Smart Waste Collection Management System

18ECP107L- MINOR PROJECT

A PROJECT REPORT

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BONAFIDE CERTIFICATE

Certified that this project report titled **Smart Waste Collection Management System** is the bonafide work **Vimala Prakash S [Reg No: RA2111004010406], Kamalraj S [Reg No: RA2111004010418], Akash M [Reg No: RA2111004010356],** who carried out the 18ECP107L-Minor Project work under my supervision. Certified further, that to the best of my knowledge, the work reported herein does not form any other project report or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

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ABSTRACT

Waste management remains a critical challenge in urban areas due to the increasing volume of waste and inefficient segregation practices. Poor waste segregation at the source leads to contamination of recyclable materials, increased landfill use, and higher processing costs, making it difficult to implement sustainable waste management systems. To address these issues, this project proposes a smart bin system that leverages Internet of Things (IoT) technology and advanced sensors such as moisture sensors, inductive proximity sensors, and capacitive proximity sensors. The smart bin automates the identification and segregation of waste into organic, metallic, and non-metallic categories, promoting source segregation as a key solution to the waste management problem. By accurately segregating waste at the point of disposal, this system reduces the need for manual sorting and improves the efficiency of recycling processes. The data collected through the sensors is transmitted to a cloud platform for real-time monitoring and analysis, enabling better decision-making in waste management strategies. This automated solution aims to enhance sustainability efforts by reducing environmental pollution and improving resource recovery rates, making it a scalable and effective approach for modern cities.

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TABLE OF CONTENTS

LIST OF FIGURES

ABBREVIATIONS

ADC	Analog to Digital Converter
DAC	Digital to Analog Converter
ESP	Espressif
IoT	Internet of Things
Wi-Fi	Wireless Fidelity

CHAPTER 1

INTRODUCTION

Trash management is a pressing issue, particularly in developing countries where rapid industrialization and urbanization have significantly increased waste generation. With population growth, the amount of waste produced rises annually, creating hazardous conditions and posing challenges to sustainable waste management. Piling garbage in large landfills occupies vast stretches of land, releasing harmful gases that pollute the atmosphere. Additionally, disposing of waste in water bodies contaminates oceans, affecting aquatic ecosystems, and diminishing the quality of drinking water. Neglecting environmental cleanliness in favor of development has led to numerous illnesses and health issues, highlighting the urgent need for improved waste management.

An effective approach to waste management is to categorize waste into three types: wet, dry, and metallic. This segregation enables better disposal, aligning with the principles of Reuse, Reduce, and Recycle. Metallic and dry waste can be recycled, while wet waste can be decomposed to create compost for plants, supporting agriculture and reducing the burden on landfills.

The Internet of Things (IoT) offers a solution to enhance waste management by automating the sorting process. IoT, known for connecting devices and facilitating data sharing, utilizes sensors, motors, and microcontrollers to streamline operations. A smart trash can, integrated with IoT, can automate waste segregation and provide real-time monitoring of waste levels, addressing several challenges in traditional waste collection.

In a smart bin system, electrical components such as sensors and Arduino technology detect and categorize waste. Metal proximity sensors identify metallic items, while capacitive proximity sensors distinguish non-metallic and organic waste. By automatically sorting waste into metal, non-metal, and wet categories, this system reduces the need for manual sorting, minimizes contamination, and makes recycling more efficient. As societies become increasingly automated, such IoT-based solutions offer a path toward sustainable waste management, reducing environmental pollution, conserving resources, and fostering cleaner, healthier communities.

CHAPTER 2

LITERATURE SURVEY

This section showcases articles relevant to our study and their contribution to our success.

Jeberson Retna Raj et.al presents an IoT-enabled waste segregation system to address urban waste management challenges. Using IR, moisture, and metal sensors, it classifies waste into biodegradable and non-biodegradable categories. A conveyor belt with DC motors ensures smooth waste transfer, while sensor data is stored in the cloud for monitoring. The system accurately segregates waste, enabling efficient recycling and reducing environmental impact by minimizing greenhouse gas emissions from traditional disposal methods. This automated solution promotes sustainability and simplifies waste management in cities.

Cherry Agarwal et.al introduces an automated waste segregation system designed to enhance cleanliness in smart cities. It uses a conveyor belt and sensors to classify waste into wet, dry, or metal, and sorts it into three bins. Servo motors handle the deflection, while ultrasonic sensors monitor bin levels and notify authorities when they are full. The system, powered by Arduino UNO and programmed in Embedded C, reduces human intervention and optimizes waste collection. India's growing waste problem underscores the need for such solutions, and future improvements could include solar power, advanced segregation methods, and increased storage capacity.

Sanathkumar G et.al highlights the rapid increase in global waste generation, driven by population growth, urbanization, and economic development, with current estimates at 2.01 billion tonnes annually, projected to rise to 3.04 billion by 2050. Many countries face challenges with proper waste collection, segregation, and disposal, which can lead to environmental hazards. The author emphasizes that recycling begins with segregation at the source, but current systems lack a one-stop solution for sorting waste into categories like glass, plastic, metal, and wet waste. The proposed system automates waste segregation using sensors and an image classifier to categorize waste efficiently, reducing the need for manual labor and lowering occupational risks. Operating at low power and cost, the system provides an easy-to-use solution. Future enhancements could include chemical sensors for detecting hazardous materials, improved mixed waste handling, IoT integration for data analytics, and bin level monitoring to streamline disposal.

George Fernandez et.al introduces the Smart Dustbin as an innovative response to the growing challenges in urban waste management. In densely populated areas, traditional waste disposal methods have been overwhelmed, leading to environmental and health risks. The Smart Dustbin leverages advanced technologies like servo motors, ultrasonic sensors, and wireless communication to optimize waste segregation, streamline collection, and provide real-time data insights. Through rigorous testing in real-world scenarios, the project aims to demonstrate its effectiveness in improving waste management practices and contributing to a more sustainable, eco-friendly urban environment.

