

**SMART GARBAGE SEGREGATION AND MANAGEMENT
SYSTEM USING THE INTERNET OF THINGS**



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B.Sc. ELECTRICAL ENGINEERING

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Session: 2020 – 2024

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Lahore, Pakistan

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Submitted to Superior University, Lahore in
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for the award of the degree of
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DECLARATION

This statement report is an arrangement of our creative study task. Moreover, additions of other peoples are elaborate, every determination is made to entitle this clearly, with due reference to the literature, and acknowledgment of combined research and discussions. We also assure you that this work is the output of our research, except we were identified by references and free from plagiarism of the work of other people.

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RESEARCH COMPLETION CERTIFICATE

It is certified that the research work contained in this dissertation titled “**Smart Garbage Segregation and Management System Using the Internet of Things**” has been investigated and carried out by Muhammad Umer, Rana Waleed, Ahmed Ali, and Farman Ali Chand for the degree of Bachelors of Science in Electrical Engineering.

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In the name of ALLAH, who is most beneficial and most merciful!

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Thank you,

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DEDICATION

We dedicate this work to our last Prophet Hazrat Muhammad (S.A.W.W), my great hero and messenger of ALLAH ALMIGHTY. One of the most influential people that humanity has ever witnessed.

LIST OF ACRONYMS

ADC	Analog-to-Digital Converter
ATmega328P	Atmel MegaAVR 328P
CNN	Convolutional Neural Network
CV	Computer Vision
DC	Direct Current
E-Waste	Electronic Waste
EEPROM	Electrically Erasable Programmable Read-Only Memory
ESP32	Espressif32
ESP8266	Extended Simple Platform 8266
GPS	Global Positioning System
GSM	Global System for Mobile Communication
HC	High Conductance
HD44780	Hitachi HD44780 LCD Controller
IC	Integrated Circuit
ID	Identification
IDE	Integrated Development Environment
IFTTT	If This Then That
IoT	Internet of Things
IR	Infrared Rays
KNN	K-Nearest Neighbor
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LEACH	Low-Energy Adaptive Clustering Hierarchy
MATLAB	Matrix Laboratory
ML	Machine Learning
NC	Normally Closed
NO	Normally Opened
NodeMCU	Node Micro-Controller Unit
PCB	Printed Circuit Board
PET	Polyethylene Terephthalate
PKR	Pakistani Rupee
PV	Photovoltaic

PWM	Pulse Width Modulation
RAM	Random Access Memory
RFID	Radio Frequency Identification
RPM	Revolutions Per Minute
SDG	Sustainable Development Goal
SMPS	Switched Mode Power Supply
SMS	Short Message Service
SRAM	Static Random Access Memory
SWOT	Strengths, Weaknesses, Opportunities, Threats
UNSDGs	United Nation Sustainable Development Goals
USB	Universal Serial Bus
Wi-Fi	Wireless Fidelity
YOLO	You Only Look Once

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ABSTRACT

Rapid population growth has increased daily waste production, making waste management a major challenge for both local and national governments. The growing waste problem has made effective waste management a critical issue to protect the environment and human health. Addressing this complicated issue requires a comprehensive approach that incorporates waste segregation, transportation, and recycling practices. The economic value of waste is often dependent on its composition, making segregation an essential step in optimizing resource recovery. However, traditional waste segregation methods can be time-consuming and hazardous to individuals. This project is focused on the development of an innovative waste management system that utilizes real-time monitoring and intelligent segregation to promote eco-friendly practices and boost recycling rates. The core of this system lies in the integration of advanced technologies, including sensors and actuators, to facilitate the sorting of waste at its source. Information gathered through these sensors is transmitted in real-time to a cloud-based database via the Internet of Things (IoT), ensuring efficient and accurate data processing. The innovative waste management system categorizes waste into specific waste types, such as metallic, wet, and plastic waste. This precise categorization enhances the overall efficiency of waste collection, as it enables unique recycling processes for each waste type. By employing cutting-edge technology, the project not only aims to revolutionize waste management but also contributes significantly to the creation of cleaner, greener, and more sustainable urban environments. In short, this initiative represents a forward-thinking approach to waste management that not only tackles the immediate challenges posed by population growth but also sets the stage for a more environmentally conscious and resource-efficient future. The integration of real-time monitoring, intelligent segregation, and advanced technologies positions this project as a symbol of innovation in the ongoing search for sustainable waste management practices.

CHAPTER 1

INTRODUCTION

1.1 Introduction to Smart Garbage Segregation and Management System

The Smart Garbage Segregation and Management System represents a creative and innovative solution to the wide range of challenges caused by global waste management. A waste management program includes activities such as collecting, transporting, processing, disposing, and monitoring waste. By examining a variety of wastes, from hazardous to municipal to industrial and agricultural, this project takes a more comprehensive approach. The importance of effective waste management is emphasized by the high daily collection requirements driven by both a growing population and rapid urbanization. In urban areas, garbage often accumulates around dustbins without proper disposal at regular intervals as shown in Figure 1.1, resulting in an unsanitary environment for people, plants, and animals [1].



Figure 1. 1: Garbage Accumulates Around Dustbin

Animals consume garbage from open dustbins, resulting in lethal injuries and damage to their digestive tracts. As a result, animals may suffer, ulcerate, become ill, grow at a slower rate, and die prematurely because of plastic, glass, metals, chemicals, and other substances [2]. A proper waste management system plays a pivotal role in preserving precious natural resources and energy, in addition to safeguarding environmental integrity and human health. However, conventional waste management methods are associated with limitations and challenges. The integration of cutting-edge technologies, such as IoT, offers a transformative solution to address these issues. The application of IoT to the segregation and management of garbage represents a groundbreaking approach. Utilizing real-time data and connectivity, IoT facilitates more precise and efficient waste management. Technology not only overcomes the limitations of traditional methods but is also aligned with the global need to adopt innovative approaches that integrate waste management with environmental sustainability. Because of the IoT, the worker receives information about the waste container, allowing him to keep track of the trash being flushed [3]. By minimizing physical labor, reducing environmental pollutants, and mitigating health risks, garbage management can be enhanced for increased efficiency and sustainability. It not only helps economic development, social welfare, and environmental preservation but also improves the environment in general. The potential exists to create a positive impact on multiple levels by simplifying waste management processes and incorporating innovative solutions, that align with the broader goals of promoting well-being, economic progress, and ecological health. There has been an increase in awareness of the environmental hazards associated with improper waste management in recent years [4]. Both waste management and living a more intelligent life benefit from a smart waste management system.

1.2 Problem Statement

The initiative aims to address the serious problem of waste management, which causes serious threats to both the environment and human health. Globally, the amount of municipal solid waste produced each year is estimated to be 2.01 billion tones, with at least 33% of the waste not being handled in an environmentally friendly manner. It has also been forecast that waste creation worldwide will increase by 70% by 2050 if immediate action is not taken. While Pakistan generates approximately 49.6 million

tones of waste a year, with an annual increase of more than 2.4%. A number of problems exist with existing waste management systems, including the lack of ability to separate waste when it comes together on a conveyor belt and the failure to identify different types of waste with sensors.

Therefore, in this project, a smart garbage segregation and management system using IoT will be developed. Here, the garbage will be put on the conveyor, various types of garbage will be segregated using sensors and the servo-operated barriers will place the garbage in the required bin accordingly.

1.3 Scope and Significance of Study

The scope of this study encompasses the development and implementation of a Smart Garbage Segregation and Management System utilizing the Internet of Things (IoT) to enhance waste management processes. This project aims to design an intelligent system that uses sensor-based technology to automatically segregate waste into different categories. The system will also integrate real-time monitoring and data analysis capabilities, enabling efficient waste segregation.

The significance of this study lies in its potential to revolutionize waste management practices by reducing human intervention, increasing recycling rates, minimizing environmental impact, and promoting sustainability. By leveraging IoT, this project seeks to contribute to smarter cities with improved public health, reduced operational costs, and promote a cleaner environment.

1.4 Project Overview/Goal

This innovative project revolves around the integration of internet-connected devices, sensors, and actuators to automatically sort and monitor various waste categories, including metallic, wet, and plastic materials. The ultimate goal is to elevate the sustainability and efficiency of waste management practices by mitigating labor demands, eliminating environmental pollutants, and minimizing associated health hazards. The automation of waste categorization not only promises a reduction in human intervention but also sets the stage for a more effective, eco-friendly, and sustainable approach to waste management, aligning with the crucial need for innovative solutions in the face of escalating global waste challenges.

1.5 Proposed Methodology

This system proposed uses internet-connected devices, sensors, and actuators to automatically sort and monitor different types of waste, such as metallic, wet, and plastic. The system will help manage garbage collection more effectively, dispose of waste after segregating it more easily, and separate recyclable things according to their categories. The waste will be sorted using sensors and the information will be transferred in real-time to a cloud database through IoT. The system separates waste into different categories, including metallic, wet, and plastic materials. Moreover, the results of segregation are displayed on the LCD. The block diagram of the system is shown in Figure 1.2 and the flowchart of the system is shown in Figure 1.3.

