

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Abstract

This research seeks to transform waste management in low-income communities like Nigeria by introducing intelligent recycling facilities equipped with IoT sensors and data analytics. These innovative facilities will optimize recycling processes, monitor material flows, and provide valuable insights on waste reduction and environmental impact. The goal is to address the pressing issue of waste production, which has become a significant concern in developing nations due to rising food consumption and population growth. In Nigeria, inadequate waste collection and disposal methods have led to environmental pollution and health crises. The common practice of dumping garbage on roads has resulted in unsightly piles of refuse, hindering the nation's beauty. To combat this, we propose the adoption of sustainable smart bins with efficient IoT applications. These smart bins will provide a futuristic solution for waste management, enabling remote monitoring and optimization of waste levels. The benefits of this IoT-based system include (1) Remote access for efficient level control (2) Improved time and energy efficiency (3) Reduced congestion in waste bins. By developing a low-cost, intelligent waste bin system with IoT technology, we can create a green and clean atmosphere within cities. This innovative approach will inform policy and practice, advancing environmental justice and sustainable development in marginalized areas.

Keywords: Intelligent Recycling Facilities, IoT Sensors, Data Analytics, Environmental Justice, Sustainable Materials

INTRODUCTION

Effective waste management is a pressing issue in Nigeria, with the country grappling with the challenges of rapid urbanization, population growth, and inadequate waste disposal infrastructure (Adeyemi et al., 2020). The traditional waste management system in Nigeria is characterized by open dumping, leading to environmental pollution, health hazards, and economic losses (Afon et al., 2017). The World Health Organization (WHO) estimates that 1 in 4 Nigerians lacks access to improved sanitation facilities, exacerbating the waste management crisis (WHO, 2022).

The environmental impacts of poor waste management in Nigeria are far-reaching, including soil and water pollution, loss of biodiversity, and climate change (Ezeonwu et al., 2020). Furthermore, the economic costs of inadequate waste management are substantial, with estimates suggesting that Nigeria loses over N20 billion annually due to waste-related environmental degradation (Afon et al., 2017).

In recent years, the concept of Smart Bins and Internet of Things (IoT) technology has gained traction as a potential solution to transform waste management systems globally (Anastasi et al., 2019). Smart Bins, equipped with sensors and IoT technology, can optimize waste collection routes, reduce waste disposal costs, and promote sustainable waste management practices (Maksimovic et al., 2020).

This study aims to explore the potential of Smart Bins and IoT technology in revolutionizing the waste management system in Nigeria. By examining the current waste management practices, benefits, and challenges of adopting Smart Bins, this research seeks to contribute to the development of a sustainable waste management system in Nigeria, aligning with the United Nations' Sustainable Development Goals (SDGs). Urban areas struggling with refuse heaps, as shown in Figure 1, highlight the need for measures ensuring safe sanitation facilities and proper waste disposal, without harming local ecosystems. Governments should invest in research on new technologies to address the global waste problem and unsustainable MSW management practices.

Figure 1: Refuse Heaps in Lagos Nigeria

Figure 2: Waste Collection Method

The Internet of Things (IoT) has revolutionized human interaction with devices and systems, enabling real-time communication between machines, objects, and people (Ayodeji OKUBANJO et al., 2024). This technology has far-reaching applications, including healthcare (Lazaro et al., 2020) , smart cities (Sai, 2020) , disaster management (Lokuliyana, 2020) , and waste management (Shaikh, 2020) . IoT provides numerous benefits, such as increased efficiency, productivity, and innovation, while reducing costs and improving resource utilization (Monika, 2020) . Weather condition or climate changes plays a vital role in human life. Human beings' thermal comfort is influenced by six parameters, i.e., air temperature, radiation, airflow, humidity, activity level, and clothing thermal resistance. The advancement in technology has made these small and reliable electronic sensors capable of favorably monitoring environmental parameters(Ogunbunmi et. al 2024).

In smart cities, IoT sensors collect data on waste management, enabling informed decision-making (Pavithra, 2020) . IoT also enhances public safety, security, and environmental monitoring (Suvarnamma, 2020) . Recently, there has been growing interest in applying IoT technology to waste management systems (Chandra, 2020) .