K.Sony et.al highlights progress toward healthier waste management in India through a Smart Bin system. Overflowing trash cans and inefficient disposal, worsened by urbanization, require urgent attention. The Smart Bin automates waste segregation into dry and wet categories using Arduino UNO, ultrasonic sensors, and a conveyor belt. It also monitors bin capacity with IoT, providing alerts when full and minimizing human intervention. The system improves waste collection at household and industrial levels, reducing health risks and manual labour. Looking ahead, advancements in IoT, waste-to-energy conversion, and smart monitoring will enhance recycling and sustainable waste practices.

Anupam Kumar et al. explores automation in waste management, focusing on cleanliness and hygiene in developing nations affected by improper waste disposal. The "smart dustbin" concept combines hardware and software, including Wi-Fi, to encourage users to keep their environments clean. This system employs technologies to measure waste volume, track movement, and communicate information, with moisture sensors to distinguish between solid and wet waste. Operating on a client-server architecture, it aims for a healthier, pollution-free society. IoT-based smart waste management systems can enhance cost efficiency, productivity, and recycling rates while reducing environmental impact, despite challenges like deployment costs. Overall, these systems promise significant advancements toward sustainability.

Kiran Ingale et.al highlights that India, a rapidly growing economy, faces significant waste management challenges, generating 64 million tons of waste annually and ranking seventh worldwide. Careless dumping has led to unsightly litter and serious health risks in many communities. To tackle this issue, an efficient waste management system is urgently required. The study proposes an

IoT-based solution to monitor waste levels in bins, sending data to a cloud platform for real-time analysis. Automated alerts will notify municipal authorities when bins approach capacity, enabling prompt intervention. Ultimately, the project aims to leverage IoT technology to create a proactive waste management system, reducing illegal waste disposal and fostering a cleaner, healthier, and more sustainable India.

G Shubha et.al addresses the challenges of waste segregation caused by mixed garbage, aiming to optimize trash collection through an IoT-based Smart Dustbin. The smart dustbin utilizes Arduino and various sensors, including ultrasonic, metal proximity, humidity, and gas sensors (MQ135) for odor detection, to identify and segregate waste into dry, metal, and wet bins. An anti-odor spray is activated to suppress unpleasant smells. Notifications about the garbage level are sent via Blynk software to municipal authorities for timely collection, ensuring clean surroundings. Ultimately, the smart dustbin enhances the efficiency of garbage collection and segregation, promoting cleanliness in society.

Priyanka Thirumugam et.al describes the development of a smart dustbin and garbage monitoring system utilizing Internet of Things (IoT) technology. This system features a smart dustbin equipped with a GSM module and wireless sensors, all connected through an ESP32 microcontroller. It is capable of detecting wet or dry waste, displaying the fill level, and sending alerts to cleaning authorities when full. Additionally, sensor data is stored in a cloud platform for further analysis, enhancing waste management while promoting health and hygiene. The proposed solution encompasses a smart device and a software application designed using IoT technologies, such as NodeMCU and GSM. Key benefits include automatic lid operation, waste type detection, waste separation, and monitoring, which help prevent bin overflow and associated health issues.

Shafi Shaik et.al proposes an efficient smart trash separation bin model for urban scenarios, addressing the unhygienic environment created by rapid population growth and waste accumulation. Additionally, the proposed model includes an ESP32 module that processes input from various sensors, such as the ultrasonic, gas, and temperature sensors, to transmit data to a real-time database server. Furthermore, the NodeMCU is programmed to send the dustbin's status to the cloud, enhancing waste management efficiency and promoting a cleaner environment.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Statement of Problem

Waste management is a growing concern, particularly in urban areas, where rapid industrialization and population growth have led to an increase in waste generation. Traditional waste collection and disposal methods struggle to keep up with the volume of waste, often leading to unsorted trash in landfills and improper disposal methods. This contributes to environmental pollution, contaminates water sources, harms ecosystems, and poses serious health risks to communities.

One critical issue is the lack of an efficient waste segregation system at the source, which hinders recycling and composting efforts. Manual sorting is time-consuming, labor-intensive, and prone to error, leading to higher contamination levels and inefficient recycling processes.

There is a need for an automated solution that can effectively separate waste into categories—wet, dry, and metallic—right at the disposal point. Such a system would not only facilitate efficient recycling and resource recovery but also reduce the environmental impact of waste disposal and support sustainable practices.

3.2 Scope for the study

The study encompasses the design, development, and evaluation of a smart bin system that automatically segregates waste at the source. The solution is designed for diverse settings, including public spaces, educational institutions, and residential complexes, where waste generation is consistent and significant. By incorporating IoT technology, the system also allows for real-time monitoring, enabling better waste collection planning and more efficient logistics.

This project's scope extends beyond the immediate benefits of waste segregation; it also contributes to the global effort to reduce pollution, promote sustainable practices, and optimize resource recovery. The findings and results from this study can inform future development of smart waste management solutions, offering valuable insights into implementing automated waste sorting at scale.

3.3 Objective of the study

- **Design and Implementation**: To create a smart bin system equipped with sensors for detecting and classifying waste into wet, dry, and metallic categories.
- **Data Sharing and Monitoring**: To leverage IoT technology, allowing for the real-time transmission of data related to bin fill levels and waste composition, supporting efficient waste collection planning.
- **Automation and Efficiency**: To reduce the reliance on manual sorting and to improve recycling rates by minimizing contamination of recyclable materials.
- **Sustainability and Scalability**: To develop a prototype with scalable potential for urban areas, public spaces, and institutions, aligning with environmental sustainability goals and encouraging cleaner waste disposal practices.