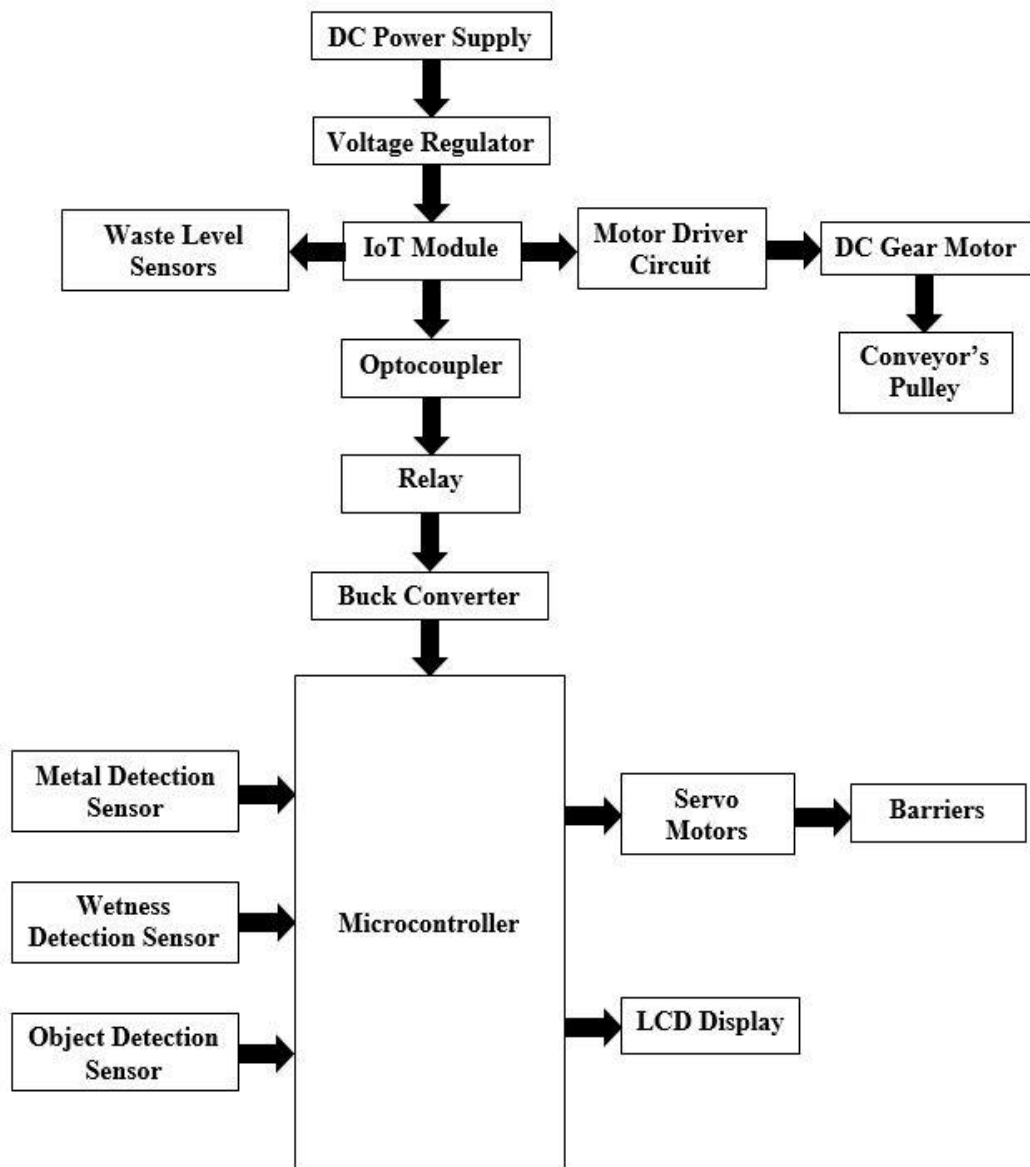


Figure 1. 2: Block Diagram of the System

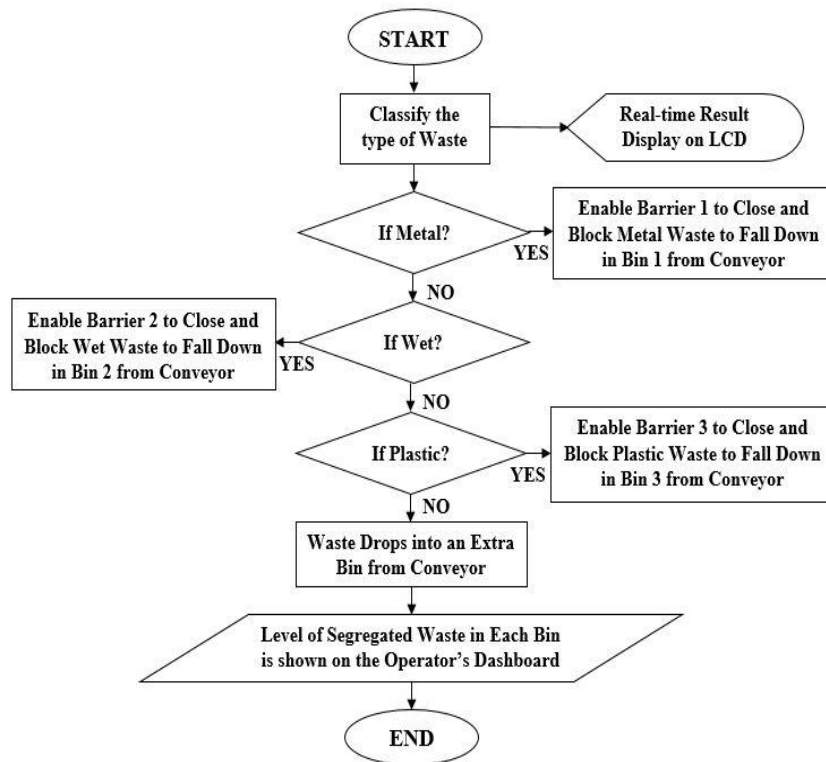


Figure 1. 3: Flowchart of the System

1.6 United Nations Sustainable Development Goals

This project aligns with the following United Nations Sustainable Development Goals (UNSDGs):

1.6.1 Good Health and Well-being (SDG-3)

Proper waste management, as facilitated by our Smart Garbage Segregation and Management System, contributes to environmental cleanliness. Clean surroundings reduce the risk of diseases and health issues associated with unhygienic conditions. By promoting a healthier environment through effective waste management, our project indirectly supports Goal 3. The icon of SDG-3 is shown in Figure 1.4.



Figure 1. 4: Icon of SDG-3

1.6.2 Industry, Innovation, and Infrastructure (SDG-9)

Our project directly aligns with Goal 9 as it involves the incorporation of IoT technology into waste management, representing innovation in infrastructure. The use of IoT devices for smart garbage segregation showcases an innovative approach to improving waste disposal infrastructure, contributing to more efficient and sustainable systems. The icon of SDG-9 is shown in Figure 1.5.



Figure 1. 5: Icon of SDG-9

1.6.3 Sustainable Cities and Communities (SDG-11)

Our project directly aligns with Goal 11 by addressing the challenges of waste management in urban areas. By implementing a smart garbage segregation and management system, contributes to creating sustainable and smart cities. This aligns with the broader objective of making urban areas inclusive, safe, resilient, and sustainable. The icon of SDG-11 is shown in Figure 1.6.



Figure 1. 6: Icon of SDG-11

1.7 Work Division

The work division between group members is defined in Table 1.1.

Table 1. 1: Work Division between Group Members

Sr. No.	Name	Allocated Task
1.	Rana Waleed	Research and Data Analysis
2.	Muhammad Umer	Mechanical Structure Design and Documentation
3.	Ahmed Ali	Software Logic Development
4.	Farman Ali Chand	Prototype Assembling

1.8 Thesis Outline

In this thesis, Chapter 1 serves as the foundation, providing a comprehensive introduction to our project, the "Smart Garbage Segregation and Management System Using the Internet of Things (IoT)." The chapter presents the methodology employed in developing our system and defines clear goals and objectives. Additionally, it emphasizes the alignment of our project with the United Nations Sustainable Development Goals (UNSDGs).

Moving on to Chapter 2, a comprehensive study of the literature review follows, focusing on key aspects of our system. This section thoroughly defines waste types, and explores the types of sensors and actuators employed in existing systems, providing insights into the technological components that drive its functionality. It explores the integration of IoT systems and explains the role of advanced technologies in optimizing waste management processes. This structured approach lays the groundwork for the following chapters, providing a clear roadmap for the development, implementation, and evaluation of our Smart Garbage Segregation and Management System.

In Chapter 3, the focus turns to the practical implementation of the "Smart Garbage Segregation and Management System Using the Internet of Things (IoT)." Utilizing the Proteus simulation platform and Arduino programming, the study thoroughly examines the performance of the system under various scenarios. This chapter strategically highlights the vital role played by Proteus Software, Arduino Programming, and ESP32 Programming in crafting a dynamic and interactive simulation platform, with a specific emphasis on the accurate simulation of physical components through virtual sensors and actuators.

Chapter 4 focuses on the design, development, and integration of various hardware components essential for the system's functionality. By detailing the selection,

functionality, and integration of sensors, microcontrollers, actuators, and power regulators, it provides a comprehensive understanding of the hardware infrastructure. This chapter demonstrates the system's accuracy, efficiency, and reliability in automating waste sorting and management, showcasing its potential to revolutionize waste management practices through IoT-driven automation.

In Chapter 5, summarizing the key findings and contributions of the "Smart Garbage Segregation and Management System Using Internet of Things (IoT)." It provides a comprehensive overview of the project's achievements, highlighting its impact on waste management practices. Additionally, this chapter identifies research gaps and suggests avenues for future work, laying the groundwork for continued exploration and innovation in the field of IoT-driven waste management systems.

The Chapter 6, dedicated to the business description, provides a comprehensive overview of the strategic and financial aspects of the project. It delineates the organizational structure, vision, and objectives, underlining the project's ambition to transform waste management in Pakistan through IoT technology. Through SWOT analysis and marketing assessments, the chapter provides valuable insights into market dynamics and potential challenges, while also outlining a clear financial plan.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The ever-increasing challenges faced by traditional waste management systems have prompted the development of innovative and sustainable solutions. In this era of rapid technological advancement, the integration of IoT into waste management offers a promising opportunity to address existing problems and enhance overall sustainability. Our literature chapter explores the evolving landscape of smart garbage segregation and management systems via key concepts, theoretical frameworks, and empirical studies that provide the framework for our study. We narrow our focus to "Smart Garbage Segregation and Management System Using the Internet of Things (IoT)" as we set out on this journey. The integration of cutting-edge technology with environmental sustainability has the potential to revolutionize waste management practices. Using existing work in this field, we aim to gather insights that guide the design, implementation, and evaluation of our system.

This chapter comprehensively reviews the existing literature on IoT-based smart garbage segregation and management systems. In order to achieve this objective, the literature chapter relies on an extensive review of research articles gathered from Google Scholar. We've searched through the latest research articles to propose a state-of-the-art smart garbage segregation and management system using IoT. This analysis serves as a critical foundation for the following chapters, guiding the development and validation of our Smart Garbage Segregation and Management System. The presence of groundbreaking works by researchers in IoT and waste management emphasizes the significance of this literature review. These foundational elements contribute not only to the theoretical framework of our research but also provide a context for understanding the real-world implications of implementing smart systems in garbage segregation and management.

Our journey through this chapter follows a well-organized roadmap, guiding us through various aspects of smart waste management. The chapter navigates through the categorization of waste into types, from metallic to wet, and plastic, explores challenges in waste management, discusses the pivotal role of IoT, and examines the

interconnected network of sensors and actuators. We also explore how cloud computing can transform waste management practices and consider the environmental impact of such systems. In the end, the chapter summarizes key insights gained from the literature after a comprehensive review of related works. Through this exploration, we aim to contribute to the growing body of knowledge at the intersection of IoT and waste management, laying the groundwork for a smart garbage segregation and management system that is effective and sustainable.

2.2 Types of Waste

In order to develop effective waste management strategies, it is essential to understand waste categories. According to their nature, composition, and origin, waste can be classified into several different types. These are some of the most common types of waste:

2.2.1 Metallic Waste

Metallic waste consists of discarded materials primarily composed of metals as shown in Figure 2.1. This category includes both ferrous and non-ferrous metals. Ferrous metals like iron and steel, are magnetic, while non-ferrous metals like aluminum and copper, lack magnetic properties. Metallic waste includes old appliances, steel beams, aluminum cans, copper wiring, etc. Proper disposal and recycling process of metallic waste is essential for minimizing environmental impact, as metals can persist in the environment for a long time and cause soil and water pollution.



