DEVELOPMENT OF AN IOT-BASED WASTE MANAGEMENT SYSTEM

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Abstract
This research appropriately outlines the methodology employed in the development of a smart waste management system equipped with sensors for data collection on waste disposal. The material selection process is detailed, highlighting the criteria for choosing suitable components. The research is on the functionality of ESP32 microcontroller selection over other alternative microcontrollers. The ESP32 microcontroller is a wonderful choice for this research because it can be programmed in a variety of other programming languages, including Python, C++, MATLAB, and a whole host of others. The GPS Module and ESP32 sensors were connected and put within an enclosed box, which is mounted at the front of the bin. The Ultrasonic sensor is mounted inside the bin, at the top of the cover, for effective calculation of the distance of waste/Fill level. The real-time monitoring device's hardware, designs component selection, and data transmission components to ensure adequate monitoring of the Bins. The result from the Smart Bin data analyzed shows how waste disposal rates correlate with population density. The work underscores the relationship between population density and waste generation, examining factors such as economic development, urbanization, consumer behavior, and waste management infrastructure. By implementing such a system, we can achieve better waste management practices, reduce cost, and create a cleaner and healthier environment for everyone. The research emphasizes the performance testing of the developed system and offers insights into maintenance procedures. Implementing a robust system for continuous monitoring and regular maintenance of smart bins is imperative. This involves establishing protocols for real-time data analysis and promptly addressing any technical issues that may arise. Such measures are essential to ensure the longevity and effectiveness of the deployed IoT-enabled waste management infrastructure. In conclusion, considerations for comprehensive waste management strategies should be made by recognizing the complex interplay of social, economic, and environmental factors in waste disposal rates.

1. Introduction

Waste management is a serious issue due to its human health and environmental sustainability. It is really a pressing issue the world is facing today, since a high percentage of waste is currently disposed of by open dumping (Schiopu, Apostol, Hodoreanu, and Gavrilescu, 2019; Abdelnaser, and Gavrilescu 2020; Abdelnaser, EI-Amrouni, Latifa, Pakir, Ramli, and Aziz, 2020; Narayana, 2017). To buttress this assertion (Zamorano, Molerob, Grindlayb, Rodriguezc, Hurtadoa & Calvo, 2019; Jalil, 2019; Adekunle, Adebola, Aderonke, Pius and Toyin, 2011) posit that Waste Management is a globally challenging issue, especially in developing countries, due to its adverse environmental effects. Mankind naturally depends on the environment to sustain their lives. Still, solid waste is one of the three major environmental problems in Nigeria, and this threatens many other developing and even developed countries. It plays a significant role in nature's ability to sustain life within its capacity. Domestic waste management, collection, and disposal have always been universal. This is because efficient and appropriate collection and disposal of solid waste has been recognized as essential to the hygiene and health of urban societies since the nineteenth century. Throughout the first half of the twentieth century, sanitary engineers and the broader public also came to understand that the inappropriate treatment of waste could cause significant environmental degradation. At the same time, recycling could contribute significantly to environmental sustainability. Waste management is imperative because improperly stored refuse can cause health, safety, and economic problems. All living organisms create waste, but humans create far more waste than other species. Humans must manage and store their waste efficiently and safely to prevent damaging the Earth's ecosystems and maintain a high quality of life for the planet's inhabitants. Poor waste disposal habits of the people, corruption, weak government regulation, poor work attitude, insufficient funds, and inadequate facilities such as plants and equipment, among others, are factors militating against effective waste management towards sustainable development in Nigeria as a whole. Therefore, if there is sustainable development in Nigeria's waste management, land (for landfill), human resources, adequate funds, plant and equipment, and other tools must be readily available. We need to protect the future for the next generation by cleaning up our environment of all types of waste, considering both the state's physical and population development. Generally, waste management is defined as the collection, keeping, treatment, disposal, and recycling of wastes in such a way as to render it harmless to human and animal life, the ecology in particular, and the environment in general. Despite this laudable attention, collection, disposal, processing, treatment, recycling, and utilization have defied solution. At present, private sector waste disposal operators diligently visit homes and carry away refuse bags, load them into waiting trucks, and cart them away for final disposal. Recognizing the importance of waste management as an instrument of achieving sustainable development in Anambra State, government has intensified efforts to create wealth and job opportunities for the teeming unemployed youths in the state, a sizeable portion of land has been acquired in Silas Works, Fegge area in Onitsha, by the state government to establish a recycling plant.

The recycling plant at Onitsha will be transferred through a transfer system to Awka, Nnewi, and other major cities in the state to recycle and decompose waste that comes from these major cities. The Managing Director, Anambra State Waste Management Agency (ASWAMA), Mr. Mike Ozoemena, said that the plant, which will soon start, will generate wealth for the state, but expressed fear that Anambra State may not have enough waste to accommodate the plant if established. Recycling of waste generates wealth for states. This will, in turn, ensure sustainable development in the state. ASWAMA, in collaboration with the state Ministry of Local Government, has been moving around to address these problems, and very soon, they will start house-to-house inspections because we need to nurture and groom our environment like a baby. They have been trying to sensitize our people to keep our environment clean. Under the auspices of the foregoing, the study sets out to ascertain the effect of waste management on sustainable development in Nigeria.