3.4 Realistic Constraints

- **Cost:** Balancing functionality with budget constraints is essential, as sensors and IoT components can be costly, particularly in large-scale implementations. Cost-efficient component selection is necessary to ensure affordability without compromising on quality.
- **Technical Limitations:** The sensors may experience variability in accuracy based on environmental factors, such as humidity and dust levels. This could impact the precision of waste segregation and require regular calibration to maintain effectiveness.
- **Power Consumption:** The system must consider efficient power management, especially in locations without consistent power supply. The smart bin may require alternative power sources or low-power sensors to ensure functionality.
- **Maintenance and Durability:** Routine maintenance is essential to keep sensors and mechanical parts operational. In high-use environments, durability and regular servicing will be crucial for prolonged functionality.
- **Data Security and Privacy:** As an IoT-enabled device, the smart bin system transmits data to a cloud platform, necessitating robust security measures to prevent unauthorized access and ensure the privacy of data collected.

3.5 Engineering Standards

The smart bin system aligns with various engineering standards to ensure safety, environmental impact reduction, and reliable IoT operation:

- **ISO 14001 (Environmental Management Systems):** This standard provides a framework for sustainable design and operations, ensuring the project contributes positively to environmental management.
- **IEEE 2413 (IoT Architecture):** Ensures the system's IoT aspects are structured to maintain compatibility, scalability, and secure connectivity across IoT devices.
- **ISO/IEC 27001 (Information Security):** Guarantees data security and privacy for the IoT system, protecting data on waste types and collection schedules from unauthorized access.
- **CE and RoHS Compliance:** Ensures that components used are safe, reliable, and compliant with environmental regulations, restricting hazardous materials in electronics.

CHAPTER 4

DESIGN AND METHODOLOGY

4.1 Theoretical Analysis

4.1.1 Module

The smart bin system comprises three primary modules that work together to provide automated waste segregation and data sharing:

- **Sensing Module:** Includes metal proximity sensors to detect metallic items, capacitive proximity sensors to identify non-metallic waste, and moisture sensors to determine wet or organic waste. These sensors enable the system to categorize waste in real-time.
- **Control Module:** Utilizes an Arduino or equivalent microcontroller to process data received from sensors. The microcontroller interprets sensor signals and triggers the appropriate motorized actions for waste segregation, directing each type of waste to its designated compartment.
- **Communication Module:** Through an IoT module, such as ESP8266, the smart bin communicates with a cloud platform, allowing remote monitoring and data logging for efficient waste collection scheduling. This module sends data on the bin's fill level, waste type distribution, and operational status to a central system.

4.1.2 Methodology

The proposed waste classification system uses sensors to sort waste into different compartments of a single bin. Waste enters the dustbin, and the capacitive sensor analyzes whether moisture is present to determine if the waste is wet or non-wet. If the waste is wet, it proceeds to the next stage. The inductive proximity sensor then checks if the waste is metal. After that, the capacitive proximity sensor determines if the waste is paper or plastic. If the waste is detected, the servo motor will rotate 360 degrees, opening the corresponding bin door, and the waste will be deposited into the appropriate bin. All sensors and the servo motor are interfaced with the Arduino UNO. Additionally, the ESP32 microcontroller is interfaced with an ultrasonic sensor that measures the bin level and the data is uploaded to the Blynk platform, where results are displayed on the Blynk web page.