Figure 2. 1: Discarded Metallic Waste

2.2.2 Wet Waste

Wet waste consists of organic and biodegradable materials that decompose easily as shown in Figure 2.2. This category includes agricultural waste, green or yard waste, kitchen waste, etc. In the decomposition of wet waste, methane is released as a potent greenhouse gas. Efficient composting and anaerobic digestion are essential for mitigating the environmental impact of wet waste.



Figure 2. 2: Organic and Biodegradable Waste

2.2.3 Plastic Waste

Plastic waste's non-biodegradable nature is a major environmental concern. This category includes a wide range of plastic materials, electronic waste (E-Waste), wasted PV cells, etc. As plastics can persist for centuries in the environment, recycling and proper disposal methods are crucial to minimizing the harmful effects of plastic waste on our environment. The various types of plastic waste are shown in Figure 2.4.



Figure 2. 3: Plastic Waste

2.3 Challenges in Waste Management

Waste management is essential to environmental sustainability and public health. Urbanization and population growth increase the challenges associated with effective waste management. There is a detailed discussion of the following challenges:

2.3.1 Urbanization and Population Growth Challenges

There is an increase in waste generation due to urbanization, which puts stress on waste management infrastructure. The rapid growth of the population increases the complexity of managing waste, requiring scalable and adaptive solutions.

2.3.2 Inadequate Infrastructure for Waste Collection

The lack of adequate physical and administrative waste collection systems is a significant problem. As a result of inefficient collection systems, irregular waste disposal leads to environmental degradation and health hazards.

2.3.3 Limited Resources and Funding for Waste Management

A continuing challenge is the limited availability of resources and funding for waste management initiatives. Achieving effective waste management while balancing economic constraints remains a challenge.

2.3.4 Technological and Educational Gaps in Waste Sorting

The lack of advanced technological infrastructure and awareness of waste sorting methods contributes to inefficient segregation. Reducing technological and educational gaps is essential for enhancing waste sorting practices.

2.3.5 Illegal Dumping and Littering Issues

The improper disposal of waste through illegal dumping and littering poses an environmental threat. Preventing such practices and implementing strict measures to stop illegal waste disposal are the challenges.

2.3.6 Lack of Public Awareness and Participation

Inadequate public awareness and participation limit the success of waste management initiatives. Encouraging public engagement through educational programs and awareness campaigns is vital for developing a culture of responsible waste disposal.

2.3.7 Environmental and Health Risks of Poor Waste Management

Poor waste management practices contribute to environmental pollution and health risks. To address these risks, we need to implement strategies that promote proper waste disposal, recycling, and reducing hazardous waste materials.

2.3.8 Climate Change and Sustainability Implications

Climate change and sustainability are significantly impacted by waste management practices. It is important to adopt eco-friendly waste disposal methods and promote sustainable practices to mitigate these consequences.

2.3.9 Global Perspectives and Varied Regulatory Frameworks

Implementing standardized waste management practices is challenging due to diverse regulatory frameworks across regions and nations. A flexible and adaptable waste management solution is necessary to adapt to global perspectives and follow varied regulations.

2.3.10 Technological Integration and Adaptation Challenges

The integration of cutting-edge technologies into existing waste management systems faces hurdles. Overcoming technological integration challenges involves careful planning, pilot programs, and compatibility with diverse infrastructures.

2.4 IoT in Waste Management

Waste management has become a critical aspect of urban planning and sustainability due to growing populations and urbanization. In urban centers with ever-increasing waste volumes, traditional waste management systems are inadequate. To address these issues, the integration of the Internet of Things (IoT) into waste management practices has emerged as a promising solution, offering a step towards smarter and more effective waste management strategies.

In recent years, waste management systems have been inactive, responding to rising amounts of waste without a strategic approach. This reactive strategy often leads to inefficiencies, resource waste, and environmental degradation. With IoT technologies, waste management can be revolutionized through real-time monitoring, data analytics, and automation. In the context of waste management, IoT involves the deployment of smart sensors, communication networks, and data analytics platforms to gather and analyze waste generation, collection, and disposal information.

One of the key advantages of integrating IoT into waste management is the ability to monitor waste levels in real time. Smart sensors deployed in waste bins can detect fill levels and transmit information to a centralized platform. Real-time data enables dynamic and adaptive waste collection schedules, reducing unnecessary trips and optimizing resource utilization. Furthermore, IoT facilitates waste collection route optimization by analyzing historical data, current fill levels, and other relevant parameters. This approach reduces fuel consumption and emissions but also minimizes traffic flow impact, contributing to a more sustainable and less disruptive urban environment.

The implementation of IoT in waste management has environmental and economic benefits. It streamlines collection processes, reduces fuel consumption, and promotes recycling initiatives, contributing to an overall reduction in carbon footprints associated with waste management activities. Additionally, optimized resource use results in cost savings for municipalities, making waste management operations more economical and viable. However, addressing challenges such as data security, connectivity, and the initial investment for infrastructure development is crucial. Future research in this field should focus on developing standardized methods, enhancing sensor technologies, and exploring innovative business models to ensure the sustainable and widespread adoption of IoT in waste management.

2.5 Cloud Computing in Waste Management

Integrated Cloud Computing has transformed waste management by offering scalable and data-driven solutions. The advancement of technology has led to more efficient waste collection, monitoring, and optimization. There is a growing interest in utilizing Cloud Computing for waste management, where cloud-based systems provide centralized platforms for data storage, analysis, and decision-making in real-time. In

order to maximize resource efficiency and prevent waste from building up, it is critical to monitor fill levels continuously, analyze results, and make informed decisions about collection routes and schedules. Cloud Computing and the Internet of Things (IoT) are interconnected, with smart sensors on waste bins creating massive amounts of data that can be automatically stored and processed in the cloud.

Optimizing collection routes is one of the key applications of cloud computing in waste management. The use of data analytics and optimization algorithms on cloud platforms can allow municipalities to efficiently plan routes, reducing fuel consumption and mitigating environmental impacts associated with inefficient collection processes. This not only contributes to economic sustainability but also aligns with environmental goals. As well as these benefits storing sensitive waste management data in the cloud involves challenges, such as security and privacy concerns. Providing strong encryption and authentication mechanisms for cloud-based solutions is crucial to ensuring their integrity and confidentiality.

The future of waste management lies in further integrating Cloud Computing with emerging technologies like artificial intelligence and machine learning. Cloud computing provides flexible and responsive solutions to waste management systems in urban environments. Research in the future should focus on developing advanced analytics tools, enhancing data security measures, and fostering interoperability between different waste management systems. As a result of this comprehensive approach, waste management practices will be more effective, sustainable, and technologically advanced.

2.6 Environmental Impact of Smart Waste Management

Effective waste management is crucial to maintaining public health and mitigating the environmental impact of waste generation. The integration of smart technologies into waste management systems has increasingly become viable in recent years. Smart waste management has the following environmental impacts:

2.6.1 Reduction in Environmental Pollution

Smart waste management systems contribute to environmental pollution reduction. Using real-time monitoring and automated processes minimizes littering and illegal dumping, preventing pollutants from entering ecosystems.

2.6.2 Enhanced Monitoring of Environmental Health

Real-time monitoring capabilities included in smart waste management systems facilitate environmental abnormality detection. Whether it be leakage from waste bins or irregularities at waste disposal sites, the system enables swift responses, minimizing potential harm to the environment.

2.6.3 Minimization of Landfill Usage

One of the primary environmental benefits of smart waste management is landfill reduction. By diverting recyclable and biodegradable waste to appropriate processing facilities, these systems contribute to the preservation of land resources and mitigate the negative environmental consequences associated with landfills.

2.6.4 Mitigation of Greenhouse Gas Emissions

The decomposition of organic waste in landfills contributes significantly to greenhouse gas emissions. The use of smart waste management systems, which concentrate on sorting waste efficiently and reducing landfill usage, contributes to mitigating climate change.

2.6.5 Promotion of Recycling and Reuse

Smart waste management encourages recycling and reuse. By incorporating intelligent sorting mechanisms, the system identifies recyclable materials, diverting them away from landfills. This conserves valuable resources and diminishes the environmental impact associated with new materials extraction and production.

2.6.6 Energy Efficiency and Sustainable Practices

Smart waste management systems often integrate renewable energy sources, such as solar panels, to power various components. This enhances energy efficiency and aligns waste management practices with sustainable, eco-friendly principles. The incorporation of renewable energy reduces the overall environmental impact of waste management operations.

2.6.7 Optimized Resource Utilization

Smart technologies optimize resources for waste collection and disposal. Efficient routing algorithms and sensor-based monitoring ensure collection routes are strategically planned, minimizing fuel consumption and reducing waste management's carbon footprint.

2.6.8 Integration with Environmental Regulations

The adoption of smart waste management aligns with and supports environmental regulations and policies. This ensures that waste management practices adhere to legal frameworks, promoting environmental sustainability and fostering responsible waste disposal practices.

2.7 Related Work

The state-of-the-art smart garbage segregation and management system using the IoT is proposed below:

In [5], the authors address the critical issue of solid waste management and recognize its significant impact on the environment. They propose a smart bin system that sorts solid waste into biodegradable, non-biodegradable, and recyclable categories through real-time object recognition. The system is powered by solar panels as a sustainable energy source. To prevent bin overflow, an ultrasonic sensor is employed, and SMS notifications are sent when bins require emptying. The integration of hardware components such as the Raspberry Pi, GSM Module, and CNN algorithms enhances waste management efficiency while advancing environmental sustainability.

In [6], the authors state that solid waste management is becoming a global issue due to population growth, city government dysfunction, and inadequate funding. The authors propose a smart bin system equipped with ultrasonic and infrared sensors for waste level detection and human presence determination. The system utilizes microcontrollers and ultrasonic sensors for real-time garbage status updates on LCD screens and smartphones. To enhance waste collection and management efficiency, the system integrates an ESP8266 Wi-Fi router and an Arduino. Further, it uses Dijkstra's algorithm to optimize truck routes to reduce fuel consumption and time.

In [7], the authors state that recycling and landfilling are critical issues in waste management. The authors propose a waste sorting system featuring a CNN at its core

that efficiently classifies waste into biodegradable and non-biodegradable categories. This system presents a smart trash bin equipped with a variety of sensors, harnessing IoT and Bluetooth connectivity for real-time data monitoring. Waste materials were scanned through a camera module, with the captured images processed and classified by a Raspberry Pi microprocessor. Effective implementation of servo motors ensured efficient waste deposition into designated bins that speed up waste sorting.

In [8], the authors state the importance of waste segregation and the principles of Reuse, Reduce, and Recycle (3 Rs) in responsible waste management. They propose a robotic bot to collect and sort litter into biodegradable and non-biodegradable categories, reducing human effort and promoting environmental cleanliness. The system utilizes the L293D motor driver IC with a Raspberry Pi to control DC motors, alongside a Raspberry Pi camera for image capture. Additionally, a YOLOv4 deep learning model, based on CNN, is trained on the Google Colab platform to enhance waste categorization, ultimately contributing to more efficient and sustainable waste management practices.