1.1. Literature Review

The collection, transport, treatment, and disposal of solid wastes, particularly wastes generated in medium and large urban centres, have become a relatively complex problem for those responsible for their management. The problem is even more acute in economically developing countries, where financial, human, and other critical resources are generally scarce (UNEP, 2021). Nigeria, as one of the developing countries, is not left out; Nigerian cities are witnessing a high rate of environmental deterioration and are rated among urban areas with the lowest livability index in the world. Although studies have identified various ecological problems in Nigeria, little attention has been given to their implications for sustainable development in the literature (Daramola and Ibem 2019). The level of environmental management awareness in Nigeria is still very low, yet the knowledge of environmental management techniques can guarantee life sustainability in Nigeria (Uwadiegwu and Iyi, 2019). Against this backdrop, Odunjo (2022) maintains that sustainable environmental management is far from achieved in Nigeria because human activities still degrade the environment. The country can only be sustainably developed if it can pay attention to environmental sanitation and conservation.

According to Sridhar (2017), waste is any matter that has no further use based on its composition, e.g., garbage, trash, junk, domestics, or ashes. It may be domestic, nonhazardous, hazardous, or infectious. In another piece of literature, Polprasert (2018) classified solid wastes from human activities as those from residential, commercial, street sweepings, institutional, and industrial categories.

1.2. Waste Management Policies in Nigeria

Solid waste management has become a global issue that every government in the 21st Century has shown uncommon commitment to tackle, especially when making policies on public health and environment (Okoli et al, 2020). This is due to the rapid increase in volume and types of solid and hazardous waste because of continuous economic growth, urbanization, and industrialization (UNEP, 2019). The National Environment Protection Agency (FEPA) was set up in 1988 to manage the increasing concern of waste management in Nigeria (Onibokun and Kumuyi 2019, cited in Maiyaki, 2020). Vision 2010 was for FEPA to address environmental problems in the country that would lead to sustainable development. Concerning solid waste management, the report says the objective is to "accomplish at least 80% successful management of the volume of urban solid waste produced at all levels and guarantee environmentally stable management" (Vision 2020, 2019, cited in Maiyaki, 2020). Others are Ministry of Environment, Federal Environmental Protection Agency (FEPA), and Niger Delta Development Commission

(NDDC). At the State level, environmental agencies include the State Environmental Protection Agency (SEPA) and the Ministry of Agriculture and Natural Resources. At the same time, local governments operate through the Department of Community Development and the Department of Agriculture and Forestry. Often, these government agencies have laudable plans and programmes, but many of the programs fail because of financial problems and their management (Odunjo 2019). Yet, apart from Lagos State that has commercialized waste management and created institutions to support it, all other states still see waste management from the social service viewpoint, thus, rather than earn revenue for the State, the State spends high junks of her revenue on managing waste (Okoli et al, 2020). Considering the deleterious health effects of improper waste management, policy changes to encourage proper waste management potentially benefit urban dwellers. Possible benefits include reduced infectious disease rates, reduced mortality, and improved quality of life and outlook on life based on a clean environment (Omenka, 2016). Waste generation and its likely effects on human and environmental health and the urban landscape have become recurring dismal in Nigeria today (Olukanni, 2022). All stakeholders concerned with our environment's safety and beautification need to realize the negative consequences of nucleated solid wastes found in residential neighborhoods and many places in cities. These solid wastes have become recurring features in our urban environment. It is no longer news that Nigerian towns are inundated with the challenges of unclean solid waste (Osinibi, 2019). Consequently, urban residents are often confronted with the hazardous impact of nucleated solid wastes in their environment.

Solid waste disposal has become one of the environmental problems that the government is concerned about. Recent estimates indicate that the total amount of domestic waste per annum in Nigeria is about 63 million tonnes (0.45kg/capita/annum). In general, the volume of solid waste overwhelms urban administrators' capacity to plan, evacuate, and dispose of waste. Much of the generated waste is either burned or dumped haphazardly in illegal landfills or streets, where it creates health hazards and blocks drains, contributing to urban flooding (National Policy of the Environment, Revised 2016). Walling et al. (2004) averred that the total size of the solid waste issue in Nigeria is difficult to grasp. Perhaps, due to the absence of an appropriate system for regulation and poor planning, the volume of waste that piles up in a few hours is beyond what waste collectors could responsibly transport in a day. Based on these narratives, the Nigerian waste “dumps” are situated along the major roads at the edge of urban areas, and there are no public waste containers. As a result, waste regularly spreads into the street, blocking traffic, gutters, and so on. Hence, a reasonable amount of waste remains uncollected; when waste piles up, households and businesses gather it in the middle of main roads and burn it (Warren, personal experience). Consequently, these lead to inadequate waste management with far-reaching ramifications for public and environmental health (Zainu & Songip, 2017).