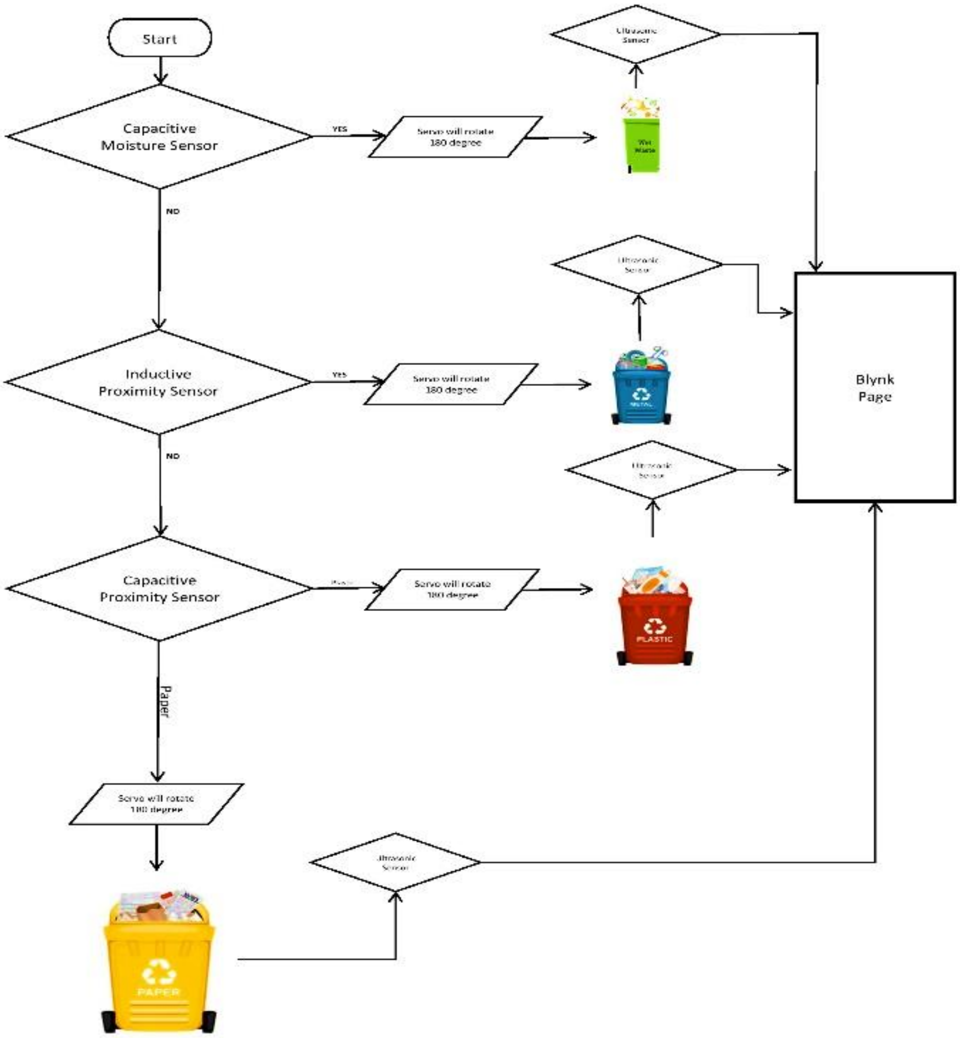

Fig 4.1 Flow chart of the proposed system

I. Microcontroller

The smart bin system is powered by microcontroller platforms, with Arduino and ESP32 serving as the core components that drive the system's operations. These microcontrollers enable seamless integration of sensors, actuators, and cloud connectivity, allowing for effective waste segregation, real-time data monitoring, and improved waste management practices. Below are detailed descriptions of each microcontroller's role within the system.

Arduino Uno is based on the ATmega328P microcontroller, a robust platform well-suited for handling the various input-output operations required in the smart bin system. It features 14 digital I/O pins, 6 of which are capable of providing Pulse Width Modulation (PWM) output, and 6 analog input pins to handle analog signals from sensors. The Arduino Uno acts as the primary control unit, processing signals from multiple sensors, such as the moisture sensor, inductive proximity sensor, and capacitive proximity sensor. Upon receiving data from these sensors, it directs automated responses such as opening and closing the bin lid, ensuring efficient waste segregation. The Arduino Uno also organizes data for real-time tracking of waste levels and types, making it central to the smart bin's automated and analytical functions.

ESP32 microcontroller, equipped with built-in Wi-Fi and Bluetooth, is particularly suited for IoT applications that require reliable wireless connectivity. With 34 programmable GPIO pins, the ESP32 supports numerous protocols, including I2C, I2S, SPI, UART, ADC, DAC, and PWM, making it highly versatile for handling complex tasks. In the smart bin project, the ESP32 facilitates continuous data transmission between the smart bin's sensors and the cloud platform, Blynk. By managing real-time data transfer, it enables users to monitor fill levels, sensor readings, and waste types remotely. This connectivity not only supports timely notifications for waste collection but also provides valuable data for optimizing waste management strategies based on usage patterns. The ESP32's role in linking sensor inputs with cloud-based data ensures the smart bin system operates with high efficiency and responsiveness, making it a key component of the overall IoT-based architecture.

The Arduino Uno and ESP32 microcontrollers collectively enhance the smart bin's functionality, providing a synchronized system that automates waste sorting, enables real-time monitoring, and supports data-driven waste management solutions. This integration of hardware and software ultimately contributes to sustainable practices in urban waste management.

II. Sensors

The smart bin system incorporates various sensors to optimize waste segregation and operational efficiency. Each sensor plays a specific role in identifying and classifying waste types and tracking bin fill levels. The sensors include moisture sensors, inductive proximity sensors, capacitive proximity sensors, and an ultrasonic sensor. By combining these sensors, the system can achieve high accuracy in sorting waste into wet, dry, and metallic categories. Below is a detailed description of each sensor's function and operational mechanism.

The **NPN Inductive Proximity Sensor** is a non-contact sensor specifically designed to detect the presence of metallic objects. It operates through a high-frequency electromagnetic field generated by an internal coil and oscillator circuit. When a metal object enters this electromagnetic field, eddy currents are generated on the object's surface, which reduces the amplitude of oscillations within the sensor. This reduction is detected, signaling the presence of a metal object. This sensor is crucial in the smart bin system, as it accurately identifies metallic waste without physical contact, directing it to the correct compartment. Its reliability, low maintenance, and rapid response time make it highly effective for applications requiring precise metal detection, such as recycling initiatives.

The **capacitive moisture sensor** functions by leveraging the principles of capacitance, which is affected by changes in the dielectric material. It consists of two conductive plates (electrodes) separated by a gap, functioning similarly to a capacitor. When a substance with a high dielectric constant, such as wet organic waste, comes into contact with the sensor, the capacitance value rises. Since organic or wet waste has a higher dielectric constant than dry waste, this sensor can differentiate between the two types, directing wet waste to an appropriate compartment. The capacitive moisture sensor produces an analog output, providing nuanced data on the type of waste it contacts. This capability is integral to the system's goal of effective waste separation, as it enables the diversion of biodegradable waste for composting, supporting sustainable practices.

Ultrasonic sensor measures the fill level of the trash bin, ensuring that it does not overflow and can be emptied on time. It consists of a transmitter and a receiver. The transmitter emits ultrasonic sound waves, which bounce back upon hitting an object (in this case, the trash inside the bin). The receiver detects the reflected sound waves, and the distance is calculated based on the time taken for the waves to return. This sensor provides precise measurements of bin fill levels by converting the time interval into a distance value, allowing the system to send notifications when the bin is nearing capacity. By monitoring trash levels, the ultrasonic sensor facilitates timely waste collection, preventing overflow and ensuring cleanliness.

III. Actuators

The smart bin system employs actuators to enable the automated mechanical actions necessary for sorting waste and controlling bin operations. A servo motor is used as the primary actuator in this project, driven by Pulse Width Modulation (PWM) signals. The actuator's role in the system is essential for automating the opening and closing of bin compartments, ensuring efficient waste segregation and user convenience.

Servo motor in the smart bin is designed to convert electrical signals into precise mechanical motion. Controlled by PWM signals, the motor's angle of rotation is determined by the width of the pulse. The servo motor is programmed to operate at specific angles, opening and closing bin compartments according to the waste type detected by the sensors. For instance, when the system detects metallic waste, the servo motor rotates to position the compartment for metal; similarly, it adjusts for wet or dry waste compartments. This level of control enables the smart bin to operate with high accuracy, reducing the need for manual intervention. Servo motors are compact, reliable, and efficient in applications requiring precise control, making them ideal for the automated actions in the smart bin system.