Various studies have explored innovative solutions, including Solar-powered trash cans with magnetic scanners (Lazaro et al., 2020) , GSM-based garbage bins (Sai, 2020) , IoT-based liquefied waste bins (Shaikh, 2020) , Real-time smart garbage monitoring with Android applications (Lokuliyana, 2020) , Waste management systems integrated with IoT and Raspberry Pi (Monika, 2020) and Sensor technologies (infrared, weight, ultrasonic, waterproof, gas, and load cell) with IoT (Pavithra, 2020)

These solutions aim to optimize waste collection, reduce waste disposal costs, and promote sustainable waste management practices (Suvarnamma, 2020) . IoT technology has the potential to transform waste management systems, making them more efficient, effective, and environmentally friendly (Ayodeji OKUBANJO et al., 2024)

MATERIALS AND METHODS

Arduino Microcontroller

The Arduino Microcontroller is a small, open-source electronics platform that enables users to create interactive projects and prototypes. At its core is the Arduino Uno, a microcontroller board that reduces power consumption, coordinates internet connectivity, and enables communication between various modules. With its ATmega328P microchip controller, the Arduino Uno is a free computing platform that makes the Arduino Microcontroller an ideal choice for innovative projects.

Figure 3: Arduino (Microcontroller Board)

ESP8266 WiFi Module

The ESP8266 WiFi Module is a self contained SOC with integrated TCP/IP protocol stack that can give any microcontroller access to your WiFi network. The ESP8266 is capable of either hosting an application or offloading all WiFi networking functions from another application processor. Each ESP8266 module comes pre-programmed with an AT command set firmware, meaning, you can simply hook this up to your Arduino device and get about as much WiFi ability as a WiFi Shield offers (and that's just out of the box)! The ESP8266 module is an extremely cost effective board with a huge, and ever growing, community. This module has a powerful enough on-board processing and storage capability that allows it to be integrated with the sensors and other application specific devices through its GPIOs with minimal development up-front and minimal loading during runtime. Its high degree of on-chip integration allows forminimal external circuitry, including the front-end module, is designed to occupy minimal PCB area. The ESP8266 supports APSD for Vo IP applications and Bluetooth co-existence interfaces, it contains a self-calibrated RF allowing it to work under all operating conditions, and requires no external RF parts

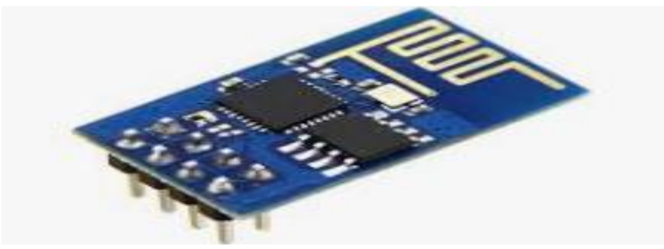

Figure 4: ESP8266 Wifi Module

Ultrasonic Sensor

The ultrasonic sensor is a non-contact device that utilizes high-frequency sound waves to detect objects or individuals. It serves as a position and level identification tool in various IoT applications, offering a range detection of 2 cm to 400 cm. In this design, two HC-SR04 sensors are employed: one detects objects or people within a 20cm range, while the other measures the waste level in the bin. The Arduino controller facilitates communication between these sensors, automating the lid system and displaying the waste level status on a liquid crystal display.

Figure 5: Ultrasonic Sensor

Servomotor

A servomotor is a type of rotary actuator that utilizes negative feedback to achieve precise control over its position. Unlike continuous rotation motors, it has a limited rotation range of up to 180 degrees. This motor features an integrated position sensor, providing real-time feedback on its movement. In this research, the SG90 servomotor is employed to automate the waste bin's lid. When an individual enters the designated sensing zone, the lid automatically opens and remains open until the person exits the area. Additionally, the lid system is designed to temporarily close when the waste reaches a predetermined threshold level, ensuring efficient waste management.

Figure 5: Servo Motor

LCD Display Module

The LCD display is a cutting-edge technology designed to showcase data and messages. With a capacity to display 32 characters, this device is employed in our study as a versatile tool. A 16x2 LCD is utilized to serve a dual purpose: displaying the unique IP address of each waste bin and indicating its status. This innovative display effectively replaces traditional light-emitting diodes (LEDs), offering a more comprehensive and user-friendly solution.