In [9], the authors highlight a critical aspect of waste management and emphasize the significance of efficient garbage collection methods. The authors propose a novel approach involving smart bins equipped with ultrasonic sensors and servo motors, including TowerPro SG90 Servo Motors for automated lid operation. These smart bins, controlled by an Arduino Uno microcontroller, use IoT sensors to distinguish between dry and wet waste. Once the bin reaches 80% capacity, it autonomously notifies the garbage collector. As part of their self-sustaining design, the smart bins utilize renewable energy via 800-watt solar panels powered by a battery bank. Furthermore, the authors introduced an optimal route selection algorithm aimed at reducing end-to-end delays and contributing to waste management in smart cities.

In [10], the authors emphasize the crucial importance of waste segregation and recycling in waste reduction. They propose a system that employs a conveyor belt equipped with sensors to identify various types of waste as they move along the belt. Servomotor-driven four multi-colored dustbins at the end of the conveyor ensure precise sorting of waste into Wet, Dry, and Hazardous categories. The system is driven by an Arduino Mega, and incorporates an array of sensors, including passive infrared sensor, NodeMCU, infrared sensor, and Soil Moisture Sensors, as well as DC and Servo Motors, and Capacitive Sensors, to enable precise waste categorization. The infrared sensor monitors bin status and communicates via IFTTT for SMS notifications.

In [11], the authors discuss the significant role of waste segregation in mitigating environmental challenges. They emphasize the importance of proper waste sorting for reducing landfill waste and methane emissions, which are significant greenhouse gases. They propose a smart bin system that divides waste into dry and wet categories. An object detection module, a waste level detection module, and a notification generation module make up the three essential modules that make this system work. This system uses different sensors like a rain sensor, ultrasonic sensor, motion sensor, servo motor, and GSM to enable the alert of waste collection to personnel and city authorities when waste levels reach a certain level. Their system consumes electricity when in the absence of sunlight, otherwise it consumes solar energy which saves energy consumption on sunny days.

In [12], the authors state that rag-picker dependence can be reduced by segregating municipal waste at its source. Segregating waste into basic streams such as wet, dry, plastic, and metallic increases its potential for recovery, recycling, and reuse. Their proposed project aims to make municipal waste management useful at the domestic level. This system segregates biodegradable and non-biodegradable waste, and a sensor system detects the amount of waste substances in it, and a message is sent to the municipality office for timely waste collection. It includes a conveyor belt, an Arduino UNO, a GSM modem, a GPS module, and an LCD display.

In [13], the authors state the threat of contamination and its adverse impact on public health due to the ever-increasing global population. They propose an IoT-based smart waste segregation and management system. This system employs sensor devices to detect dustbin contents, automatically sorting waste materials upon detection, and transmitting data swiftly to a cloud database via IoT. A microcontroller serves as an intermediary between sensors and IoT modules. The incorporation of image processing algorithms, including the KNN algorithm, and camera technology, facilitates the precise identification and separation of plastics and degradable items using MATLAB. The system integrates key components such as Arduino Mega, Ultrasonic Sensor, Inductive Proximity Sensor, Moisture Sensor, Servo Motor, and LCD Display.

In [14], the authors address the challenge of waste management to solve the problem of overflowing garbage. They propose IoT-based garbage management systems that effectively segregate dry and wet waste. These systems employ a network of sensors to continuously monitor garbage bin status, transmitting real-time data on the amount of waste collected via web connectivity. Utilizing HC-SR04 ultrasonic sensors positioned

above the bins to accurately measure garbage levels. An Arduino microcontroller controls the process and a Wi-Fi modem sends the data to a server. Each garbage bin is equipped with a cost-effective device for tracking its level and a unique ID is assigned to identify which bins are full.

In [15], the authors state that waste is a vital problem that must be addressed intelligently. Overflowing trash bins are a result of irregular trash collection, which encourages people to dump waste in public places. To address this issue, the authors propose a smart solution as they create a smart trash can system equipped with ultrasonic sensors connected through a mesh network. These sensors monitor bin levels and wirelessly transmit data to a central server. The information is then used to alert waste collection teams, saving time and effort while maintaining a clean environment. The LEACH algorithm ensures effective data routing by providing the shortest path to the truck driver without human interference.

In [16], the authors state the significant role of cleanliness in maintaining human health. They present a novel solution to waste disposal challenges by introducing a smart bin system. This intelligent bin continually monitors the garbage level through sensors and alerts the waste collector when it reaches a specific level. Additionally, the system ensures effective waste segregation into biodegradable, non-biodegradable, and recyclable categories. Using CV technology, the system detects and reports inappropriate materials present within the bin. This system comprises Arduino UNO, servomotor, infrared sensor, image sensor, inductive proximity sensor, ultrasonic sensor, and ESP8266 Wi-Fi module.

In [17], the authors state that waste management is among the biggest problems facing the world, affecting both developed and developing nations alike. They propose a smart alert system for efficient garbage clearance. This system sends instant alerts to the municipal web server when a dustbin reaches its capacity which is determined by an interfaced ultrasonic sensor and Arduino UNO. The system ensures proper verification through RFID tag confirmation by waste collection personnel. An Android application linked to the web server facilitates the communication of alerts from the microcontroller to urban offices and enables remote monitoring of the cleaning process. Notifications are seamlessly transmitted to the Android application using a Wi-Fi module.

Table 2. 1: Comparison with Current State-of-the-Art Approaches

Sr. No.	Year	Author	Proposed Work	Limitations
1.	2023	J. Sigongan et al. [5]	Solar-Powered Smart Garbage Segregation Bins with SMS Notification and ML Image Processing	The proposed system relies heavily on real-time object recognition using CNN algorithms for waste sorting, which can lead to significant computational load and processing time constraints. Although solar panels are utilized as a sustainable energy source, their effectiveness may diminish in areas with limited sunlight or during adverse weather conditions, potentially affecting system reliability. Furthermore, the SMS notifications, integral to previous systems for basic bin status alerts, rely on cellular network coverage and may involve ongoing communication costs. The integration of multiple hardware components such as Raspberry Pi and GSM modules introduces complexity and increases power consumption, thereby impacting overall system reliability and maintenance requirements.
2.	2023	S. Prabhakaran et al. [6]	Smart Dustbin Using IoT	The proposed work primarily focuses on waste level detection and human presence determination using ultrasonic and infrared sensors. However, these sensors may not offer sufficient granularity for effective waste segregation into different types such as metallic, wet, and plastic. The

				system updates garbage levels on LCD screens and smartphones but does not involve a segregation process. The system used Dijkstra's algorithm to optimize truck routes for waste collection, aiming to reduce fuel consumption and time. However, this approach may not directly contribute to improving waste segregation or real-time management within the bins themselves.
3.	2022	M. W. Rahman et al. [7]	Intelligent Waste Management System Using Deep Learning with IoT	The proposed work relies heavily on image processing with a CNN-based system for waste classification, which can be computationally intensive and time-consuming. However, this approach may not be suitable for real-time waste segregation, particularly in scenarios where rapid processing and sorting are essential. The integration of multiple components such as a Raspberry Pi microprocessor and camera module in this complex setup could lead to increased hardware costs and maintenance efforts.
4.	2021	Akanksha et al. [8]	Smart Robot for Collection and Segregation of Garbage	The proposed work involves a robotic bot equipped with a Raspberry Pi, DC motors controlled by the L293D motor driver IC, and a YOLOv4 deep learning model. This integration introduces complexity in hardware and maintenance. The reliance on a Raspberry Pi camera and YOLOv4 for

				waste categorization may lead to delays and errors in image processing, particularly in dynamic waste sorting environments. Furthermore, the scalability of the robotic bot system could be constrained by the requirement for sophisticated hardware and ongoing model training.
5.	2021	M. Ashwin et al. [9]	IoT Based Intelligent Route Selection of Wastage Segregation for Smart Cities Using Solar Energy	The proposed work utilizes ultrasonic sensors and servo motors for lid operation to distinguish between dry and wet waste in smart bins. However, this approach may lack the precision required for detailed waste segregation into metallic, wet, and plastic. Additionally, while employing 800-watt solar panels and battery banks, there are potential limitations in maintaining consistent power supply, particularly in regions with variable sunlight or during extended periods of inclement weather. Although it autonomously notifies garbage collectors when bins reach 80% capacity, it may lack comprehensive real-time monitoring capabilities and cloud-based data transmission.
6.	2021	S. Pandey et al. [10]	Smart Garbage Segregator Using IoT	The proposed work utilizes multiple sensors and actuators controlled by an Arduino Mega, which could potentially increase system complexity and maintenance

				requirements. It employs IFTTT for SMS notifications based on bin status monitored by infrared sensors, yet it may lack real-time data transmission and cloud-based storage capabilities. Additionally, the system features a conveyor belt-based mechanism with servo-motor-driven dustbins for sorting waste into Wet, Dry, and Hazardous categories.
7.	2020	S. Sarker et al. [11]	Energy Saving Smart Waste Segregation and Notification System	The proposed work categorizes waste into dry and wet categories using basic sensors like rain and ultrasonic sensors, but it lacks the capability for detailed segregation into specific types such as metallic, wet, and plastic. Additionally, reliance on solar power may restrict continuous operation in regions with inconsistent sunlight or during extended periods of low light conditions. The system utilizes GSM for waste-level notifications, yet it may not offer comprehensive real-time data transmission and cloud-based monitoring capabilities.
8.	2020	C. Bhangale et al. [12]	Smart Garbage Segregation & Handling System Using IoT	The proposed work segregates waste into biodegradable and non-biodegradable categories, but it lacks the capability for detailed and automated segregation into specific waste types such as metallic, wet, and plastic. It relies on GSM for message

				<p>notifications to municipal offices and uses an LCD display for local feedback. However, this setup may limit real-time data transmission and remote monitoring capabilities. Additionally, reliance on GSM introduces potential delays and communication challenges.</p>
9.	2019	S. N et al. [13]	Smart Garbage Segregation & Management System Using IoT & ML	<p>The proposed work integrates image processing algorithms such as the KNN algorithm in MATLAB for waste identification and separation, which introduces significant computational load and processing time. This approach may cause delays in real-time waste sorting. Moreover, reliance on MATLAB and camera technology for waste classification restricts the system's flexibility and scalability in practical deployment scenarios.</p>
10.	2019	E. Johar et al. [14]	IoT Based Intelligent Garbage Monitoring System	<p>The proposed work effectively segregates dry and wet waste but cannot identify and sort multiple waste types such as metallic, wet, and plastic with detailed precision. Each garbage bin is equipped with a device to track its level, potentially adding complexity and cost when scaling to larger municipal or smart city applications.</p>

11.	2018	P. Anitha et al. [15]	Smart Garbage Maintenance System Using IoT	<p>The proposed work focuses on monitoring bin levels using ultrasonic sensors and transmitting data via a mesh network to optimize waste collection routes. However, it cannot segregate and sort different types of waste such as metallic, wet, and plastic with precision and efficiency. The reliance on a mesh network for sensor communication and a centralized server for data processing and route optimization may introduce complexities in network management and scalability, particularly in densely populated urban environments. Although the LEACH algorithm optimizes data routing to waste collection teams, it may not efficiently handle the real-time data processing and sorting tasks necessary for dynamic waste management scenarios.</p>
12.	2018	S. Paul et al. [16]	Smart Garbage Monitoring Using IoT	<p>The proposed work segregates waste into biodegradable, non-biodegradable, and recyclable categories using computer vision (CV) technology. However, the system may not achieve the required precision in sorting metallic, wet, and plastic waste types. The reliance on CV technology for detecting and reporting inappropriate materials within the bin introduces challenges in</p>

				real-time processing and may not be suitable for high-throughput waste management scenarios.
13.	2018	S. Suryawanshi et al. [17]	Waste Management System Based On IoT	The proposed work lacks the capability for detailed waste segregation into different types such as metallic, wet, and plastic. The reliance on RFID tag confirmation by waste collection personnel adds an additional step that may not be necessary for automated systems. Although the Android application linked to the web server facilitates communication and alerts, the system's reliance on a Wi-Fi module for transmission limits scalability and may introduce connectivity issues in large-scale deployments.