IV. Cloud Platform

The cloud platform plays a crucial role in managing data collected from the smart bin, enabling real-time monitoring, notifications, and remote access. Blynk, a versatile IoT platform, is used in this project to connect the smart bin to a user-friendly mobile application. This application interface not only displays the bin's status but also allows users to receive alerts and manage settings remotely.

Blynk is an IoT development platform designed to simplify communication between hardware and user interfaces. In this project, it serves as the primary interface for monitoring the smart bin's status. Through the Blynk app, users can track bin fill levels, receive notifications when the bin is nearing capacity, and view real-time data on waste type segregation. When the ultrasonic sensor detects that the bin is close to full, Blynk triggers a notification, alerting the relevant waste management authorities or users to empty the bin. Blynk's drag-and-drop interface allows for easy customization, so users can tailor the app to suit specific needs, such as setting up alert thresholds or accessing usage history for data analysis.

Additionally, Blynk's cloud services ensure that data is stored and accessible even when users are not within proximity to the bin, enhancing flexibility and usability. For instance, waste collection personnel can monitor bins in different locations through a single dashboard, optimizing collection schedules and routes. The Blynk platform also enables integration with other data processing tools, allowing for further analysis of waste management trends, fill rates, and collection frequency, which can inform future improvements in waste management practices.

This combination of sensors, actuators, and cloud connectivity through Blynk creates an intelligent waste management system. It empowers users and administrators with real-time data, enhances sorting accuracy, and enables more effective and responsive waste collection. By leveraging IoT technology, this project aims to transform traditional waste management practices, supporting environmental sustainability and resource efficiency.

4.2 Description of system environment

The smart bin system is designed to function effectively across a range of settings, including urban environments, educational institutions, healthcare facilities, and public spaces with high waste generation rates. These locations often face significant challenges with waste management due to high foot traffic, diverse types of waste, and the need for efficient disposal solutions. By integrating IoT technology, the smart bin system addresses these challenges by enabling real-time monitoring, data analysis, and automated waste segregation, which helps reduce human involvement and ensures a cleaner, more organized environment.

The system's IoT functionality relies on a stable internet connection, which is essential for continuous data sharing between the smart bin and the cloud platform. The connection facilitates remote monitoring and enables notifications when the bin approaches its capacity, ensuring timely waste collection. Through the Blynk IoT platform, users can monitor bin status and data related to waste segregation and fill levels in real-time, enhancing the efficiency of waste management processes. However, in cases where connectivity is intermittent, the system is designed to store data temporarily, uploading it when the connection is reestablished. This feature ensures minimal data loss and uninterrupted monitoring of the bin's status.

A consistent power supply is another critical requirement for the smart bin system, as it powers all components, including sensors, motors, and microcontrollers, ensuring they function reliably. The system is designed to run on electricity, with the option to integrate rechargeable batteries or solar power to enhance sustainability and ensure functionality during power outages. This uninterrupted power source is crucial for maintaining sensor accuracy and actuator responsiveness, which are essential for proper waste segregation and bin operation. The system can also be optimized for energy efficiency, ensuring that power consumption remains minimal while delivering maximum functionality.

4.3 Design Specifications

The design specifications for the smart bin system include a range of hardware and software components to enable efficient waste segregation, data collection, and remote monitoring. Each component is selected based on the project's methodology, focusing on automation, real-time tracking, and minimal maintenance.

4.3.1 Hardware Required

- **Arduino Uno:** Serves as the main microcontroller for processing inputs from the various sensors. It controls the bin's automated mechanisms, such as lid operations, and manages data collection for real-time monitoring of waste levels.
- **ESP32 Microcontroller:** An advanced microcontroller equipped with Wi-Fi and Bluetooth capabilities, the ESP32 handles data transmission to the cloud, enabling remote monitoring and real-time notifications. It also allows for communication between the sensors and the IoT platform, optimizing the overall functionality of the smart bin.
- **Inductive Proximity Sensor:** Detects metallic objects in the waste stream without direct contact, which is crucial for identifying recyclable metallic items. By using electromagnetic fields, it enhances the accuracy of metal detection, allowing for effective segregation of recyclable materials.
- **Capacitive Moisture Sensor:** Utilized to identify wet or organic waste based on dielectric properties. This sensor distinguishes between wet and dry waste, allowing organic waste to be separated for composting. Its ability to measure moisture content makes it vital for correctly classifying waste types.
- **Ultrasonic Sensor:** Measures the fill level of the bin by detecting the distance between the sensor and the waste surface. This information is essential for monitoring bin capacity and ensuring timely collection. It uses ultrasonic waves, making it ideal for accurate level measurement regardless of the type of waste.
- **Servo Motor:** Acts as the actuator, facilitating mechanical movement in the sorting mechanism. Controlled via PWM signals, the servo motor

operates the bin’s doors and internal compartments, automatically sorting waste into metal, wet, and dry categories.

- **Power Supply Unit:** Provides consistent power to all components, including the sensors, ESP32, Arduino Uno, and servo motor. This unit can be supplemented by a battery backup to ensure uninterrupted operation during power outages, maintaining system reliability.
- **Cloud Platform (Blynk):** Enables real-time data storage, monitoring, and notification capabilities for waste levels. Blynk’s user-friendly interface allows remote access, helping to ensure timely waste collection and efficient management.

4.3.2 Software Required

- **Arduino IDE:** Essential for programming and uploading code to the Arduino Uno and ESP32 microcontrollers. The IDE allows for controlling sensor interactions and the motorized sorting mechanism, enabling efficient and autonomous bin operations.
- **Blynk IoT Platform:** Serves as the primary IoT platform for data visualization, remote monitoring, and real-time alerts. It provides a user interface where users can view waste fill levels and receive notifications, ensuring efficient waste management.
- **Sensor Libraries:** Specialized libraries for the Arduino and ESP32 platforms facilitate sensor integration, providing smooth communication between the microcontroller and sensors. These libraries ensure accurate data readings from the inductive proximity sensor, capacitive moisture sensor, and ultrasonic sensor.