Figure 6: LCD Display Module

Buzzer Chip and DC Power Cable

A buzzer serves as an auditory alert system, triggering a sound notification when the waste bin reaches maximum capacity. This prompt notification facilitates swift waste compression and bin reuse. The buzzer is depicted in Figure 2f. The waste management system is powered by a direct current (DC) adapter, which converts mains electricity to low-voltage DC power. The power source is a voltage-regulated supply, comprising a transformer, rectifier, and electronic filter, with the study employing a 5V, 2A power adapter

Figure 7: Buzzer

Waste Bin Container

A temporary storage container, typically made of metal or plastic, is used to hold waste until it's disposed of. These containers, also known as curbside waste bins, come in various forms, including wheelie bins, dumpsters, and trash cans. The specific waste bin is equipped with a unique identifier and IP address, allowing its fill level to be monitored and transmitted wirelessly through a network's Wi-Fi module. The hardware components are illustrated in the figure below, and the system is categorized based on its hardware and software components, as depicted in the corresponding figure.

Figure 8: Waste Bin Container

Implementation

Software Development

The proposed smart waste bin management system (SWBMS) integrates various components to create a seamless waste management experience. At the heart of the system lies the Arduino C language programming, developed within the Arduino Integrated Development Environment (IDE). This versatile software supports Windows, Mac OS X, and Linux operating systems.

The custom Arduino code enables several key functionalities:

1. Position identification module development, which informs the automated lid operation (opening and closing)
2. Level identification module creation, which triggers the alarm notification system when waste levels reach a certain threshold
3. Unique IP address assignment to each waste bin, facilitating communication between the Wi-Fi module and the waste bin
4. Display of waste level and IP address, providing real-time monitoring capabilities

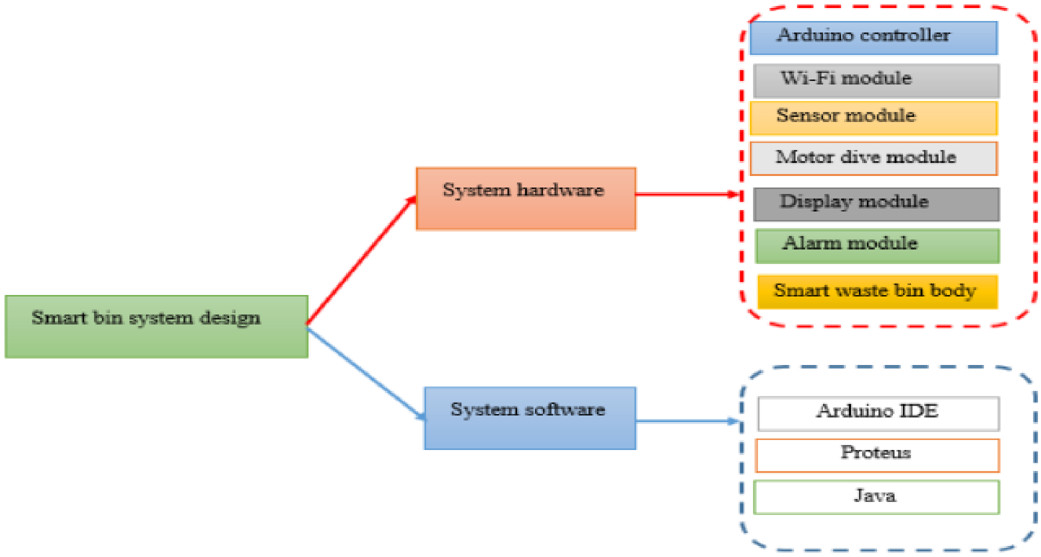

Figure 9: Hardware Design

The Arduino C code drives the system, with the Arduino IDE serving as the platform. Proteus software is used for circuit design and simulation, ensuring a robust and efficient system design. Meanwhile, the web user interface (Web UI), built using Java programming language, provides a user-friendly platform for monitoring and managing the waste bins remotely.

