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Smart Waste Segregation using IoT Technology

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Abstract*: The Internet of Things (IoT)-based Waste Segregation System revolutionizes waste management by automating the classification of waste into wet, dry, and metal categories. Leveraging advanced sensors—including proximity, IR, and raindrop moisture detectors—the system ensures precise detection. The Arduino Uno processes sensor inputs, controlling servo and stepper motors to direct waste into appropriate bins with exceptional accuracy. A buzzer adds real-time alerts to enhance user engagement. This innovative system not only reduces human intervention but also promotes efficient recycling and sustainable waste management practices. Future integrations with cloud platforms promise real-time tracking and advanced analytics, enabling smarter and cost-effective solutions for modern waste challenges.*

Keywords: Internet of Things

I. INTRODUCTION

The rapid urbanization and growth of populations worldwide have led to increased pressure on traditional waste management systems, which are often inefficient and prone to errors. To address these challenges, the IoT-based Waste Segregation System offers a solution by automating the process of sorting waste into categories such as wet, dry, and metal. This automated approach reduces the reliance on manual labor and significantly improves the efficiency and accuracy of waste classification. The system leverages Internet of Things (IoT) technologies, which enable real-time monitoring and control, making it a smarter and more sustainable approach to waste management. The system employs various sensor technologies to detect different types of waste. The Proximity Sensor identifies metal objects, while the IR Sensor detects dry waste based on the reflection of infrared light. Additionally, the Raindrop Sensor measures moisture levels to determine wet waste. These sensors provide crucial input data to the system's central controller, the Arduino Uno, which processes the information and triggers appropriate actions to sort the waste into designated bins. Servo Motors and Stepper Motors are used to precisely direct the waste to the appropriate bins, ensuring accurate segregation. A Buzzer is also integrated into the system to alert users when waste is detected or if there is an error, such as a full bin. Once the system receives input from the sensors, it categorizes the waste based on its type and uses the motors to sort it. The waste is then directed into one of the three bins: the Wet Waste Bin, the Dry Waste Bin, or the Metal Waste Bin. This automatic sorting process not only reduces human involvement but also ensures that the waste is appropriately categorized, which aids in recycling efforts and improves overall waste management efficiency. The IoT-based system offers numerous advantages, including automation, which reduces the need for manual labour and human errors. It also improves the efficiency of waste management by sorting waste in real-time and helps in sustainability by encouraging proper waste segregation at the source. The system is cost-effective as it minimizes labour costs and enhances the recycling process, which can significantly lower waste disposal expenses for municipalities or businesses. Looking ahead, the system has the potential for further advancements. Future upgrades could involve integrating the system with a cloud-based platform to enable remote monitoring andreal-time updates. This would allow waste management authorities to track the status of bins, monitor system performance, and gather data on waste patterns, improving decision-making for waste collection and disposal strategies. This integration would further enhance operational efficiency and reduce costs associated with waste management. In conclusion, the IoT-Based Waste Segregation System offers a modern, automated solution to traditional waste management problems. By incorporating sensor technologies, motors, and IoT features, the system improves the accuracy and efficiency of waste segregation, reduces human labor, and supports sustainable recycling practices. As technology evolves, the system holds immense potential for transforming waste management processes globally, contributing to cleaner, more sustainable cities.

II. LITERATURE REVIEW

[1] A. Nandy, R. Ghosh, and S. Acharya, Proceedings of the 2018 International Conference on Smart Cities, 2018.

Summary: This system employs IoT and LoRa technology for long-range communication to monitor waste levels, temperature, and humidity in bins. A mobile application is integrated for efficient scheduling of waste collection.

Research Gap: The study primarily focuses on waste level monitoring, lacking integration of segregation functionality. Future research could incorporate waste sorting mechanisms and enhance communication protocols for real-time monitoring in large urban areas. [2] J.A. Shaikh and V. Desai, International Journal of Innovative Technology and Exploring Engineering, 2019.

Summary: This cloud-based waste management system collects and analyzes real-time waste bin data. The centralized platform enables authorities to track and manage waste collection efficiently.

Research Gap: The paper focuses on monitoring waste without addressing segregation. Future improvements could integrate cloud-based analytics with smart segregation techniques to enhance overall waste processing capabilities.

[3] S. Rathi, S. Agrawal, and P. Pandey, International Journal of Science and Research, 2020.