1.3. Research Papers

The most current related work is done by Zavare and his colleagues on sensor nodes connected to an Arduino board-based control station, which uses a GSM module to send the sensor nodes’ data by SMS to the garbage collecting vehicle and a server hosting a web application via a Wi-Fi connection. The sensor nodes of the smart bins rely on the ultrasonic sensor to sense the fullness percentage according to pre-calculated bin depth. Moreover, a GPS module is used to get the bin location. The GPS module and the ultrasonic sensor are controlled by the Amica R2 NodeMCU microcontroller board, which has a built-in Wi-Fi module that is used to connect to the control station. Singh, Mahajan, and Bagai did another work on wireless sensor networks. The bins in his work are equipped with an accelerometer sensor to sense the opening and closing of the bin lid, a temperature and humidity sensor to check the present organic waste, and an ultrasonic sensor to sense the fullness status of the bin. All these sensors are controlled by a Zigbee Pro microcontroller board, which has a built-in Wi-Fi module that is used to send the sensors' data to a gateway. This paper also used the same type of microcontroller board in the gateway to receive the bins' data and send it to a control station, which contains a server, over GPRS. The server in the control station relies on the Caspio database management system with a web-based user interface.

A paper by Navghane, Killedar, and Rohokale examined the use of a weight sensor and three IR sensors to check the smart bin's fullness status and send the sensors' data to a web page over a Wi-Fi network to a mobile phone. The microcontroller board used in this paper was an ARM.

LPC2148. Students at California Polytechnic State University did a report, thoroughly exploring the economic and power consumption aspects of converting a conventional outdoor trash bin into a smart one. According to the literature, the project is based on a u-blox C027-U20 microcontroller board, which has a built-in GPS module and a cellular module. The board is used to control the HC-SR04 ultrasonic sensor, which measures the bin's fullness level, and a temperature sensor for monitoring weather conditions and fire alerts. The setup is contained in a 2×4×6 plastic box and powered by a 12V rechargeable lead-acid battery. The report mentioned that the system generates an HTTP POST request using the data from the sensors and sends it to a web application, which is built using Python and the Flask framework on top of an SQLite database. The web application receives the HTTP request and checks if the bin is full, then sends an SMS message using the Twilio service. Moreover, the Leaflet JavaScript library is used to visualize the collected data on a map.

1.3.1. Commercial and Industrial Solutions

Several companies offer smart trash bins managed by a web-based application. ECUBE Labs and Bigbelly offer smart trash compactor bins, which are powered by a solar cell panel and a battery. Clean CUBE bin uses an ultrasonic sensor, and Bigbelly smart trash bin uses a laser sensor to measure fullness status. Moreover, most companies offer IoT sensors, which can be easily

installed on available trash bins. ECUBE Labs, ENEVO, and SMARTBIN offer battery-powered versions of these ultrasonic IoT sensors. Moreover, CUBE labs offer solar solar-powered one. However, COMPOLOGY offers an IoT sensor that uses a camera to detect the fullness status of large industrial trash containers. Most of these IoT sensors and smart bins integrate temperature, tilt, and acceleration sensors to detect vandalism, fire, trash collecting, and usage events. All these solutions make use of cellular networks to send data from the IoT sensors and bins to their cloud-hosted web application portal over the internet. These web applications monitor fullness level, energy usage, fire alerts, and give real-time readings and historical reports in addition to schedules and routes for optimized trash collection. Finally, contrary to the mentioned solutions, this paper aims to reduce cost by sending a fullness alert without the need for an internet connection and web applications.

1.4. Internet of Things (IoT)

The simplest definition of the Internet of Things is the interplay of the physical and digital worlds (Vermesan et al.). Current Internet of Things (IoT) research mostly focuses on how to make it possible for common objects to independently see, hear, and smell the physical environment and connect them to share observations. In this way, Sarika et al. (2019) argue that monitoring and decision-making can be transferred from the human to the machine side.

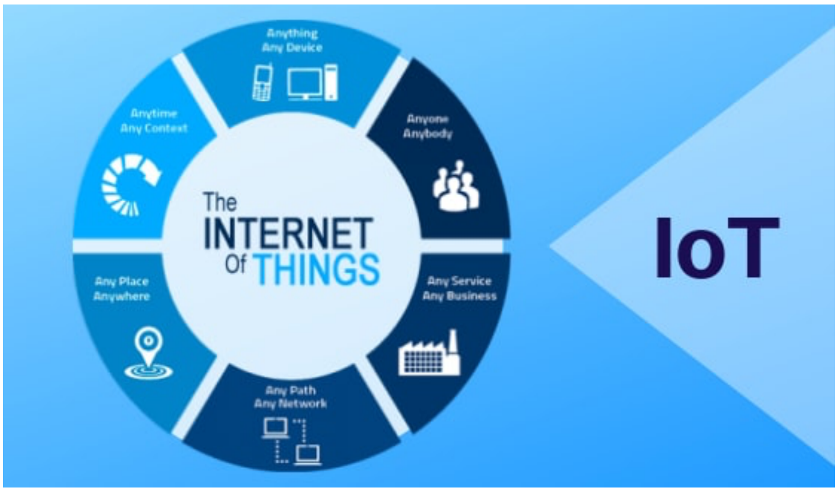

Figure 1: Definition of IoT (Sarika et al., 2019).