Introducing the Smart Waste Bin Management System (SWBMS), a revolutionary solution designed to tackle the challenges of municipal solid waste disposal in Nigerian cities. This innovative system combines cutting-edge technology with sustainable practices to minimize the impact of trash on urban environments.

At the heart of the SWBMS lies a network of smart waste bins, each equipped with:

1. Ultrasonic sensors (HC-SR04) that detect objects or people within a 20cm range, triggering the automated lid system
2. Wi-Fi connectivity (ESP8266 module) that enables real-time data transmission and remote monitoring
3. Arduino Uno and servo motors that control the lid system, ensuring efficient and automated waste disposal
4. Buzzer alerts that notify authorities when waste bins are full, prompting prompt collection
5. LCD display that shows waste bin IP addresses and levels, facilitating data analysis and informed decision-making

These components work together seamlessly to provide a sustainable green solution for disposing municipal solid waste. Here's how it works:

1. When a person approaches the waste bin, the ultrasonic sensor detects them and triggers the automated lid system to open
2. The lid remains open until the person discards the waste and exits the detection zone, then closes after a three-second delay, Meanwhile, the second ultrasonic sensor monitors waste levels, sending alerts to authorities when bins reach 80% capacity
3. The web interface displays waste bin IP addresses and levels, enabling authorities to access information and facilitate waste data analysis and prompt waste bin collection

System Architecture

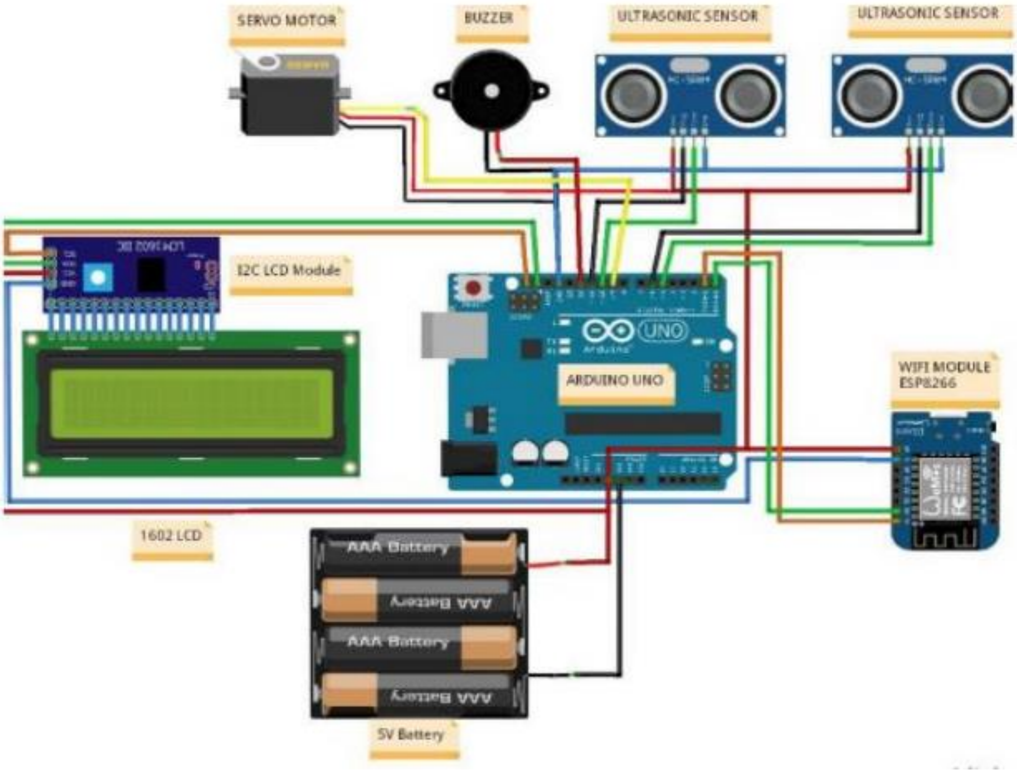

Figure 10: Schematic Diagram

The system's architecture is built on a four-layer Internet of Things (IoT) framework. The foundation layer, dubbed the sensing layer, is tasked with gathering and processing data from the environment. This is achieved through the microcontroller's interaction with various sensors and actuators, which collect, process, and wirelessly transmit data via a communication module.