2.8 Summary

This chapter provides an overview of traditional waste management challenges and advocates for modern solutions. It conducts a comprehensive literature review to propose an advanced garbage management system, delving into various waste types and underscoring the necessity for tailored waste management strategies. The complexities of waste management amidst urban development and population growth are thoroughly discussed. The integration of IoT into waste management is emphasized as a transformative solution, aimed at enhancing efficiency and sustainability. Key technologies such as sensors, actuators, and integrated cloud computing are highlighted for their role in improving waste management efficiency and promoting environmental sustainability. Furthermore, the chapter critically assesses the limitations of existing proposed systems, identifying research gaps that require further investigation to advance the field.

CHAPTER 3

SIMULATION AND RESULTS

3.1 Introduction

The present study examines "Smart Garbage Segregation and Management System Using the Internet of Things (IoT)" to improve urban sustainability and waste management practices. IoT-based solutions have become necessary due to the increasing challenges caused by inefficient waste disposal methods.

In this simulation chapter, we describe the systematic creation and evaluation of a cutting-edge system designed to optimize garbage segregation and management. The simulation environment for this innovative project is constructed within the versatile framework of Proteus. This simulation platform facilitates a comprehensive examination of the Smart Garbage Segregation and Management System. Throughout this simulation, an Arduino controller, alongside an ESP32 module, controls an array of sensors placed precisely to capture and analyze dynamic scenarios within the waste management ecosystem. Our simulation relies on Arduino programming to manage a complex network of sensors and actuators within the simulated environment. The interaction of these components ensures a comprehensive monitoring and control framework, creating an intelligent and responsive garbage management system.

This chapter presents comprehensive simulation results, including a flowchart illustrating the systematic operation of the developed system within Proteus. As a result of the subsequent sections, it is possible to gain a deeper understanding of the Smart Garbage Segregation and Management System's efficiency and potential.

3.2 Simulation Environment

The simulation environment serves as a pivotal aspect of the development and testing of the "Smart Garbage Segregation and Management System Using the Internet of Things (IoT)" project. Within this virtual environment, hardware and software components are precisely integrated and the system's functionality and efficiency are evaluated. A simulation environment is established using Proteus Software coupled with Arduino Programming, providing a comprehensive platform for simulating real-world situations.

3.2.1 Proteus Software

The choice of Proteus software as the simulation platform brings a reliable and flexible tool for hardware simulation. The well-known Proteus modeling tool allows us to create a dynamic and interactive environment where the Smart Garbage Segregation and Management System can be accurately tested and refined. Its user-friendly interface and comprehensive component library make it an ideal choice for simulating the detailed interactions between the various elements of the Smart Garbage Segregation and Management System.

3.2.2 ESP32 Programming

ESP32 programming is crucial for our simulation, enabling internet connectivity to control and monitor the system. The ESP32 module, programmed using Arduino software, ensures seamless communication and control of the Smart Garbage Segregation and Management System. By leveraging the Blynk protocol, the ESP32 facilitates real-time data transmission and remote control, making it a crucial component for integrating IoT capabilities into the system. The programming of the ESP32 module encompasses the setup of Wi-Fi connectivity, sensor integration, and communication protocols to ensure robust and efficient operation.

3.2.3 Arduino Programming

Arduino programming serves as the brain behind our simulation, controlling and coordinating its components intelligently through its programming capabilities. In this subsection, we examine the rationale behind choosing Arduino coding, explaining how it facilitates the integration of sensors, actuators, and communication modules. The programming techniques are explained to showcase how Arduino programming ensures the smooth execution of our Smart Garbage Segregation and Management System, making it responsive to waste disposal demands.

3.2.4 Hardware Simulation

The simulation environment extends beyond just code execution by simulating the hardware interactions of the Smart Garbage Segregation and Management System. To replicate the physical component's behavior accurately, virtual sensors, actuators, and

communication modules are used. As a result, a comprehensive evaluation of system performance is possible, taking real-world constraints into account.

3.2.5 Scenario Testing

The simulation environment allows for the creation of diverse scenarios, including various waste disposal situations, network disruptions, and sensor malfunctions. This comprehensive scenario testing ensures that the system remains stable in the face of unforeseen challenges, providing valuable insights into adaptability and reliability.

3.2.6 Data Visualization and Analysis

Proteus software's simulation environment enables real-time data visualization and analysis. This feature facilitates a detailed examination of data flow, system responses, and the effectiveness of garbage segregation and management algorithms implemented within the IoT ecosystem. The results obtained serve as a foundation for subsequent chapters, where real-world implementations and validations are explored in-depth.

3.3 System Components

The main components of the project are:

- Arduino UNO
- Metal Sensor (Inductive Proximity Sensor)
- Wetness Sensor
- Object Detection Sensor (Infrared Sensor)
- DC Gear Motor
- Servo Motor
- LCD

3.4 Sensors Mathematical Calculation

Understanding the mathematical calculations is crucial for effectively utilizing sensors in real-world scenarios, ensuring accuracy, and optimizing performance. We will explore the mathematical calculations for four commonly used sensors in our system including inductive proximity sensor, wetness sensor, infrared sensor, and ultrasonic sensor.

3.4.1 Inductive Proximity Sensor

Inductive proximity sensors are employed to detect the presence of metallic objects without physical contact. They work by generating an electromagnetic field and measuring changes in inductive reactance when a metal object enters the field. Here are the basic equations that are commonly associated with inductive proximity sensors:

- **Inductive Reactance**

$$X_L = 2 \pi f L \quad (3.1)$$

Where,

X_L : Inductive reactance in ohms.

f : Operating frequency of the sensor in hertz.

L : Inductance of the coil in henry.

- **Resonant Frequency**

$$f_{\text{res}} = \frac{1}{2 \pi \sqrt{LC}} \quad (3.2)$$

Where,

f_{res} : Resonant frequency in hertz.

L : Inductance of the coil in henrys.

C : Capacitance in farads.

- **Voltage Across the Coil**

$$V = I X_L \quad (3.3)$$

Where,

V : Voltage across the coil in volts.

I : Current flowing through the coil in amperes.

X_L : Inductive reactance in ohms.

3.4.2 Wetness Sensor

Wetness sensors measure the wetness content in the different types of waste, which is crucial for efficient segregation. Here, we'll provide a basic overview of the mathematical calculation for a wetness sensor:

- **Voltage Divider Equation**

$$V = V_{cc} \frac{R_{sensor}}{R_{sensor} + R_s} \quad (3.4)$$

Where,

V: Output voltage across the sensor in volts.

V_{cc}: Supply voltage in volts.

R_{sensor}: Resistance of the sensor in ohms.

R_s: Resistance of the series resistor (in ohms) in the voltage divider circuit.

- **Calibration Curve**

$$\text{Wetness} = a V + b \quad (3.5)$$

Wetness: Wetness Content.

V: Output voltage of the sensor in volts.

a: Slope of Calibration Curve.

b: Intercept of Calibration Curve.

3.4.3 Infrared Sensor

Infrared sensors detect objects by emitting and receiving infrared radiation. They can be used for proximity sensing, object detection, and distance measurement. Here are some general concepts and calculations associated with IR sensors:

- **Infrared Emission**

$$B(\lambda, T) = \frac{2 h c^2}{\lambda^5 e^{\frac{hc}{\lambda k T}} - 1} \quad (3.6)$$

Where,

B(λ,T): Spectral radiance of a black body by planck's law.

h: Planck's constant.

c: Speed of light.

λ: Wavelength.

k: Boltzmann's constant.

T: Absolute temperature.

- **IR Reflection**

$$R = \frac{I_{reflected}}{I_{incident}} \quad (3.7)$$

Where,

R: Reflectance.

$I_{\text{reflected}}$: Intensity of reflected infrared radiation (detected signal).

I_{incident} : Intensity of incident infrared radiation (emitted signal).

- **Infrared Interruption**

$$I = \frac{I_0}{r^2} \quad (3.8)$$

Where,

I: Intensity at distance r (detected intensity).

I_0 : Initial intensity at the source (emitted intensity).

r: Distance from the source in meters.

3.4.4 Ultrasonic Sensor

Ultrasonic sensors measure distance by emitting ultrasonic waves and calculating the time it takes for the waves to reflect off an object and return to the sensor. Here are the key mathematical calculations associated with ultrasonic sensors:

- **Speed of Sound**

$$v = 331.4 + 0.6 \times T \quad (3.9)$$

Where,

v: Speed of sound in meters per second.

T: Ambient temperature in degrees celsius.

- **Distance Calculation**

$$D = \frac{t v}{2} \quad (3.10)$$

Where,

D: Distance to the object in meters.

T: Time taken for the ultrasonic waves to travel to the object and back in seconds.

v: Speed of sound in meters per second.

- **Measurement Accuracy**

$$R = \frac{t_{min} v}{2} \quad (3.11)$$

Where,

R: Resolution of distance measurement in meters.

t_{\min} : Minimum measurable time in seconds.

v: Speed of sound in meters per second.

- **Distance vs. Voltage**

$$V = m \times D + b \quad (3.12)$$

Where,

V: Voltage in volts.

m: Slope of the linear relationship.

D: Distance in meters.

b: Y-intercept.

3.5 Simulation Setup

The simulation setup of the project is shown in Figure 3.1.