These hardware and software elements work in conjunction to enable a fully automated, IoT-enabled smart bin system, supporting efficient waste segregation, real-time data monitoring, and predictive analytics to enhance urban waste management.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Experimental Results

The following section presents the results obtained from the implementation of the smart bin system.

Fig 5.1 Smart bin system

Fig 5.1 showcases the cross-sectional view of the main bin body where the waste is deposited and segregated

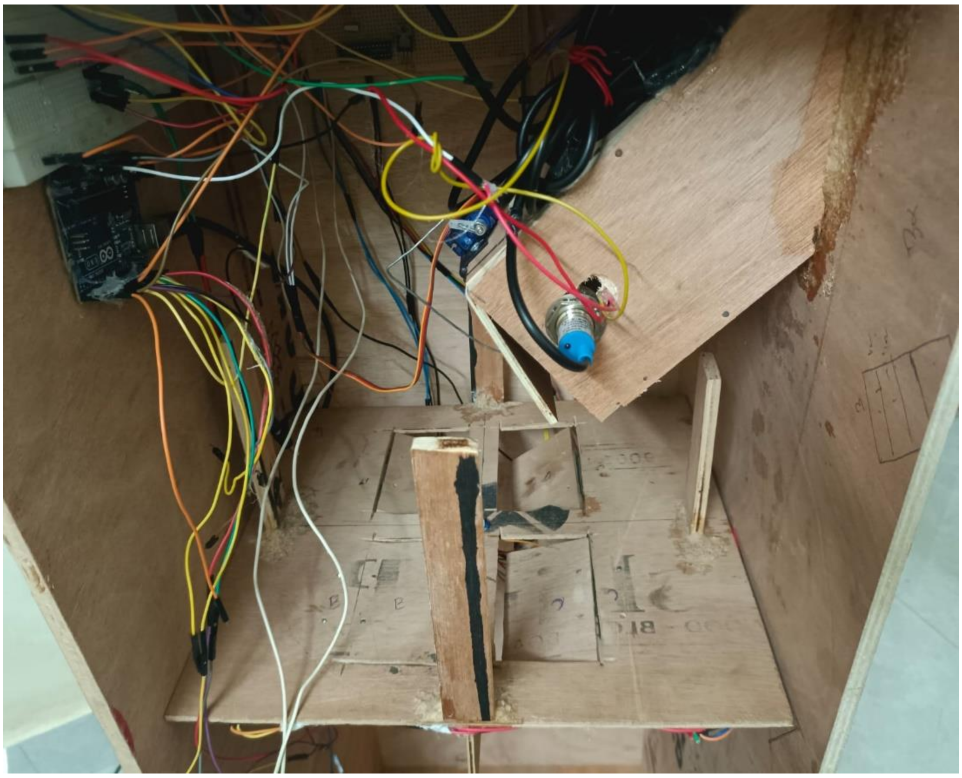

Fig 5.2 Cross sectional view of the waste segregation unit

Fig.5.2 showcases the cross-sectional view of the waste segregation system where the workings of the model rest. This is the region where the separation of waste takes place.

Fig 5.3 Blynk Interface of wet and metal waste

Fig.5.3 highlights the Blynk interface where the green color section represents the wet waste and the orange color represents the metal waste. From the fig.5.3 we can infer that around 88% of both wet waste and metal waste compartments are filled. It also indicates the moisture content present.

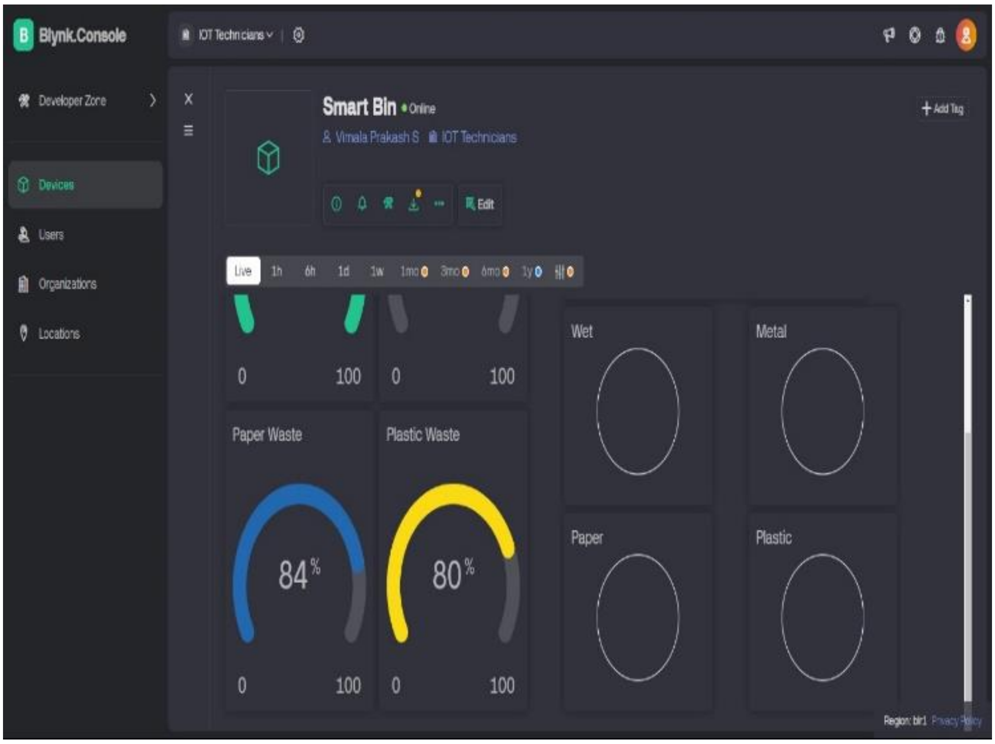

Fig 5.4 Blynk interface of paper and plastic waste

Fig.5.4 highlights the Blynk interface where the blue color section represents the paper waste and the yellow color represents the plastic waste. From the Fig.5 we can infer that around 84% of paper waste and 80% of plastic waste compartments are filled.