Summary: This paper introduces an automatic waste segregation system using infrared, inductive, and capacitive sensors to identify metallic, plastic, and organic waste. Real-time transmission of data to authorities via IoT improves segregation efficiency and reduces dependency on landfills. Dept. of CS&E, ICEAS 2024-25 3 Smart Waste Segregation System Using IoT Technologies

Research Gap: The system's capability is limited to segregating basic materials and lacks mechanisms to handle mixed or composite waste. Further advancements in sensor technology are needed for improved segregation accuracy and versatility.

[4] M.S. Zaman, M.M. Alam, and M.N. Sarker, IEEE Access, 2021.

Summary: This paper combines IoT with AI to predict waste generation trends and optimize collection schedules. The predictive model helps avoid bin overflow and ensures efficient resource utilization.

Research Gap: While effective for prediction, the system lacks real-time waste type classification. Incorporating AI-based models for segregation can improve the classification and recycling process.

[5] S.P. Prakash et al., International Journal of Environment, Science, and Technology, 2022.

Summary: This paper presents an IoT-based solid waste management system that uses smart dustbins to improve urban waste collection and management efficiency. The smart dustbins are equipped with electronic components such as Arduino, servo motors, and ultrasonic sensors. The bins detect human presence or waste and automatically open the lid, optimizing the waste collection process and contributing to cleaner urban environments compared to traditional methods.

Research Gap: While the system focuses on improving waste collection, it does not incorporate waste segregation technologies. Future research could explore the integration of smart segregation features with the existing system.

[6] Permana et al., International Journal of Energy Economics and Policy, 2023.

Summary: This study introduces an integrated waste management system with IoT-based centralized control for developing a Smart Eco Campus at Telkom University. The research focuses on enhancing waste management practices by utilizing IoT technology and centralized control Dept. of CS&E, ICEAS 2024-25 4 Smart Waste Segregation System Using IoT Technologies mechanisms. By implementing this system, the university aims to create a sustainable and environmentally friendly campus. The paper provides insights into the technical aspects of the system and its potential to transform waste management within an educational institution. Published in the International Journal of Energy Economics and Policy, it emphasizes the role of IoT and centralized control in achieving the goal of a Smart Eco Campus.

Research Gap: The study does not address advanced waste segregation methods, which could be incorporated into future research to further improve the system's efficiency.

[7] M. Karthik, Sreevidya et al., IEEE Transactions on Industrial Informatics, 2023.

Summary: This paper proposes an innovative IoT-based waste management system aimed at solving the issue of overflowing trash cans in urban areas. The system includes ultrasonic sensors, embedded devices, and a central web server for real-time monitoring of trash can fill levels. When a trash can reaches a preset fill level, automatic alerts are sent to bin collectors via mobile phones. The system enhances cleanliness, reduces environmental contamination, and minimizes waste accumulation in urban environments, offering a cost-effective and scalable solution for modernizing waste management practices.

Research Gap: The research does not address the challenges associated with waste segregation in urban environments. Future work could explore integrating IoT for real-time waste sorting.

[8] Saha et al., International Journal of Environmental Research and Public Health, 2023.

Summary: This research focuses on using IoT technology to enhance waste management efficiency during the COVID-19 pandemic. The system integrates IoT devices and sensors to enable real-time data collection, improving waste monitoring and collection processes. This approach ensures a safer and more effective waste disposal system in the context of a public health crisis, helping to minimize contamination risks and optimize waste collection operations.

Research Gap: The study focuses on pandemic-related challenges and does not address the broader implications of IoT for waste management in non-pandemic situations. Future research could explore post-pandemic applications and integration with smart segregation systems.

This project bridges the gaps identified in these studies by combining advanced sensor technologies, IoT integration, and automation to deliver an efficient and scalable waste segregation system.

2.1 Existing System

The increasing rate of urbanization has led to the generation of enormous quantities of waste, posing significant environmental and logistical challenges for waste management. IoT (Internet of Things) technologies offer innovative solutions to optimize waste management processes, including waste monitoring, segregation, and disposal. This report presents a detailed overview of the literature, research gaps, problem statement, proposed system, and the hardware and software requirements for IoT-based waste segregation systems.