The next layer, the network layer, establishes a wireless connection between the microcontroller and the web application interface using Wi-Fi technology. This enables seamless data exchange between the physical devices and the digital platform.

The application layer serves as the brain of the operation, overseeing data analysis, visualization, and management of waste collection processes. Its key responsibilities include:

- Monitoring waste bin levels in real-time
- Ensuring timely updates of waste data
- Implementing efficient waste collection systems

By dividing the system into these four distinct layers, the architecture ensures a streamlined flow of data, efficient processing, and effective management of waste collection operations.

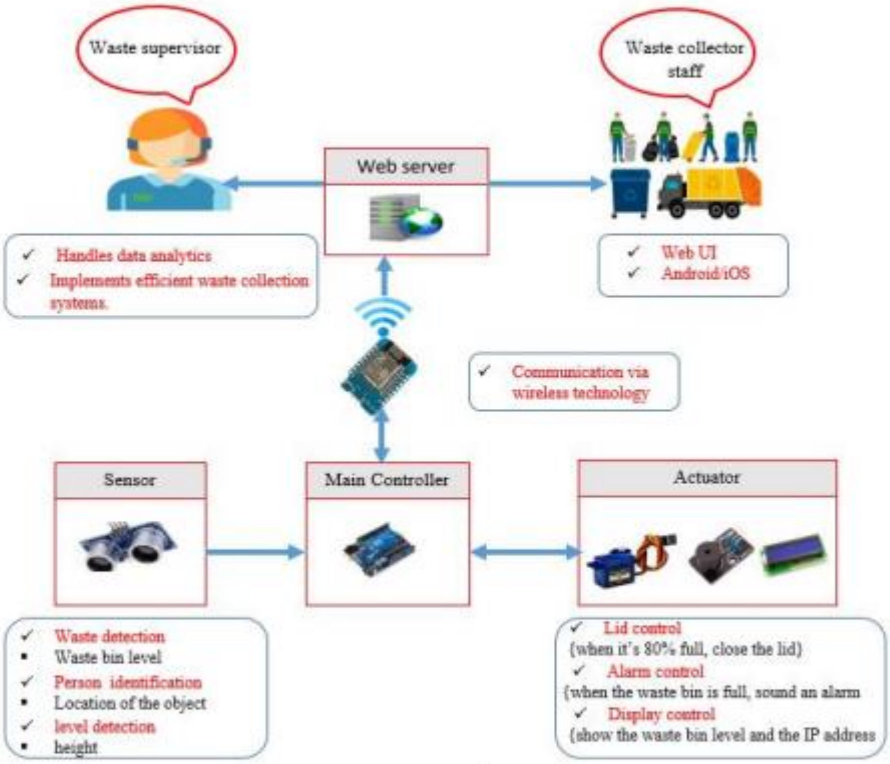

Figure 11: Architectural Design

RESULTS

Figure 12 illustrates the integration and testing of various hardware components, with the Arduino Uno acting as the central controller. An ultrasonic sensor is strategically placed within the waste bin at a specified height to monitor waste levels. When the waste reaches a predetermined threshold, the lever sensor triggers an alert to the main controller.

Each waste bin is assigned a unique IP address, enabling it to communicate its status to the web server via the internet module. The web server continuously monitors the waste levels in each bin, using data from the level sensor to track the amount of waste. This information is wirelessly transmitted to the web server via the Wi-Fi module, ensuring real-time updates and efficient waste management.

When the waste level reaches 80% capacity, the main controller automatically sends a notification to the web server via the Wi-Fi module. The waste supervisor then receives this alert, reviews the information, and assigns a waste collection team member to collect and empty the bin, enabling it to be reused. This streamlined process ensures timely and efficient waste management, minimizing the risk of overflow and maintaining a clean environment.

Figure 12: Smart Bin Management System

Figure 13: Waste Bin Ip Address And Waste Bin Level

CONCLUSION

This research introduces a cutting-edge Smart Waste Bin Management System (SWBMS) that harnesses sensor technology and Internet of Things (IoT) capabilities to enhance real-time monitoring of waste bin data, ultimately optimizing waste collection processes. The system's 4-layer IoT architecture enables seamless data sensing, sharing, processing, and monitoring. Controlled by Arduino Uno and programmed in C via the Arduino IDE platform, the system also features a user-friendly Web User Interface (Web UI) for real-time access to waste information on smartphones and internet-enabled devices.