5.2 Suggestions and Enhancement

To further improve the smart bin system and ensure it operates effectively across diverse environments, several enhancements and optimizations can be implemented:

1. **Energy Efficiency Improvements**: Integrating renewable energy sources, such as solar panels, could provide a sustainable power source for the smart bin, reducing dependency on the electrical grid. Additionally, optimizing sensor and microcontroller power consumption through sleep modes can extend battery life if the system is off-grid.
2. **Enhanced Sensor Calibration**: Periodic calibration of sensors, especially the moisture and proximity sensors, would ensure consistent accuracy. This

can be achieved with automated calibration routines that adjust the sensor parameters based on environmental conditions, like temperature and humidity, to minimize errors in waste classification.

3. **Machine Learning Integration**: Advanced machine learning models could be incorporated to improve the smart bin's waste identification capabilities. For example, image recognition models could help identify specific types of waste based on shape and color, further enhancing the system's accuracy in segregating waste.
4. **Scalability for Urban Deployment**: To make the system viable for large-scale urban deployment, a centralized waste management platform could be created. This platform would integrate data from multiple smart bins in different locations, enabling real-time monitoring and more efficient scheduling of waste collection services.
5. **Public Awareness and User Interaction**: Adding a display screen or voice prompt feature could encourage users to properly dispose of their waste by displaying helpful messages or reminders. This could also improve user engagement and make the smart bin system more effective by encouraging correct waste disposal practices.
6. **Durability and Weatherproofing**: Reinforcing the smart bin with waterproof and rust-resistant materials would enhance its lifespan, especially in outdoor environments. Weatherproofing components like the servo motor and sensors would make the system more resilient to harsh weather conditions, reducing maintenance needs and increasing its operational reliability.

5.3 Conclusion

The smart bin project demonstrates an innovative approach to addressing the growing waste management challenges in urban and high-traffic environments. By incorporating IoT technology, various sensors, and real-time monitoring capabilities, this system facilitates efficient waste segregation, reducing the burden on manual sorting processes and supporting sustainable waste disposal practices. The combination of Arduino and ESP32 microcontrollers enables effective control and data communication, while the use of Blynk provides an accessible platform for remote monitoring and timely alerts. This system not only enhances waste management efficiency but also promotes environmentally responsible behaviour through automated sorting and data-driven insights., the smart bin project offers a viable solution for modern waste management needs and paves the way for smarter, cleaner, and more sustainable urban environments.

5.4 Future Enhancement

There are several avenues for future enhancements to maximize the smart bin’s functionality, sustainability, and scalability:

1. **Advanced AI-Powered Sorting**: Integrating advanced artificial intelligence algorithms for waste classification would enable more complex sorting based on material composition. By training models on a larger dataset of waste images, the system could automatically detect and sort specific waste types more accurately.
2. **Smart Waste Collection Scheduling**: Future iterations could incorporate predictive analytics to optimize waste collection schedules. Using historical data, machine learning models could predict when bins will reach capacity, allowing waste management services to efficiently allocate resources and reduce collection frequency.
3. **Expanded Sensor Integration**: Including additional sensors, such as gas or odor sensors, could enhance the system’s ability to detect hazardous or decaying waste. This would be especially useful in healthcare and food service environments, where waste may pose health risks if left unattended for too long.
4. **Integration with Smart City Infrastructure**: As cities become more connected, the smart bin system could be integrated with larger smart city ecosystems. Data from the bins could contribute to citywide waste management dashboards, informing city planners and enabling more comprehensive sustainability efforts.
5. **User Incentive Program**: Adding a user reward system based on correct waste disposal could encourage community engagement and foster more responsible waste management practices. Points, discounts, or tokens could be given for correctly sorted waste, reinforcing positive environmental habits.
6. **Blockchain for Waste Tracking**: Incorporating blockchain technology to securely track and log waste data could provide transparency and accountability in waste disposal and recycling processes. This would allow stakeholders to verify waste’s origin, type, and final disposal, supporting circular economy initiative

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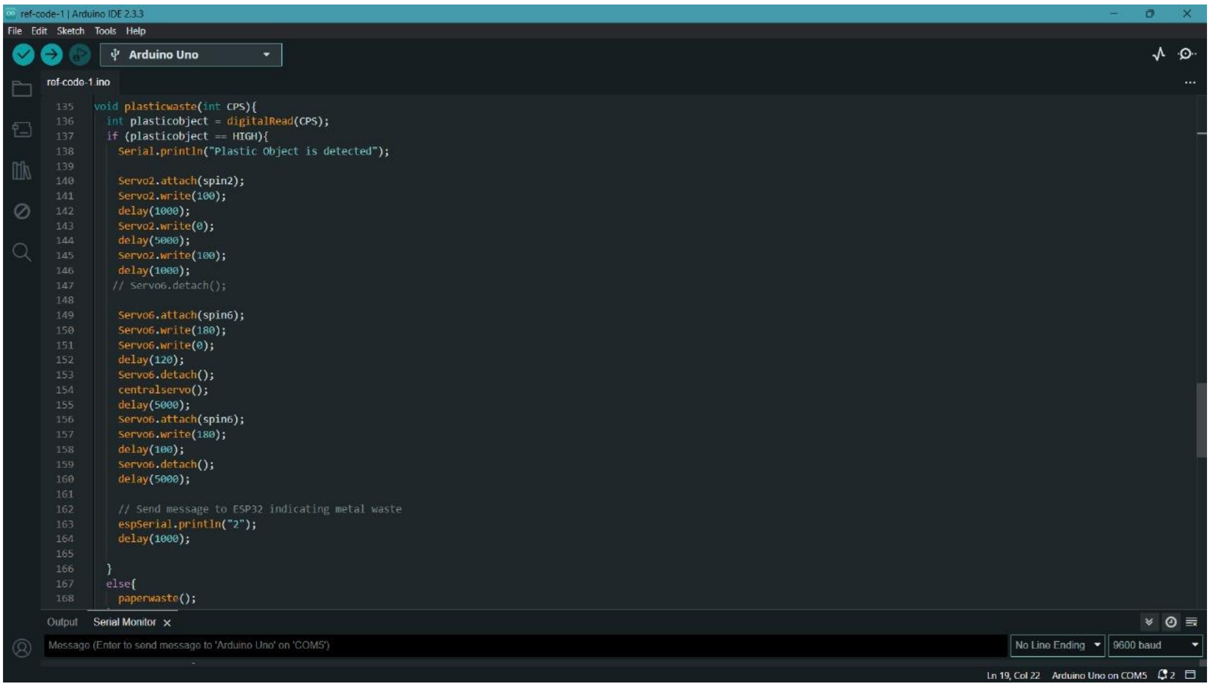
APPENDIX