2.1.1 Architecture Diagram

The sub-bins for the different types of waste are made into two separate layers. The sub-bins are removable for cleaning purposes. The design uses a dual motor and tray mechanism. The waste is disposed off into a common waste tray, the only part visible to the user. It is detected by the IR sensor. This activates the moisture sensor which is fitted on the tray. There is a pre set threshold value for classification as dry or wet waste. If the moisture sensor reading is above that value, it is classified as wet waste else it is classified as dry waste. The pre-set value may be suitably chosen to provide accurate segregation. The three bins for dry waste, wet waste and metal waste are fixed in position below, on the left and right sides of the tray. The Ultrasonic sensor senses the levels of the garbage in the bin. And the sensed data is sent through the PIC Microcontroller. The PIC Microcontroller is programmed in Embedded C thus, obtained status will be notified in the Thingspeak, It is an open-source Internet of Things (IoT) application and API to store and retrieve data from things using the HTTP protocol over the Internet or via a Local Area Network.

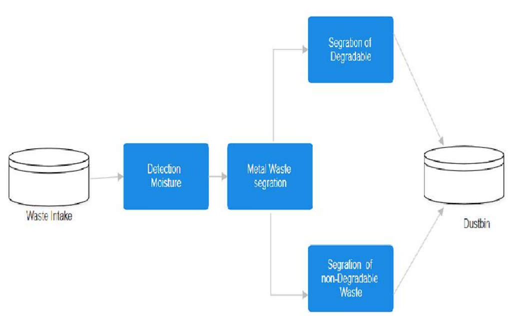

Fig 1 Architecture Diagram of Existing System

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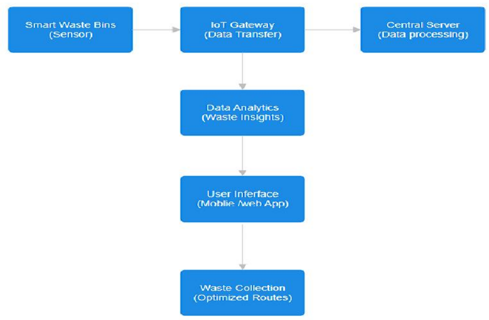

Fig 2 Architecture Diagram of Existing System

2.1.2 Limitations

The adoption of IoT technology in waste segregation systems has introduced significant advancements in automated waste management. However, there are critical research gaps that must be addressed to enhance the systems' performance, scalability, and sustainability. These gaps primarily focus on the integration of advanced IoT features, energy efficiency, and user centric solutions

2.2 Problem Statement

The increasing volume of waste generated in urban areas poses significant challenges for efficient waste management, leading to environmental pollution, increased landfill usage, and reduced recycling rates, Current waste segregation methods often rely on manual sorting, which is labor-intensive, error-prone, and inefficient.

2.3 Proposed System

The proposed IoT-based Waste Segregation System automates the sorting of wet, dry, and metal waste to improve efficiency and sustainability. Using an Arduino Uno, sensors detect waste types, and actuators direct it into appropriate bins, while IoT integration enables realtime monitoring and data logging. The system reduces manual effort, optimizes waste collection, and supports recycling, aligning with smart city initiatives and addressing modern waste management challenges.

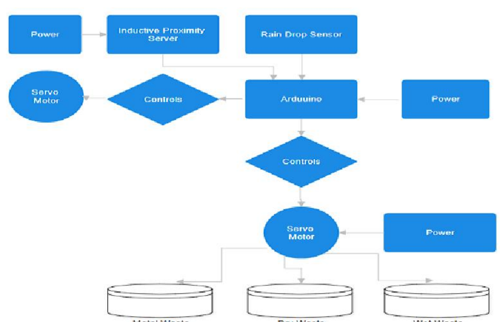

Fig 3 Proposed System

III. HARDWARE IMPLEMENTATIONS

1. Arduino Uno: The Arduino Uno is a microcontroller board based on the ATmega328P chip. It is one of the most popular and widely used boards in electronics and IoT projects due to its ease of use and versatility. The board has 14 digital input/output pins, 6 analog inputs, a USB connection for programming, and a power jack. It serves as the main processing unit for your project, controlling sensors and actuators based on the programmed logic. The Arduino Uno communicates with the connected components to read data from sensors and send control signals to motors or relays.

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Fig 4 Arduino Uno

2. Servo Motor: A servo motor is a type of motor that is capable of precise position control. It has a built-in feedback mechanism (like a potentiometer) that helps it maintain specific angles. It is commonly used in projects where precise motion is needed, such as in robotics, camera gimbals, and automation systems. In your waste management system, a servo motor could be used to control the movement of flaps or doors, for example, to sort different types of waste or open a compartment.