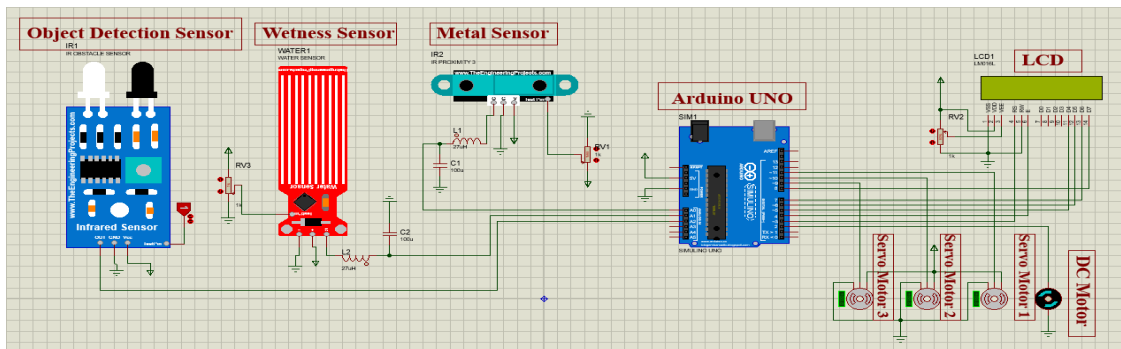


Figure 3. 1: Simulation Setup

3.6 Simulation Results

As shown in Figure 3.2, simulation is enabled.

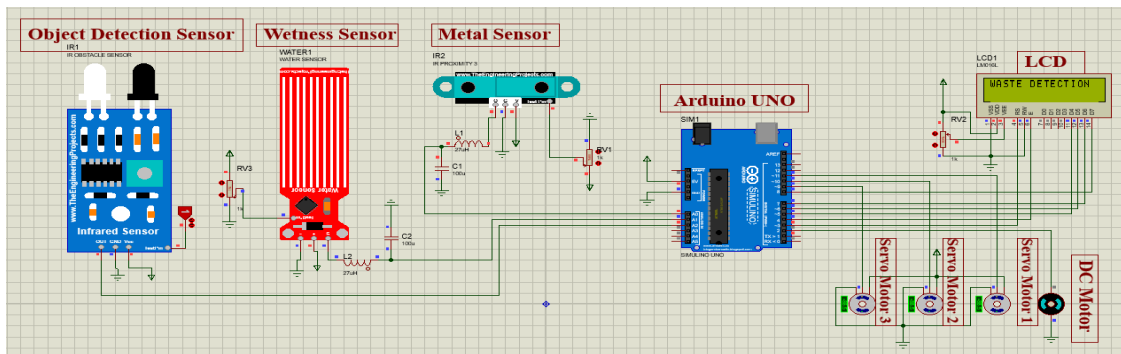


Figure 3. 2: Simulation is Enabled

3.6.1 Metallic Waste Detection

In Figure 3.3, the metallic waste is detected by the metal sensor (inductive proximity sensor), and servo motor 1 is rotated at a specific angle as shown.

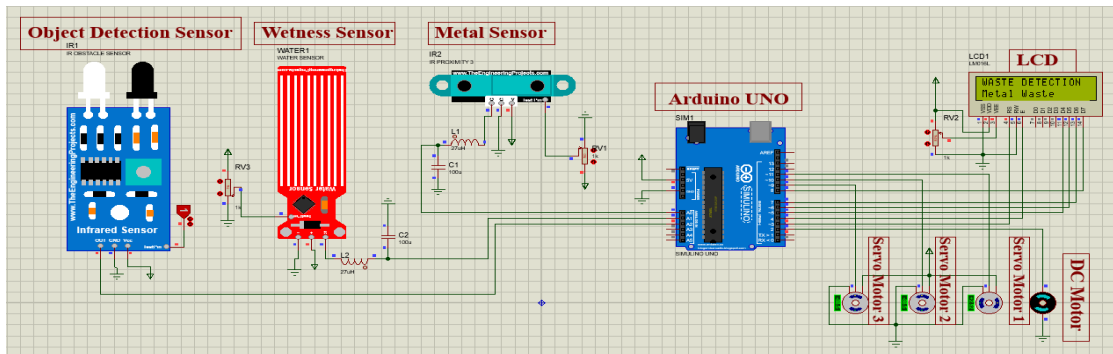


Figure 3. 3: Metallic Waste Detected

3.6.2 Wet Waste Detection

In Figure 3.4, the wet waste is detected by the wetness sensor, and servo motor 2 is rotated at a specific angle as shown.

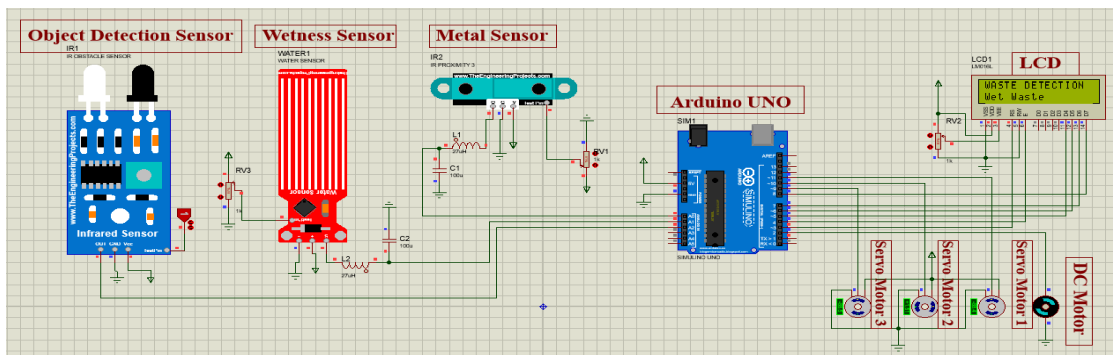


Figure 3. 4: Wet Waste Detected

3.6.3 Plastic Waste Detection

In Figure 3.5, the plastic waste is detected by the object detection sensor (infrared sensor), and servo motor 3 is rotated at a specific angle as shown.

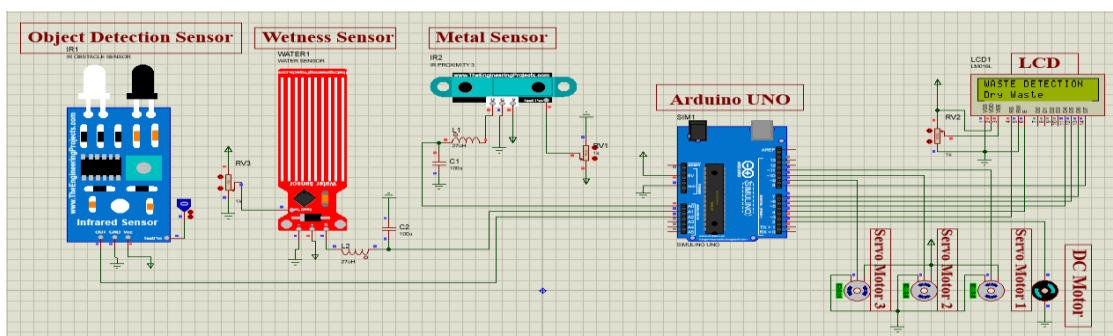


Figure 3. 5: Plastic Waste Detected

3.7 Summary

The chapter on "Simulation and Results" introduces a study on "Smart Garbage Segregation and Management System Using the Internet of Things (IoT)." The simulation of the system is performed in Proteus, utilizing Arduino programming to control an array of sensors and actuators. Additionally, ESP32 programming ensures internet connectivity and remote control using the Blynk protocol. The simulation environment allows for comprehensive testing and evaluation, considering diverse scenarios such as waste disposal situations, network disruptions, and sensor malfunctions. The chapter outlines the significance of Proteus Software and Arduino Programming in creating a dynamic and interactive simulation platform. It highlights the hardware simulation aspect, where virtual sensors and actuators replicate the physical component's behavior.

CHAPTER 4

HARDWARE DESIGN AND RESULTS

4.1 Introduction

In the modern world, effective waste management is a critical issue, and the “Smart Garbage Segregation and Management System Using Internet of Things (IoT)” aims to address this challenge by automating the process of sorting and managing waste. This project leverages IoT technology to create a system that can efficiently segregate garbage, thereby improving recycling rates and reducing environmental impact. The hardware implementation of this system is fundamental to its operation, providing the necessary infrastructure to detect, categorize, and manage waste automatically.

This chapter details the design, development, and integration of the various hardware components that make up the smart garbage segregation system. The key objectives of this chapter are to outline the selection and integration of each hardware component, explain how they work together to achieve the desired functionality, and demonstrate the system's effectiveness through testing and validation. The components involved in this project include sensors for detection, microcontrollers for processing, and actuators for sorting the waste, all of which are crucial for the system's performance.

The hardware implementation is significant because it directly impacts the system's accuracy, efficiency, and reliability. By using advanced sensors and robust processing units, the system can accurately identify different types of waste and sort them accordingly. The integration of IoT technology enables real-time monitoring and control, making the system adaptable and scalable.

4.2 List of Components

The list of components is defined below in Table 4.1.

Table 4. 1: List of Components

Sr. No.	Name of Component	Quantity
1.	ESP32	1
2.	Arduino UNO	2
3.	LCD Display	1

4.	Buck Converter	1
5.	Inductive Proximity Sensor	1
6.	Wetness Sensor	1
7.	Infrared Sensor	1
8.	Ultrasonic Sensor	4
9.	Servo Motor	4
10.	DC Gear Motor	1
11.	Relay	1
12.	Optocoupler	1
13.	Voltage Regulator	1
14.	Vero Board	1
15.	DC Power Supply	1
16.	DC Pin	1
17.	Diode	2
18.	Capacitor	3
19.	Resistor	5
20.	LED	2
21.	Header Pins	NA
22.	Transistor	1
23.	Variable Resistor	1

4.2.1 ESP32

The ESP32 is a series of microcontrollers designed by Espressif Systems. They are notable for their low cost, low power consumption, and integrated Wi-Fi and Bluetooth connectivity, making them ideal for Internet of Things (IoT) projects. As a mini-computer, the ESP32 can run programs and control electronic components, enabling devices to connect to the internet and communicate with other devices. Its low-power design makes it suitable for battery-powered applications. In our system, the ESP32 is utilized to remotely switch the system and monitor the level of segregated waste, leveraging its wireless capabilities for efficient and real-time communication. The

ESP32 controller is shown below in Figure 4.1 and its specifications are described in Table 4.2.



Figure 4. 1: ESP32

Table 4. 2: Specifications of the ESP32

Operating Voltage	2.2V - 3.6V
Microprocessor	32-bit
Clock Speed	80MHz - 240MHz
Performance	600DMIPS (Dhrystone Million Instructions Per Second)
RAM	520kB
ROM	448kB
Wi-Fi Speed	150Mbps
ADC	12-bit - (up to 18 Channels)

4.2.2 Arduino UNO

The Arduino Uno is a popular open-source microcontroller board designed for electronics hobbyists, artists, and anyone interested in creating interactive projects. It features the ATmega328P microcontroller, which processes instructions and interacts with electronic components. The Arduino Uno can connect to various sensors, LEDs, motors, and other components through its pins and is programmable via USB using the Arduino IDE. This user-friendly design, combined with its extensive community support, makes it an ideal choice for both beginners and experienced electronics enthusiasts. In our system, the Arduino UNO is used to control the entire system by taking inputs from sensors, operating the relevant servo motor, and displaying results

on an LCD. The Arduino UNO is shown below in Figure 4.2 and its specifications are described in Table 4.3.