1.5. The IOT Architecture

The components of the architecture of the Internet of Things are the Edge Things, Field Protocols, IoT Smart Gateway, and Cloud Protocol.

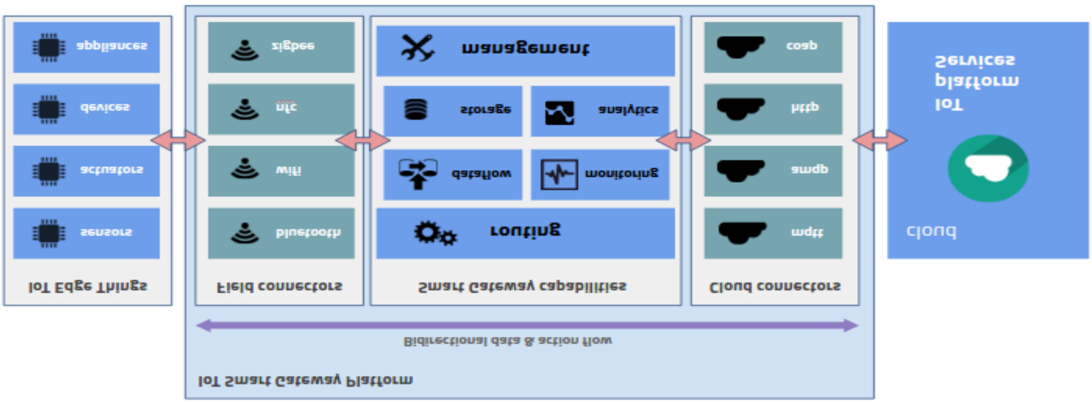

Figure 2: Shows main components of this architecture, i.e., edge side and cloud side (Rafael Rocha 2017).

Edge things: The data is gathered and processed at the edge things. These could be actuators, sensors, gadgets, and a vital component known as a gateway that manages interaction between the things as well as communication between the things and cloud services (Sarika et al.).

Field protocols, sometimes referred to as IoT Network Protocols, are a type of communication used for communication between one or more edge devices and the smart gateway, and with one another. LoRaWAN, Bluetooth, Zigbee, Wi-Fi, and near-Field Communication (NFC) are a few of the more well-known ones.

IoT Smart Gateway: This clever node links all IoT gadgets, sensors, and virtual platforms. It routes and controls data between IoT devices and the cloud.

Cloud protocol: These protocols, sometimes referred to as IoT Data Communication Protocols, make sure that data is read and interpreted by one another via sensors, devices, gateways, servers, and user applications. Message Queue Telemetry Transport (MQTT), Constrained Application Protocol (CoAP), Advanced Message Queuing Protocol (AMQP), and Hypertext Transfer Protocol (HTTP) are a few of the well-known protocols.

1.5.1. IoT-Based Waste Management and Smart Cities

Our waste generation is constantly growing, forming a global garbage crisis. Even though we compromise on creating a more sustainable and greener world with 2050 climate targets before it's too late, we still fail to recycle or handle our waste. Combining technology support with a vision of social, economic, and environmental sustainability is the only way out of this problem.

2. Methodology

This section clearly explains the design and selection of materials, methods, procedures used to develop a smart waste management system equipped with sensors which provide data on waste disposal.

2.1. Material Selection

The selection of materials and components is an essential part of this project. Material selection is an ordered process by which engineers can systematically and rapidly eliminate unsuitable materials and identify one or a small number of materials that are the most suitable based on design specification, aesthetics, availability, and cost efficiency.

2.2. List of Materials/Components of a Smart Waste Bin

1. ESP32 development board
2. Ultrasonic wave detection ranging module (Ultrasonic sensor)
3. GPS module
4. DC-DC buck converter.
5. Lipo 12V battery.

2.2.1. Microcontrollers Procedures

A microcontroller is embedded inside a system to control a single function in a device. It does this by interpreting data it receives from its I/O peripherals using its central processor. The temporary information that the microcontroller receives is stored in its data memory, where the processor accesses it and uses instructions stored in its program memory to decipher and apply the incoming data. It then uses its I/O peripherals to communicate and enact the appropriate action. They send and receive data using their I/O peripherals and process that data to perform their designated tasks.