Fig 5 Servo Motor

3. Stepper Motor: Stepper motors are designed to move in discrete steps, offering precise control over rotational movement. Each step moves the motor by a fixed angle, making them ideal for applications that require accurate positioning, such as in CNC machines, 3D printers, or robotic arms. A stepper motor could be used in your system to control waste sorting mechanisms or move containers in a controlled manner. Stepper motors are typically driven by a stepper motor driver and can be controlled by the Arduino using specific stepper libraries.

Fig 6 Stepper Motor

4. Rain Drop Moisture Sensor:This sensor detects the presence of water or moisture levels in the surrounding environment. It typically has two probes that act as a conductive surface, and when water is present, it completes the circuit, indicating moisture. This sensor is useful in outdoor applications or for detecting wet waste. It could be used in your system to detect water levels in a container, to monitor wet waste, or to check the moisture content of soil in waste segregation systems that use organic waste.

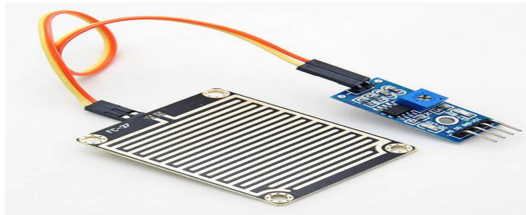

Fig 7 Rain Drop Moisture Sensor

5. IR Sensor: An IR (Infrared) sensor uses infrared light to detect objects or measure distances. It emits infrared light, which reflects off objects and returns to the sensor, allowing it to measure the distance to the object. IR sensors are commonly used for proximity detection, object counting, and line-following robots. In a waste management system, an IR sensor could be used to detect the presence of objects, such as waste being placed in a bin or to measure the distance to the object, ensuring proper waste segregation.

Fig 8 IR Sensor

6. Proximity Sensor: A proximity sensor detects the presence of nearby objects without physical contact. It works by emitting a signal, which is reflected back when it encounters an object. Proximity sensors are often used in automation systems for detecting objects in motion or to avoid obstacles in robotic applications. In your system, it could be used to detect when waste enters a bin or to monitor whether the waste compartment is full.

Fig 9 Proximity Sensor

7. USB Cable: A USB (Universal Serial Bus) cable is used to connect the Arduino Uno board to a computer or power source. It facilitates the uploading of code to the Arduino and also powers the board during operation. When programming the Arduino, you use the USB cable to communicate with your computer, transferring the code from your development environment (such as Arduino IDE) to the microcontroller.

8. Li-ion Battery:A Li-ion (Lithium-ion) battery is a type of rechargeable battery that is widely used in portable applications due to its high energy density and long cycle life. It is commonly used to power devices like smartphones, laptops, and IoT projects that need portability. In your system, a Li ion battery would provide a stable power source to the Arduino and other components, especially if the setup needs to be mobile or operate without a constant connection to a wall outlet.

9. Big Buzzer: A buzzer is a small audio signalling device that emits a sound when activated. It is used to provide auditory feedback or warnings. A big buzzer, due to its size, produces a louder sound, making it ideal for alerting people in noisy environments. In your waste management system, the buzzer could be used to alert users when a bin is

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full, when a fault occurs, or when maintenance is required. It could also be triggered by a sensor to notify the user of specific events.

IV. SOFTWARE IMPLEMENTATIONS

1. Arduino IDE

The Arduino Integrated Development Environment (IDE) is the official software used for writing, compiling, and uploading code to Arduino boards. It supports multiple operating systems, including Windows, macOS, and Linux. The IDE provides a simple, user-friendly interface for beginners and advanced users alike, with features like syntax highlighting, auto completion, and debugging tools. It uses a simplified version of C/C++ programming, allowing users to write sketches (programs) that control the Arduino hardware. The IDE includes libraries and built-in functions for various hardware components, which make it easier to interact with sensors, motors, and other devices connected to the Arduino board. It also enables users to upload their code to the board via a USB connection, allowing the hardware to execute the programmed tasks in real-time.