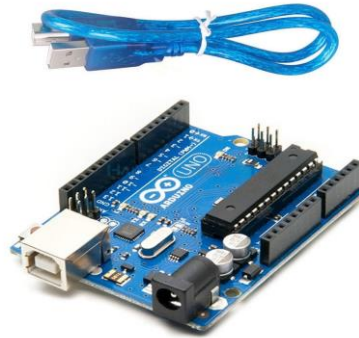


Figure 4. 2: Arduino UNO with its Connecting Cable

Table 4. 3: Specifications of the Arduino UNO

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (Recommended)	7V - 12V
Input Voltage (Limit)	6V - 20V
Digital I/O Pins	14 (of which 6 Provide PWM Output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20mA
DC Current for 3.3V Pin	50mA
Flash Memory	32kB
SRAM	2kB
EEPROM	1kB
Clock Speed	16MHz

4.2.3 LCD Display

The LCD display is a widely used electronic component for Arduino projects, offering a simple and effective way to display information. It operates using a parallel interface, which requires multiple data pins to connect to the Arduino, but can also be interfaced using I2C to reduce the number of pins needed. The display is equipped with a built-in controller (usually the HD44780) that manages the display functions and simplifies the process of writing text to the screen. In our system, the 16x2 LCD display is used to

show the results of segregated waste in real-time, providing immediate feedback and status updates to users. The 16x2 LCD display is shown below in Figure 4.3 and its specifications are described in Table 4.4.

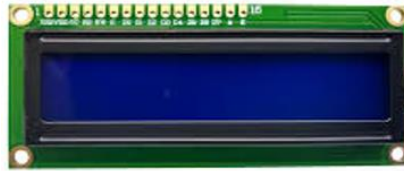


Figure 4. 3: 16x2 LCD Display

Table 4. 4: Specifications of the 16x2 LCD Display

Minimum Logic Voltage	4.5V
Maximum Logic Voltage	5.5V
Typical LED Backlight Voltage Drop	4.2V
Typical LED Backlight Current	120mA
Supply Current	2mA
Display Mode	STN/BLUE, Negative, Trans-missive
Display Format	16 (Characters) x 2 (Line)
Interface Input Data	8 bits
Driving Method	1/16 Duty, ¼ Bias
Character Size	5.20mm x 3.55mm

4.2.4 Buck Converter

A buck converter, also known as a step-down converter, is a widely used electronic circuit that converts a higher DC voltage at its input to a lower DC voltage at its output while increasing the current. It belongs to a category of power supplies called switched-mode power supplies (SMPS). They are more complex circuits compared to linear regulators and require careful design and selection of components to ensure efficient operation. In our system, the buck converter is used as a power regulator to step down voltage for various components. Buck converters offer several advantages over linear regulators, such as higher efficiency, especially for significant voltage reductions, compactness, and suitability for applications requiring variable output voltage. The buck converter is shown below in Figure 4.4 and its specifications are described in Table 4.5.

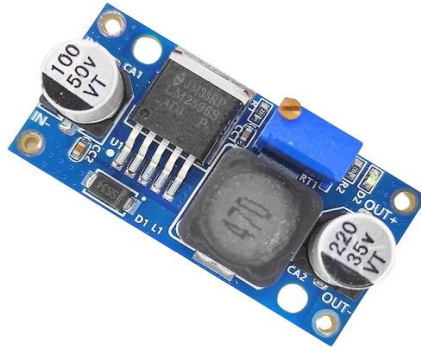


Figure 4. 4: Buck Converter

Table 4. 5: Specifications of the Buck Converter

Input Voltage	3V - 40V
Output Voltage	1.5V - 35V
Output Current	Rated Current is 2A, Maximum 3A
Switching Frequency	150kHz
Operating Temperature	Industrial Grade (-40° - +85°)
Conversion Efficiency	92% (Highest)
Load Regulation	± 0.5%
Voltage Regulation	± 0.5%
Dynamic Response Speed	5%, 200μs
Dimension	45mm * 20mm *14mm (L*W*H)
Shipping Weight	0.011kg
Shipping Dimensions	5cm × 4cm × 2cm

4.2.5 Inductive Proximity Sensor

An inductive proximity sensor is a type of sensor that can detect the presence of metal objects without physically touching them by using an electromagnetic field. It is utilized to detect metal objects within the waste in our system. Inductive proximity sensors can only detect ferrous and non-ferrous metals. These sensors are a versatile and reliable solution for various industrial automation applications where contactless detection of metal objects is required. The inductive proximity sensor's ability to detect metal objects without contact makes it an essential component in our system for identifying and segregating metallic waste efficiently. The inductive proximity sensor is shown below in Figure 4.5 and its specifications are described in Table 4.6.



Figure 4. 5: Inductive Proximity Sensor

Table 4. 6: Specifications of the Inductive Proximity Sensor

Operating Voltage	$40V_{AC} - 250V_{AC} / 20V_{DC} - 250V_{DC}$
Maximum Load Current	250mA @ 25°C 200mA @ 70°C
Switching Frequency	60Hz
Leakage Current	$\leq 2.0mA$
Voltage Drop	$\leq 12V @ < 10mA \leq 4V @ > 25mA$
Holding Current	5mA (Min.)
Protection	Resettable Short Circuit Overload Protection
Switching Hysteresis	< 15% Rated Sensing Distance
Time Delay Before Availability	< 200ms
Output Indicator LED	360° Viewable LED
Operating Temperature	-25°C - 70°C (-13°F - 158°F)
Enclosure Ratings	NEMA 4, 4X, 6, 6P, 12 and 13 (IP67)
Shock	30g, 11ms per IEC 68-2-76
Vibration	10Hz - 55Hz, 1mm Amplitude

4.2.6 Wetness Sensor

A wetness sensor is a device that detects the presence of moisture on a surface, used in various applications such as agriculture, weather monitoring, building automation, and wearable technology. In our system, it is used to identify wet waste from garbage. The wetness sensor can operate using different principles, including capacitive, resistive, and conductive methods. The wetness sensor's capability to detect moisture efficiently

ensures accurate identification of wet waste in our system, contributing to effective waste segregation. The wetness sensor is shown below in Figure 4.6 and its specifications are described in Table 4.7.



Figure 4. 6: Wetness Sensor

Table 4. 7: Specifications of the Wetness Sensor

Range	Wetness: 0% - 100% Temperature: -40°C - +80°C
Accuracy	Wetness: $\pm 3\%$ (0% - 50%), $\pm 5\%$ (> 50%) Temperature: $\pm 0.5^\circ\text{C}$
Repeatability	$< \pm 3\%$ fs
Temperature Drift	$\leq 0.2\%$ FS/ $^\circ\text{C}$
Supply	5V _{DC} , 12V _{DC} - 24V _{DC}
Output	4mA - 20mA, 0V - 5V, 0V - 2V, RS485
IP Rating	IP65
Operating Temperature	-40°C - +80°C
Dimension	65mm * 13mm * 145mm
Storage	-40°C - 70°C @ 20% - 90% RH

4.2.7 Infrared Sensor

An infrared (IR) sensor is an electronic device that detects infrared radiation, a type of electromagnetic radiation with a longer wavelength than visible light and invisible to the human eye. There are two main types of infrared sensors: Active infrared sensors, which emit and detect their own infrared light, and Passive infrared sensors, which

detect IR radiation from external sources. In our project, the infrared sensor is used for detecting objects and their proximity. The infrared sensor's ability to detect objects and their proximity is crucial in our system for accurately identifying the presence and location of various items. The infrared sensor is shown below in Figure 4.7 and its specifications are described in Table 4.8.



Figure 4. 7: Infrared Sensor

Table 4. 8: Specifications of the Infrared Sensor

Power LED	Illuminates when Power is Applied
Obstacle LED	Illuminates when an Obstacle is Detected
Board Size	3.2cm x 1.4cm
Working Voltage	3.3V _{DC} - 5V _{DC}
Operating Voltage	3.3V: ~23mA - 5V: ~43mA
Detection Range	2cm – 30cm (Adjustable using Potentiometer)
Active Output Level	The Output is “0” (Low) when an Obstacle is Detected

4.2.8 Ultrasonic Sensor

An ultrasonic sensor is a device that uses sound waves to measure distance, detect the presence of objects, and monitor movement. The sound waves used in ultrasonic sensors have a frequency higher than what humans can hear. In our system, the ultrasonic sensor is used to measure the distance to objects in bins after sorting. The ultrasonic sensor's ability to measure distance precisely is essential for our system. The ultrasonic sensor is shown below in Figure 4.8 and its specifications are described in Table 4.9.



Figure 4. 8: Ultrasonic Sensor

Table 4. 9: Specifications of the Ultrasonic Sensor

Power Supply	5V _{DC}
Operating Current	15mA
Operating Frequency	40kHz
Quiescent Current	< 2mA
Ranging Distance	2cm - 400cm
Resolution	0.3cm
Measuring Angle	15°
Trigger Input Pulse Width	10 μ s TTL Pulse
Dimension	45mm x 20mm x 15mm

4.2.9 Servo Motor

A servo motor is an electric motor that allows for very precise control of its angular position. Unlike a regular DC motor, which spins continuously when voltage is applied, a servo motor can be instructed to rotate to a specific angle and hold that position. This precise control is achieved through a combination of a motor, a gear reduction unit, and a position feedback sensor. In our system, the servo motor controls the mechanical movement for sorting waste. The servo motor's ability to precisely control mechanical movement is essential for accurately sorting waste in our system. The servo motor is shown below in Figure 4.9 and its specifications are described in Table 4.10.



Figure 4. 9: Servo Motor

Table 4. 10: Specifications of the Servo Motor

Operating Voltage	4.8V - 6.6V
Operating Speed	0.20s/60° (4.8V) 0.16s/60° (6.0V)
Stall Torque	9.4kg/cm (4.8V) 11kg/cm (6V)
Gear Type	Metal Gear
Temperature Range	0° - 55°
Rotation Angle	180°
Servo Wire Length	30cm
Dimensions	39.5mm x 20.5mm x 40.7mm

4.2.10 DC Gear Motor

A DC gear motor is an electric motor with a gearbox attached, serving to reduce speed and increase torque. In our system, the DC gear motor provides the necessary torque for moving the conveyor belt. The DC gear motor's ability to provide sufficient torque while moving the conveyor belt ensures the smooth and efficient operation of our waste sorting system. The DC gear motor is shown below in Figure 4.10 and its specifications are described in Table 4.11.