2.2.2. Choosing the right microcontroller

There are several technology and business considerations to keep in mind when choosing a microcontroller for a project. Beyond cost, it is important to consider the maximum speed, amount of RAM or ROM, number or types of I/O pins on an MCU, as well as power consumption and constraints, and development support. ESP32 microcontrollers were used in this paper because it has gained a lot of popularity among hobbyists and even manufacturing companies due to their flexible power supply, where you can connect them directly to USB (Type A, Type C, etc., depending on the controller and board) and wide connectivity options. With integrated Wi-Fi and BLE (Bluetooth Low Energy) capabilities, a dual-core processor, and a rich set of peripherals, the ESP32 is a great candidate for many embedded system designs or hobbyist projects.

2.3. Fabrication Process

The fabrication of the Smart waste bin was achieved with the following materials: a dustbin, wires (Male/Female), an ESP32, an Ultrasonic Sensor, a GPS module, and a DC-DC converter. The Smart waste bin was manufactured to meet the required specification through the following processes:

1. Software development process
2. Wiring process
3. Assembly/Coupling process

2.4. Software Development Process

This work uses the PHP and C programming languages to create intelligent application programs. The PHP programming language plays a role in realizing Web-based application programs. While, C programming language was used for programming the ESP32 with Arduino software IDE to function as a controller for other hardware work, such as sensors and servo motors. The ESP32 microcontroller controls ultrasonic sensors, a GPS Module, and Wi-Fi to detect the level of garbage filling the trash can. ESP32 is an Integrated Circuit (IC) chip equipped with Wi-Fi and Bluetooth functions. This study uses the survey method to collect quantitative data in the form of ordinal data. Jumper wires were used to connect components to the PINs of the microcontroller to form circuits.

2.5. Assembly/Coupling Process

Various technology was integrated to couple the smart waste bin to enable communication, monitoring, and control functionalities. The whole sensor system was connected and put within an enclosed box, which is now mounted at the front of the bin. The Ultrasonic sensor is mounted inside the bin, at the top of the cover. To calculate the distance of the waste/fill level effectively. These intelligent bins are equipped with advanced sensors, communication modules, and data analytics capabilities, transforming them into an integral part of the emerging Internet of Things (IoT) ecosystem. At the heart of a smart waste bin, the Ultrasonic Sensor is located, which detects the fill level of the bin in real-time. By coupling these bins with GPS and route optimization algorithms, cities can reduce fuel consumption and minimize the environmental impact of waste collection operations. Furthermore, the integration of the communication module (ESP32) in smart waste bins allows them to transmit real-time data to a centralized platform. This connectivity enables authorities to monitor the status of waste bins remotely, receive alerts when bins are full, and streamline collection schedules.

2.6. Design of the Hardware Component of the Real-time Monitoring Device.

To achieve one of the objectives of this work, which is to develop an IoT-based smart waste management system, a microcontroller was used to automatically control devices, appliances, and other embedded systems. A microcontroller is a compact integrated circuit designed to govern a specific operation in an embedded system. A typical microcontroller includes a processor, memory, and input/output peripherals on a single chip. The development of a Real-time monitoring device for the project using an economical and user-friendly microcontroller and other components was motivated by the comparatively high cost of purchasing a remote monitoring device and the difficulty with software customisation. The availability of free hardware training software and the low cost of the ESP32 hardware microcontroller led to its selection. The ESP32 microcontroller is a wonderful choice for this project because it can be programmed in a variety of other programming languages, including Python, C++, MATLAB, and a whole host of others. Additionally, it is compatible with a range of sensors and other research-useful components. This Real-time monitoring device can read the level of fill, location of the bin, and transmit the obtained reading to the server for visualization and analysis.

2.6.1. Development of the IoT Real-Time Monitoring Device

The ESP32, ultrasonic sensor, and Neo6mV2 GPS module were used to create the Real-Time monitoring device. A 12V battery will power the devices. Jumper wires are to be used to make connections.

2.6.2. Selection of a Suitable IoT Analytics Platform Service

In this project, the data collection from the Real-Time Monitoring device and feedback to the Virtual Reality environment are done using IoT platforms. Over 90 IoT systems are currently available, some of which include Google Cloud Platform, ThingSpeak, Blynk, OpenRemote, Record Evolution, IRI Voracity, Particle, ThingWorx, IBM Watson IoT, Amazon AWS IoT Core, Microsoft Azure IoT Suite, Oracle IoT, Cisco IoT Cloud Connect, Thinger.io, Upswift, etc. Many IoT platforms are appropriate for the project. However, ThingSpeak was chosen since it is less expensive and does not require server setup. It collects data, analyzes it, and triggers a reaction if necessary.