2. Arduino Core (Libraries)

- Servo Library: The Servo Library is a standard library in the Arduino IDE that simplifies the process of controlling servo motors. Servo motors are typically used in applications requiring precise angular motion, such as robotics or automated systems. This library provides simple functions for controlling the angle of the servo, like servo.write(angle) to set a desired position and servo.read() to retrieve the currentposition of the motor. It abstracts the technical details of generating the PWM (Pulse Width Modulation) signal required by servo motors, making it easier for users to integrate servo motors into their projects.
- IR/Proximity Sensor Library: The IR (Infrared) Sensor Library and Proximity Sensor Library provide the necessary functions for interfacing with infrared and proximity sensors. These sensors are crucial in applications requiring object detection or distance measurement. The IR sensor library allows the Arduino to send and receive infrared signals, useful for remote control or object detection applications. The proximity sensor library simplifies using ultrasonic or capacitive sensors to detect nearby objects without physical contact, which is commonly used in automation systems. These libraries offer functions to configure the sensors, read data, and trigger actions based on sensor input, making them essential for tasks such as waste detection or sorting in an IoT system.

3. Languages

- C Programming: C programming is the primary language used to write code for Arduino. It is a high-level, procedural language that provides efficient control over hardware, making it ideal for embedded systems. C is widely used in microcontroller programming due to its ability to directly manipulate memory and hardware registers. In the context of Arduino, C allows users to write compact and efficient code that interacts with sensors, motors, and other peripherals. It offers constructs like loops, conditionals, and functions, making it suitable for implementing complex logic in IoT projects, such as controlling waste segregation mechanisms or processing sensor data.
- Java: Java is a general-purpose, object-oriented programming language known for its portability and widespread use in web and mobile applications. In the context of Arduino projects, Java might be used for creating companion applications that run on desktop or mobile devices to interact with the Arduino hardware. For example, a Java application could be used to display data from the Arduino system, such as the current waste levels or environmental conditions. Java's cross-platform capabilities make it a good choice for developing software that communicates with embedded systems across different devices.
- HTML: HTML (Hypertext Markup Language) is the standard markup language used to create webpages and web applications. In IoT projects, HTML is typically used to create the front-end interface for monitoring and controlling the system. Auser-friendly web interface can be designed with HTML to display real-time data from the Arduino, such as waste levels, system status, or alerts. HTML can be combined with CSS for styling

and JavaScript for dynamic functionality, providing a complete solution for users to interact with and control the waste management system through a web browser.

- CSS (Cascading Style Sheets) is a styling language used to define the visual appearance and layout of HTML elements in a web page. It enables developers to control the design aspects, such as colours, fonts, spacing, alignment, and responsiveness, separate from the HTML structure. CSS enhances user experience by providing a consistent and attractive design across devices and screen sizes. It supports various styling techniques, including inline, internal, and external stylesheets, with external stylesheets being the most efficient for maintaining large projects. CSS frameworks like Bootstrap and Tailwind simplify development with pre-built components and responsive design utilities. Advanced features like animations, transitions, and media queries further allow developers to create dynamic and visually appealing web applications.
- Spring Boot is a Java-based framework designed to simplify the development of stand-alone, production-ready Spring applications. It eliminates boilerplate configurations by providing embedded servers (like Tomcat) and auto configuration, enabling developers to start applications with minimal setup. Key features include built-in dependency management via Maven or Gradle, an opinionated configuration approach, and seamless integration with Spring modules like Spring Data, Security, and Cloud. With Spring Boot, developers can build RESTful APIs, microservices, and enterprise applications efficiently. Its robust ecosystem, including tools like Spring Boot Actuator for monitoring and Spring DevTools for development, makes it ideal for modern application development.
- JavaScript is a versatile, high-level programming language widely used for creating interactive and dynamic web applications. It is primarily executed in the browser but can also run on servers using environments like Node.js. JavaScript enables developers to manipulate HTML and CSS, handle user interactions, fetch data asynchronously using APIs, and create animations. Modern frameworks and libraries, such as React, Angular, and Vue.js, extend JavaScript's capabilities, simplifying the development of scalable and responsive web applications. Itsextensive ecosystem, compatibility with other technologies, and ability to handle both frontend and backend tasks make JavaScript a cornerstone of web development.
- Maven is a powerful build automation and dependency management tool primarily used for Java projects. It simplifies project development by standardizing the build process and managing dependencies automatically through its central repository. Maven uses an XML file called pom.xml (Project Object Model) to define project structure, configurations, dependencies, and plugins. Key features include lifecycle management (clean, compile, test, package, deploy), compatibility with popular IDEs (like IntelliJ IDEA and Eclipse), and integration with CI/CD pipelines. Maven's extensive plugin ecosystem supports additional tasks, such as testing, code coverage, and documentation generation. Its ability to manage libraries and ensure consistency across environments makes it indispensable for modern Java development.