Code Snippet



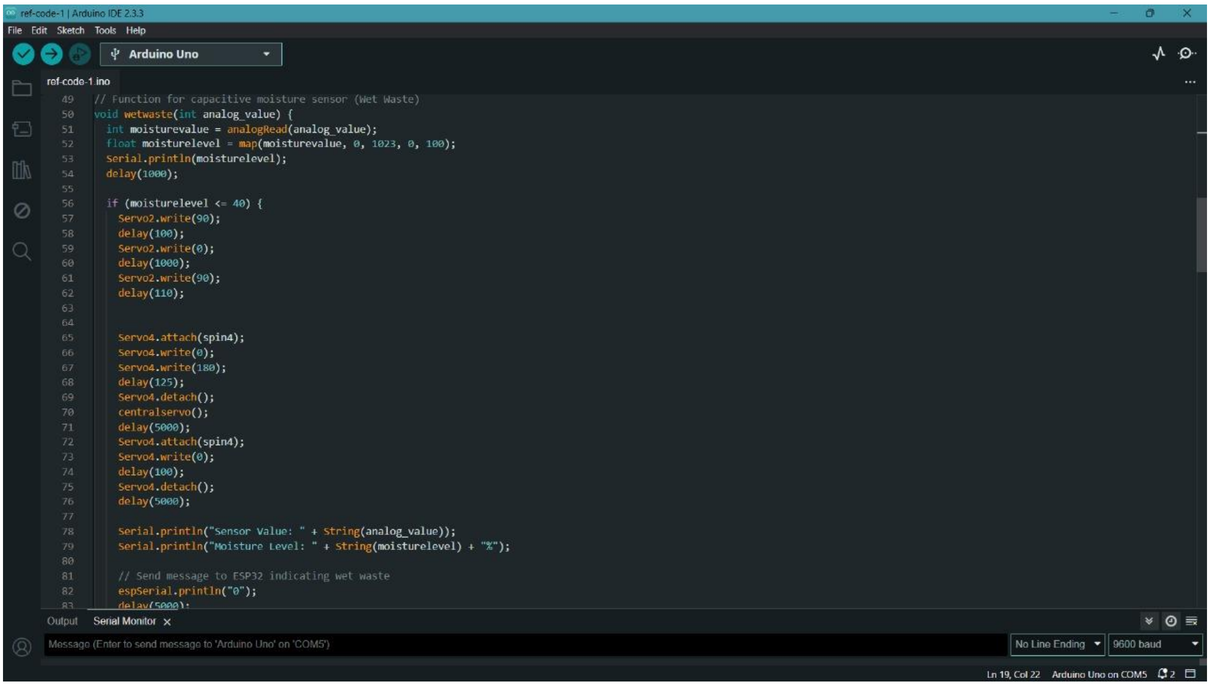

```
void plasticwaste(int CPS){
  int plasticobject = digitalRead(CPS);
  if (plasticobject == HIGH){
    Serial.println("Plastic Object is detected");

    Servo2.attach(spin2);
    Servo2.write(100);
    delay(1000);
    Servo2.write(0);
    delay(5000);
    Servo2.write(100);
    delay(1000);
   // Servo6.detach();

    Servo6.attach(spin6);
    Servo6.write(180);
    Servo6.write(0);
    delay(120);
    Servo6.detach();
    centralservo();
    delay(5000);
    Servo6.attach(spin6);
    Servo6.write(180);
    delay(100);
    Servo6.detach();
    delay(5000);

    // Send message to ESP32 indicating metal waste
    espSerial.println("2");
    delay(1000);

  }
  else{
    paperwaste();
```




```
// Function for capacitive moisture sensor (Wet Waste)
void wetwaste(int analog_value) {
  int moisturevalue = analogRead(analog_value);
  float moisturelevel = map(moisturevalue, 0, 1023, 0, 100);
  Serial.println(moisturelevel);
  delay(1000);

  if (moisturelevel <= 40) {
    Servo2.write(90);
    delay(100);
    Servo2.write(0);
    delay(1000);
    Servo2.write(90);
    delay(110);


    Servo4.attach(spin4);
    Servo4.write(0);
    Servo4.write(180);
    delay(125);
    Servo4.detach();
    centralservo();
    delay(5000);
    Servo4.attach(spin4);
    Servo4.write(0);
    delay(100);
    Servo4.detach();
    delay(5000);

    Serial.println("Sensor Value: " + String(analog_value));
    Serial.println("Moisture Level: " + String(moisturelevel) + "%");

    // Send message to ESP32 indicating wet waste
    espSerial.println("0");
    delay(5000);
```