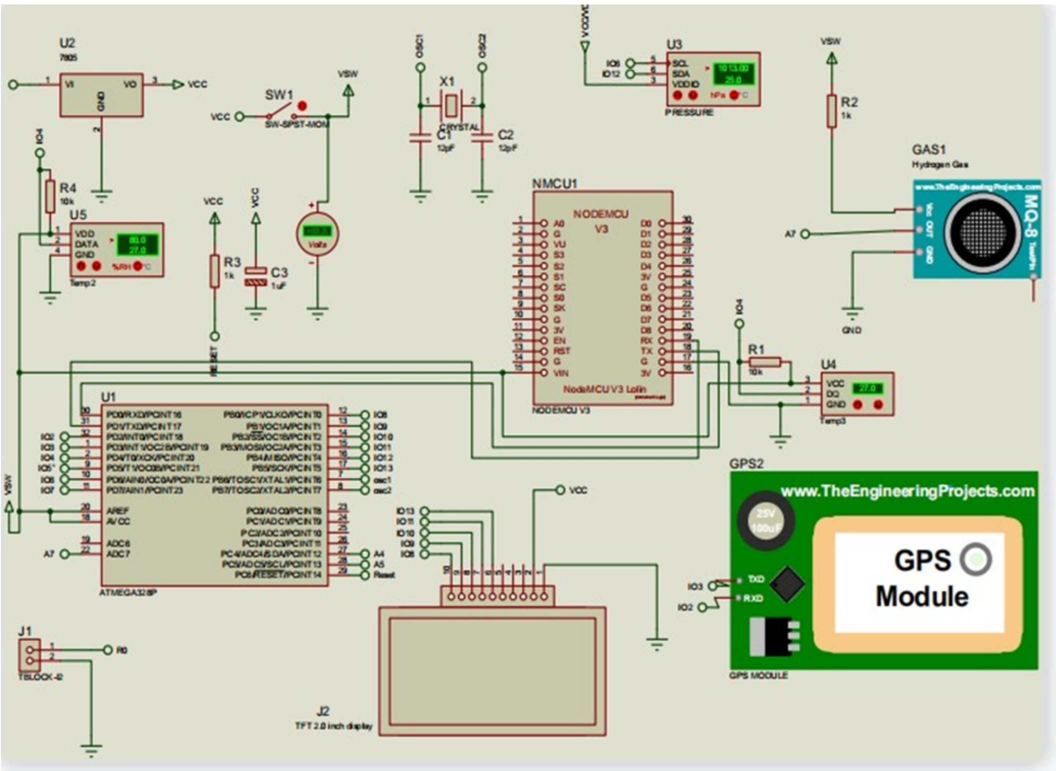

Figure 3: Real-Time Monitoring Device Circuit Diagram using the Proteus8

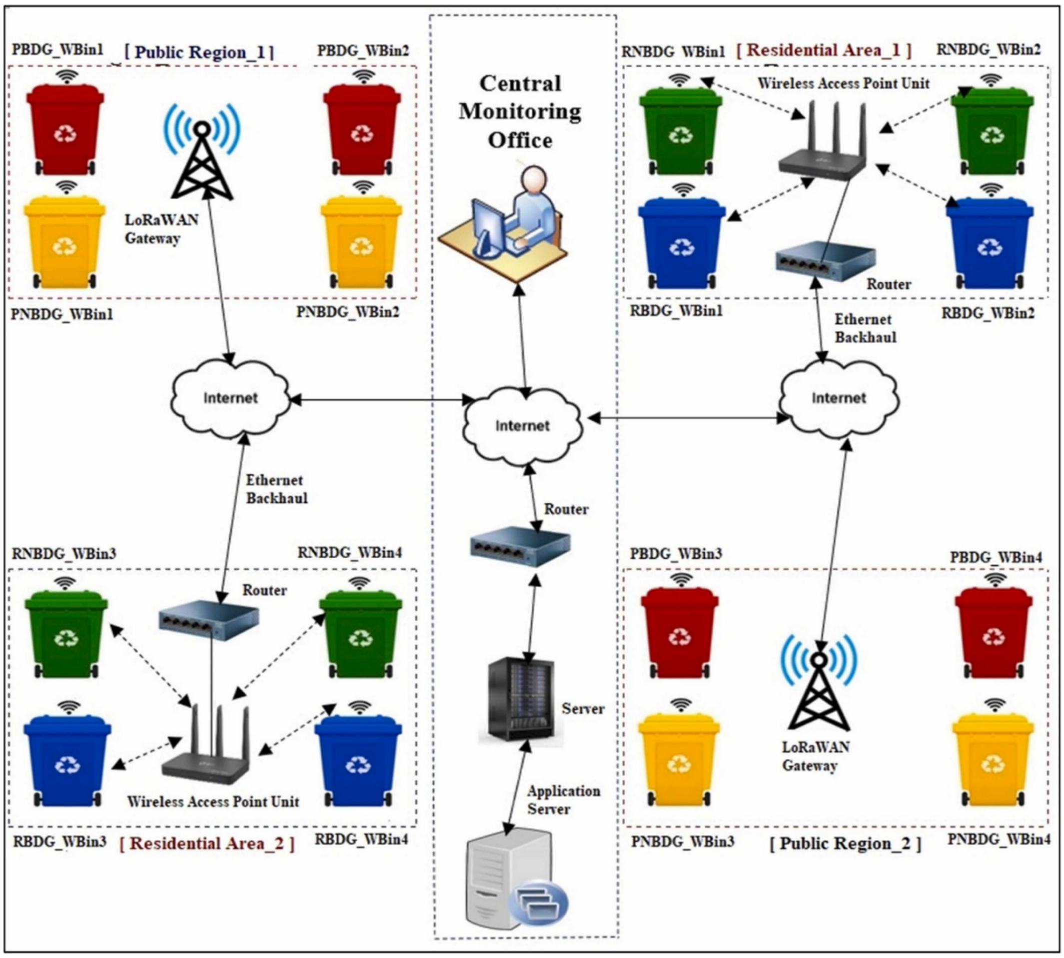

Figure 4: Architecture of the proposed framework

Wi-Fi and LoRaWAN are two of the most extensively used technologies, and when combined, they cover a wide spectrum of IoT use cases. LoRaWAN stands for low-power, wide-area network, and it is a network protocol created specifically for wirelessly linking battery-operated "things" to the Internet and other worldwide networks.

It covers critical Internet of Things requirements such as bidirectional communication and end-to-end security, mobility, and location services. Wi-Fi provides high data speeds for short- and medium-range use cases at what appears to be a penalty in battery life. LoRaWAN accommodates low-frequency device communications across great distances, allowing for battery lifetimes of up to ten years. The LoRaWAN network architecture connects IoT devices, gateways, network servers, and application servers in a star topology. In LoRaWAN operations, the LoRaWAN gateway collects data from IoT devices and sends it to the application server. Wireless communication makes use of the LoRa physical layer's long-range features, enabling a one-hop link between the end device and one or more gateways.

This framework intends to depict how LoRaWAN may be implemented alongside an existing Wi-Fi network while allowing operational cost minimization. A mutualized deployment's lower cost and operational efficiency become obvious compared to establishing both networks independently. By creating convergent solutions, users may benefit from the complementarity of Wi-Fi and LoRaWAN. Collect data via LoRaWAN on Access Points from various devices across the facility and transmit data to network servers via Wi-Fi.

3. Results and Discussion

3.1. Data Analysis