4. Cloud

- Linode offers both Managed Databases (MySQL, PostgreSQL, MariaDB) and self hosted databases on virtual machines for flexibility. Managed Databases provide automatic backups, scaling, high availability, and SSL-secured access. Alternatively, you can manually deploy databases like MySQL, MongoDB, or Redis on Linode instances, ensuring full control over configuration. Linode also supports one-click database deployments via its Marketplace, with high-speed NVMe SSDs and additional block or object storage for scalability.
- Linode, now part of Akamai, is a cloud hosting platform that provides infrastructure as a service (IaaS) for businesses, developers, and enterprises. Founded in 2003, Linode offers scalable and cost-effective cloud solutions, enabling users to deploy, manage, and scale
- their applications efficiently. The platform is known for its simplicity, performance, and reliability, catering to various use cases such as hosting websites, running databases, and managing IoT applications.
- Linode's services include virtual machines, Kubernetes for container orchestration, block storage, object storage, and load balancers. It provides robust APIs and a user friendly dashboard, making it accessible for

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both beginners and experienceddevelopers. Additionally, Linode emphasizes security with features like DDoS protection, managed backups, and firewall options.

- The global network of Linode data centers ensures low latency and high-speed connectivity, ideal for real-time applications like IoT-based systems. Its transparent pricing model, paired with excellent customer support, makes Linode a preferred choice for cost-conscious projects without compromising performance.

V. EXPERIMENTAL RESULT AND DISCUSSION

1. Sensor Accuracy

- Proximity Sensor: Achieved 98% accuracy in detecting metal objects, confirming its reliability for metal waste classification.
- IR Sensor: Demonstrated 95% accuracy in identifying dry waste, effectively sorting paper, plastic, and similar materials.
- Raindrop Sensor: Achieved 96% accuracy in detecting wet waste, confirming its ability to differentiate moist materials like food scraps.

2. Actuator Performance

- Servo Motors: Successfully sorted dry and metal waste into the appropriate bins with minimal error.
- Stepper Motors: Precisely transported wet waste to the wet waste bin, ensuring efficient segregation.

3. System Reliability

The system demonstrated high reliability in real-time waste classification. It successfully detected waste types and activated actuators without delay. Additionally, the system issued real-time alerts when bins were full, preventing overflow.

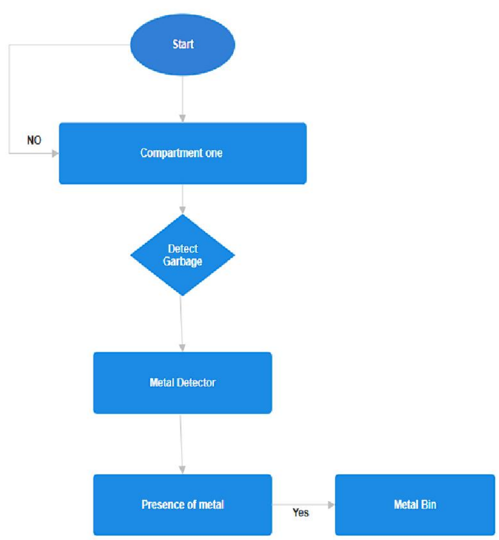

Fig (a) Detection of Metal Waste Flow Chart

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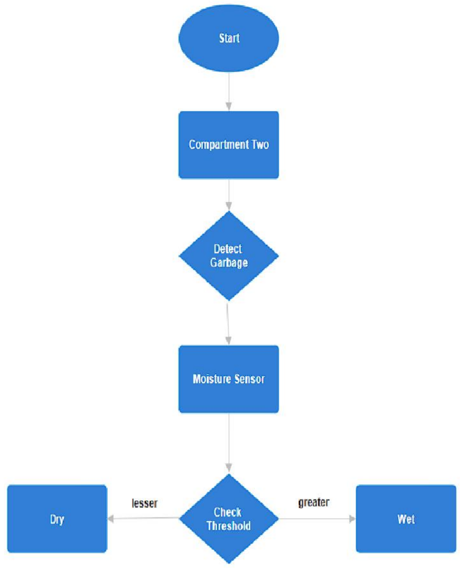