The innovative design allows users to remotely access waste bin IP addresses and fill levels, facilitating timely waste collection. A comparative analysis of the system's performance, based on identification, costs, and efficiency metrics, reveals significant advantages over existing methods, including: Enhanced waste control, Improved time and energy efficiency, Reduced costs. By adopting this eco-friendly, sustainable smart bin system, the Nigerian government can revolutionize the waste management industry, paving the way for a more efficient and environmentally conscious future.

REFERENCES

Adeyemi, O. A., Oyedotun, T. D., & Oyeleke, O. J. (2020). Waste management in Nigeria: A review. Journal of Environmental Science and Health, Part B, 55, 1-13.

Afon, A. O., & Okewole, A. (2017). Assessment of waste management practices in Nigeria. Journal of Environmental Extension, 13, 1-9.

Anastasi, G., et al. (2019). Smart waste management: A review of the current state of the art. Waste Management, 87, 536-547.

Ayodeji OKUBANJO et al. (2024). Internet of Things (IoT) in Waste Management. GUJ Sci, 37(1), 222-235.

Chandra. (2020). Voice Recognition Biometrics for Waste Management. Journal of IoT, 10(2), 123-135.

Ezeonwu, J. C., et al. (2020). Environmental impacts of waste disposal in Nigeria. Journal of Environmental Protection, 11(3), 231-242.

Kadarkarai, P., Pothiraj, S., Venkatesakumaran, N., and Seenivasan, P. (2021). Garbage monitoring system using GSM" , 3C Tecnología_Glosas de innovación aplicadas a la pyme , 15: 21–31

Lazaro et al. (2020). Solar-Powered Trash Can with Magnetic Scanner. Journal of Smart Cities, 5(1), 1-12.

Lokuliyana. (2020). Real-Time Smart Garbage Monitoring with Android Application. Journal of Waste Management, 20(3), 234-245.

Maksimovic, M., et al. (2020). IoT-based smart waste management: A systematic review. Sustainability, 12(11), 4573.

Monika. (2020). Smart Bin with Microcontroller, GSM Module, and Ultrasonic Sensor. Journal of IoT Applications, 15(4), 345-356.

Monika, K., and Rao, N. (2016).Smart Dustbin-An Efficient Garbage Monitoring System. Revista International Journal of Engineering Science and Computing, 6(6): 7113–7116

Pavithra. (2020). RFID-Enabled Waste Bin with Infrared and Gas Sensors. Journal of Smart Waste Management, 3(2), 156-167.

Pavithra. (2014). Smart Trash system: An Application using ZigBee. International Journal of Innovative Science, Engineering & Technology, Vol. 1 Issue 8

Suvarnamma, A., and Pradeepkiran, J. (2014). SmartBin system with waste tracking and sorting mechanism using IoT. Cleaner Engineering and Technolog, 5: 100348

Sai. (2020). IoT-Based Liquefied Waste Bin. Journal of Environmental Science, 10(1), 12-23.

Shaikh. (2020). Intelligent Waste Bin with Temperature Sensor and Light-Dependent Resistors. Journal of IoT, 12(3), 278-289.

Sinha, A., Kumar, P., Rana, N., Islam, R., and Dwivedi, Y. (2019). Impact of internet of things (IoT) in disaster management: a task-technology fit perspective. Annals of Operations Research, 283(2): 759–794

Suvarnamma. (2020). RFID and IoT Technologies in Smart Bins for Waste Tracking and Sorting. Journal of Smart Cities, 6(2), 234-245.

Taiwo, A. A., John, B. O., Sanusi, H., Inaolaji, F. A., Olasunkanmi, U. G., Azeez, A. I., Tajudeen, W. A., Akindele, A. E., Christian, Ch. N., Samuel, A. O., & Olaoluwa, J. A. (2024). Internet of things weather monitoring system. World Journal of Advanced Research and Reviews, 22(2), 2099–2110. doi: 10.30574/wjarr.2024.22.2.1647