The level of fill and location were transmitted to a remote IoT server. From the data analyzed ESP32 for data transmission is very efficient because it can support various communication protocols, such as MQTT (Message Queuing Telemetry Transport) and HTTP (Hypertext Transfer Protocol). This flexibility makes it adaptable to a wide range of IoT (Internet of Things) applications, where efficient and reliable data exchange is crucial. The ESP32's compatibility with low-power modes also contributes to its suitability for battery-operated devices in IoT ecosystems. Overall, the ESP32 stands out as a powerful and versatile solution for data transmission, enabling developers to create efficient and connected systems in diverse applications.

3.2. Results

This section presents the obtained results in the form of data extracted from the Waste Management sensor system, which was mainly part-daily time frequency data. A small dataset is a dataset with a small number of samples. The quantity of *small* depends on the nature of the problem to be solved. In this case study, the data provided is categorized as *small,* and due to the small dataset provided, we encounter at least the following issues:

1. Outliers - an outlier is a sample that significantly deviates from the rest of the dataset.
2. Overfitting - an analysis performs well with the training set, but it has poor performance with the test.

Table 1: Time Series Data

Datetime	waste disposal rate (Hours)	Bin Status	Population
11/1/23 2:43 PM	0	FILLED	70
11/2/23 11:18 AM	20.58	FILLED	39
11/3/23 3:29 PM	28.18	FILLED	52
11/6/23 10:14 AM	66.75	FILLED	30
11/7/23 1:50 PM	27.60	FILLED	25
11/8/23 2:01 PM	24.18	FILLED	61
11/9/23 12:37 PM	22.60	FILLED	63
11/10/23 2:14 PM	25.62	FILLED	44
11/13/23 11:56 AM	69.70	FILLED	35
11/14/23 3:47 PM	27.85	FILLED	30
11/15/23 4:33 PM	24.77	FILLED	51
11/16/23 12:24 PM	19.85	FILLED	69
11/17/23 10:55 AM	22.52	FILLED	32
11/20/23 1:16 PM	74.35	FILLED	29

Datetime	waste disposal rate (Hours)	Bin Status	Population
11/21/23 2:09 PM	24.88	FILLED	34
11/22/23 4:02 PM	25.88	FILLED	70
11/23/23 3:08 PM	23.10	FILLED	64
11/24/23 10:42 AM	19.57	FILLED	52
11/27/23 3:22 PM	76.67	FILLED	21
11/28/23 4:14 PM	24.87	FILLED	29
11/29/23 1:45 PM	21.52	FILLED	51
11/30/23 10:29 AM	20.73	FILLED	53
12/1/23 1:58 PM	27.48	FILLED	22
12/4/23 3:36 PM	73.63	FILLED	20
12/5/23 2:53 PM	23.28	FILLED	29
12/6/23 11:44 AM	20.85	FILLED	81
12/7/23 4:28 PM	28.73	FILLED	86
12/8/23 2:38 PM	22.17	FILLED	70
12/11/23 4:50 PM	74.20	FILLED	30