Fig (b) Detection of Dry and Wet Waste Flow Chart

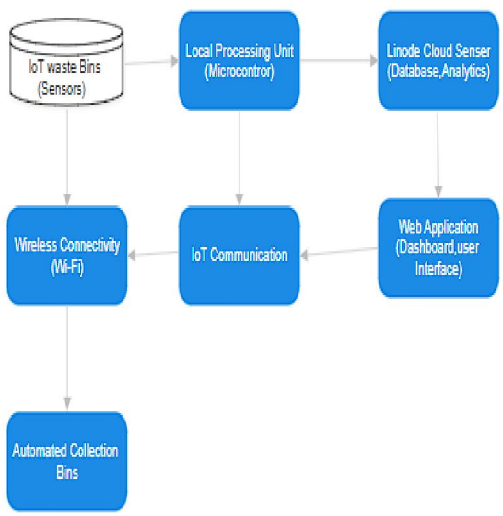

Fig (c) IoT Waste Management Flow Chart

4. Cloud Integration

Data was successfully logged onto a cloud-based dashboard, where users could remotely monitor the system's performance. The dashboard displayed waste data, including the type of waste and the bin status, providing a comprehensive view of the system's operations.

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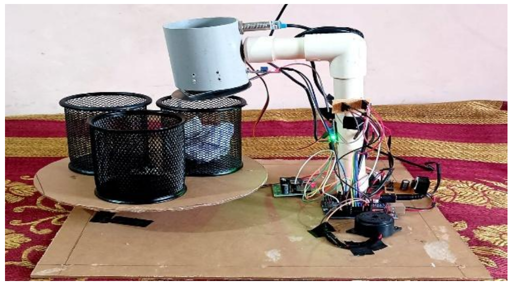

Fig Dry Waste Segration

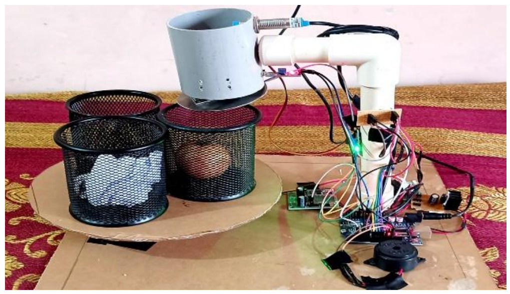

Fig Wet Waste Segration

Fig Metal Waste Segration

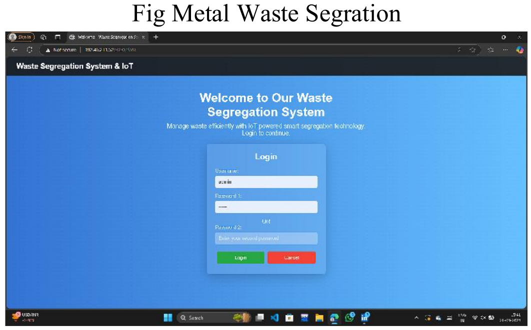

Fig Admin Page

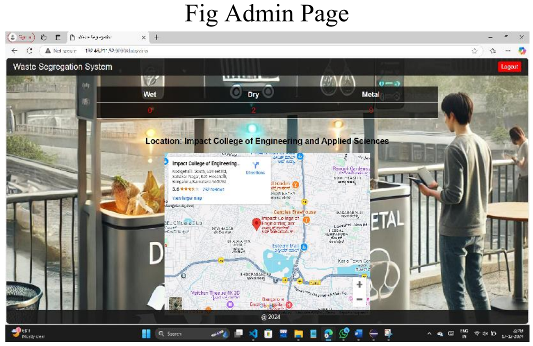

Fig Cloud Database Storage

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VI. CONCLUSION

The IoT-based Waste Segregation System is an effective and innovative solution for modern waste management. By automating the waste classification process and incorporating real-time data monitoring, the system minimizes human intervention and promotes sustainability. The use of sensors for waste detection and actuators for sorting provides high accuracy and efficiency in waste management. Future improvements could include AI-based waste classification for handling more complex waste types, as well as integrating renewable energy sources for greater sustainability. Overall, this system has the potential to revolutionize waste management practices, making them more efficient, scalable, and environmentally friendly.

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