Table 1 presents a summary of the time series data where the waste disposal rate and population were calculated and provided, respectively. The waste disposal rate was calculated as the difference between the previous date and the current date, which was represented in hours

The general process of analyzing the data is listed below:

1. Collect the data.
2. Clean the data.
3. Evaluate the data.
4. Visualize the data
5. Descriptive analysis.

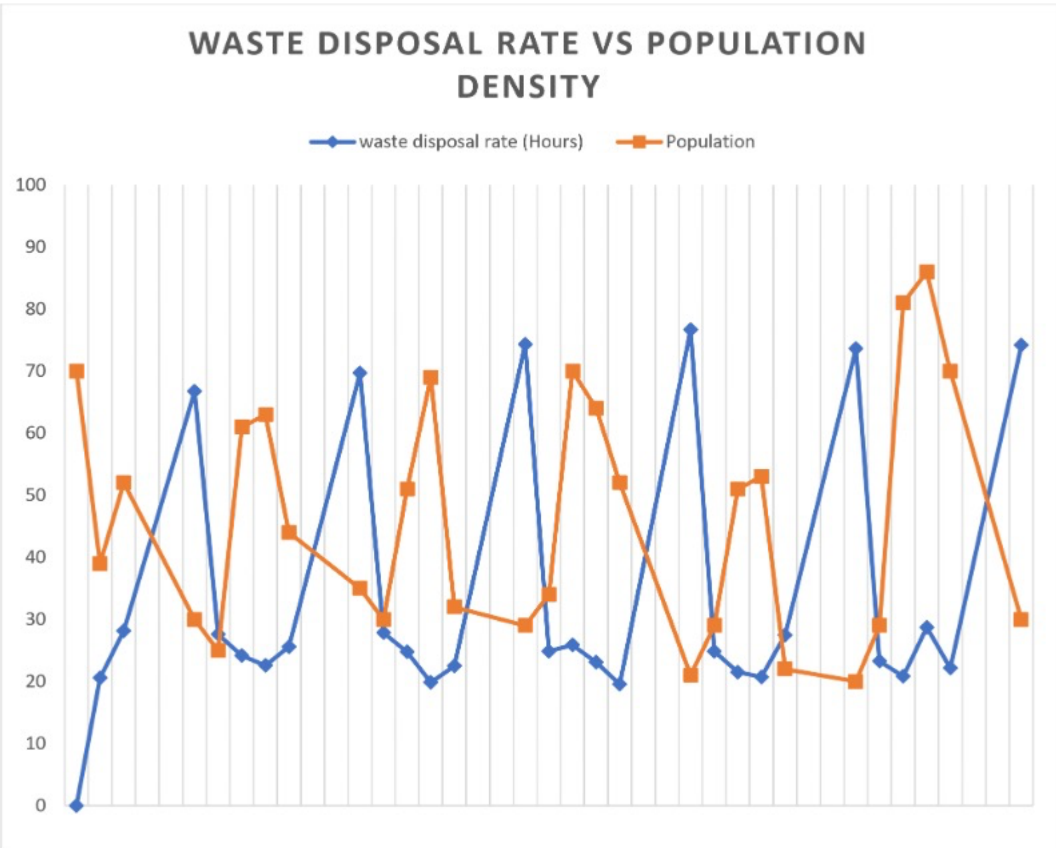

Figure 4: Waste Disposal Rate VS Population Density

From the graph, we can see that the waste disposal rate typically correlates with population size. As the population increases, so does the generation of waste due to consumption and daily activities, and the waste disposal rate in hours decreases.

3.3. Discussion of Graphical Analysis of Waste Disposal Rate and Population Correlation

The graphical representation of the obtained results provides valuable insights into the dynamics of waste disposal, particularly about population size. By identifying the top 5 highest and lowest days, we can discern patterns that contribute to strategic decision-making for waste management optimization.

Factors affecting waste disposal rate are:

1. Economic Development: Generally, economically developed areas produce more waste as they often have higher consumption patterns, increased industrial activity, and more disposable income.
2. Urbanization: Urban areas typically generate more waste than rural areas because of concentrated populations and industrial activities.
3. Consumer Behaviour: Individual and community consumption habits play a significant role. Regions with a culture of disposable products and single-use items may generate more waste.
4. Industrial Activity: The presence of industries and manufacturing activities can contribute to increased waste production.

4. Conclusion

In conclusion, this work has successfully addressed the inherent challenges within traditional waste management systems by designing and implementing IoT-enabled smart bins. The research commenced with a comprehensive exploration of the existing inefficiencies in waste disposal practices, propelling the study towards innovative solutions. The scope of the investigation involved the meticulous construction of smart bins, incorporating advanced IoT technologies and real-time waste level monitoring to optimize waste management processes. Anchored by a robust theoretical framework, including models like the Technology Acceptance Model and Innovation Diffusion Theory, the study achieved its overarching goal of transforming urban waste disposal practices. It is recommended that for there to be proper waste management, there should be continuous monitoring and maintenance, data-driven decisions, and collaborative continuous research on IoT.

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