Figure 4. 10: 12V DC Gear Motor

Table 4. 11: Specifications of the DC Gear Motor

Operating Voltage	6V - 18V
Nominal Voltage	12V
Free-run Speed at 12V	399RPM
Free-run Current at 12 V	50mA

Motor Type	DC with Gear Box, Metal Gears
Base Motor	DC 3000 RPM
Shaft Type	Circular 6mm Dia with Internal Hole for Coupling 23 mm Shaft Length
Maximum Torque	~3kg-cm at 12V
RPM	100RPM at 12V
Weight	130g
Max Load Current	~330mA at 12V
Stall Current	1200mA
Stall Torque	2.2kg.cm
Gear Ratio	1 : 21

4.2.11 Relay

A relay is essentially an electrically operated switch used for controlling high-power devices. It controls one electrical circuit by opening and closing contacts in another circuit. In our system, the relay plays a vital role in controlling various high-power devices involved in waste sorting. Its ability to safely and effectively control high-power devices is essential for the proper functioning of the system. The 12V DC relay is shown below in Figure 4.11 and its specifications are described in Table 4.12



Figure 4. 11: 12V DC Relay

Table 4. 12: Specifications of the 12V DC Relay

Trigger Voltage	12V _{DC}
Trigger Current	100mA
Nominal Coil Power	0.36W, 0.45W
Insulation Resistance	100M Ω , 500V _{DC}
Operate Time	15ms/10ms

Maximum AC Load Current	7A @ 250V _{AC} /125V _{AC}
Maximum DC load current	10A @ 30V _{DC} /28V _{DC}
Maximum Switching	300 Operating per Minute
Contact Resistance	100mΩ (at 10A, 5V _{DC})

4.2.12 Optocoupler

An optocoupler, also known as an optoisolator or photocoupler, is an electronic component that transfers electrical signals between two isolated circuits by using light. It isolates different parts of the circuit to prevent interference, such as ground loops and noise. In our system, optocouplers play a crucial role in enhancing safety and preventing interference between circuits involved in waste sorting. Optocouplers provide a reliable method of isolating high-voltage circuits from low-voltage circuits. The optocoupler is shown below in Figure 4.12 and its specifications are described in Table 4.13.



Figure 4. 12: Optocoupler

Table 4. 13: Specifications of the Optocoupler

Input Forward Current	60mA
Power Dissipation	200mW
Collector Current	50mA
Collector-Emitter Voltage	35V
Emitter-Collector Voltage	6V
Rise Time	18μs
Fall Time	18μs

4.2.13 Voltage Regulator

A voltage regulator, such as the LM7805, is an electronic circuit that maintains the voltage level at a steady and constant value, crucial for ensuring the proper functioning of electronic devices sensitive to voltage fluctuations. In our system, the voltage regulator plays a vital role in ensuring a consistent voltage supply to the components

involved in waste sorting. The voltage regulator (LM 7805) is shown below in Figure 4.13 and its specifications are described in Table 4.14

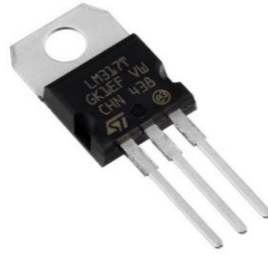


Figure 4. 13: Voltage Regulator (LM 7805)

Table 4. 14: Specifications of the Voltage Regulator (LM 7805)

Voltage Drop	2V
Minimum Input voltage	7V
Maximum Input Voltage	35V
Current Rating	1A
Maximum Output Voltage	5.2V
Minimum Output Voltage	4.8V
Output Voltage	5V
Output Current	2.2A
Mounting	THT
Kind of Package	Tube
Operating Temperature	0°C - 125°C
Number of Channels	1

4.2.14 Vero Board

A Vero board, also known as a stripboard, is a popular tool used for prototyping and assembling electronic circuits, offering a more permanent solution compared to breadboards. In our system, the vero board plays a crucial role in building and testing the circuitry involved in waste sorting. The Vero board's ability to facilitate the assembly of electronic circuits with reliability and customization options is instrumental in the development and testing phases. The vero board is shown below in Figure 4.14 and its specifications are described in Table 4.15.

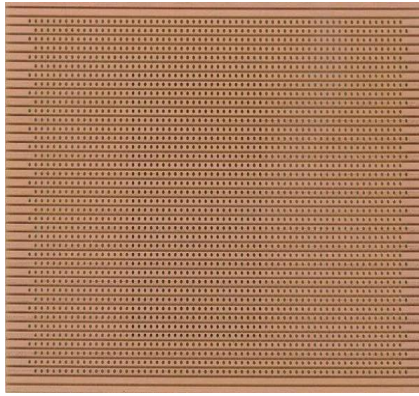


Figure 4. 14: Vero Board

Table 4. 15: Specifications of the Vero board

Material	Fiber Glass FR4
Surface	Copper PCB
Hole Diameter	1.0mm
Hole Pitch	2.54mm
Board Size	10cm x 24cm
Copper Thickness	25 Microns

4.2.15 DC Power Supply

A DC power supply is a device that converts alternating current (AC) from a wall outlet into a stable direct current (DC) voltage, essential for powering electronic devices. The DC power supply's ability to provide stable and regulated power is essential for the reliable operation of our waste sorting system, ensuring the proper functioning of electronic components and circuits. The DC power supply is shown below in Figure 4.15 and its specifications are described in Table 4.16.



Figure 4. 15: 12V DC Power Supply

Table 4. 16: Specifications of the DC Power Supply

Rated Input Voltage	100V - 240V
Full Input Voltage Range	90V _{AC} – 264V _{AC}
Rated Frequency	50Hz
Input Current (RMS Max.)	500mA
Leakage Current (Max.)	< 3.5mA
Output Voltage Rating	12V _{DC}
Output Current Range	0A - 15A
Ripple & Noise (Max.)	150mVp-p
Rated Output Power	18W
Overload Protection	< 2.5A Output Load
No Load Power Consumption	< 0.1W

4.2.16 DC Pin

In the context of our system, the term "DC pin" primarily refers to the central pin of a DC connector, used to supply power from the power supply to the circuitry of the system. The specifications of the DC connector, including the DC pin, are crucial for ensuring safe and efficient power transmission. The DC pin is shown below in Figure 4.16.



Figure 4. 16: DC Pin

4.2.17 Diode

A diode serves as an electronic gatekeeper for current flow within our system, allowing current to flow in one direction while preventing backflow. It functions as a crucial component in ensuring the proper operation and protection of electronic circuits. The

specifications of the diode are vital for its effective utilization in our system. The diode is shown below in Figure 4.17 and its specifications are described in Table 4.17.



Figure 4. 17: Diode

Table 4. 17: Specifications of the Diode

Forward Voltage Drop	0.8
Reverse Current	$30\mu\text{A}$
Average Rectified Forward Current	1A
Operating and Storage Junction Temperature	$-65^{\circ}\text{C} - +175^{\circ}\text{C}$
Non–Repetitive Peak Surge Current	30A

4.2.18 Capacitor

A capacitor, an essential electronic component, stores electrical energy by accumulating electric charges on two closely spaced surfaces insulated from each other, functioning akin to a tiny battery but utilizing an electric field for energy storage. Within our system, capacitors play a pivotal role in various circuits, facilitating energy storage, transient voltage suppression, and circuit stability. The specifications crucially dictate the capacitor's performance and suitability for specific applications. The capacitor is shown below in Figure 4.18.



Figure 4. 18: Capacitor

4.2.19 Resistor

A resistor, a fundamental component in electronics, impedes the flow of electric current within a circuit, essentially acting as a roadblock for electricity. Within our system, resistors serve various roles such as current limiting, voltage division, and signal

conditioning. The specifications of the resistor dictate its performance and suitability for specific applications. The resistor is shown below in Figure 4.19.



Figure 4. 19: Resistor

4.2.20 LED

An LED, or light-emitting diode, serves as a semiconductor device within our system, producing light when an electric current passes through it, primarily utilized as an indication of power supply within the circuit. LEDs are constructed from layers of specifically doped semiconductor materials, enabling efficient conduction of electricity in one direction. The LED's specifications crucially influence its performance and suitability for our application. The LED is shown below in Figure 4.20 and its specifications are described in Table 4.18.



Figure 4. 20: LED

Table 4. 18: Specifications of the LED

Typical Wavelength	635nm - 470nm
Maximum Intensity	48600 med - 16000 med
Viewing Angle	6° - 15°
DC Forward Current	30mA - 50mA
Typical Forward Voltage	1.9V - 3.4V

4.2.21 Header Pins

Header pins are indispensable electrical connectors within electronics, facilitating seamless connections between circuit boards (PCBs) or other electronic components. Within our system, header pins play a crucial role in establishing reliable and efficient

connections between various modules and components. The specifications of header pins significantly impact their compatibility and effectiveness in our application. The header pins is shown below in Figure 4.21.



Figure 4. 21: Header Pins

4.2.22 Transistor

A transistor, a fundamental component in modern electronics, serves as a crucial building block capable of amplifying or switching electrical signals and power within our system. Transistors play a vital role in various circuit configurations, facilitating signal amplification, voltage regulation, and switching operations. The specifications of the transistor significantly influence its performance and suitability for our application. The transistor is shown below in Figure 4.22 and its specifications are described in Table 4.19.



Figure 4. 22: Transistor

Table 4. 19: Specifications of the Transistor

Continuous Collector Current	3A
Collector-Emitter Voltage	50V
Collector-Base Voltage	50V
Collector Emitter Breakdown Voltage	45V
Collector Emitter Saturation Voltage	250mV
Collector Emitter Voltage (VCEO)	45V
Current Rating	100mA
Emitter Base Voltage (VEBO)	6V

Frequency	300MHz
Gain Bandwidth Product	300Hz
H _{FE} (Min.)	110
Collector Current (Max.)	100mA
Operating Temperature (Max.)	150°C
Power Dissipation (Max.)	500mW
Operating Temperature (Min.)	-65°C
Polarity	NPN
Power Dissipation	500mW
Transition Frequency	300MHz
Voltage Rating (DC)	45V

4.2.23 Variable Resistor

A variable resistor, a specialized type of resistor offering adjustable resistance values, serves as a versatile component within electronic circuits, enabling precise control over current and voltage levels. In our project, variable resistors play a crucial role in regulating electrical parameters, such as adjusting the brightness of LEDs, contributing to the system's functionality and adaptability. The specifications of the variable resistor determine its suitability and effectiveness for specific applications. The variable resistor is shown below in Figure 4.23 and its specifications are described in Table 4.20.



Figure 4. 23: Variable Resistor

Table 4. 20: Specifications of the Variable Resistor

Track Resistance	50kΩ
No. of Turns	1
Resistance Tolerance	± 10%
Temperature Coefficient	± 100ppm/°C
Adjustment Type	Top

Contact Resistance Variation	$\pm 1\%$
Full Power Rating Temperature	85°C
Lead Diameter	0.5mm
Operating Temperature Range	-55°C - +125°C
Resistance	50k Ω

4.3 Circuit Diagram of System

The circuit diagram of the system is shown below in Figure 4.24.

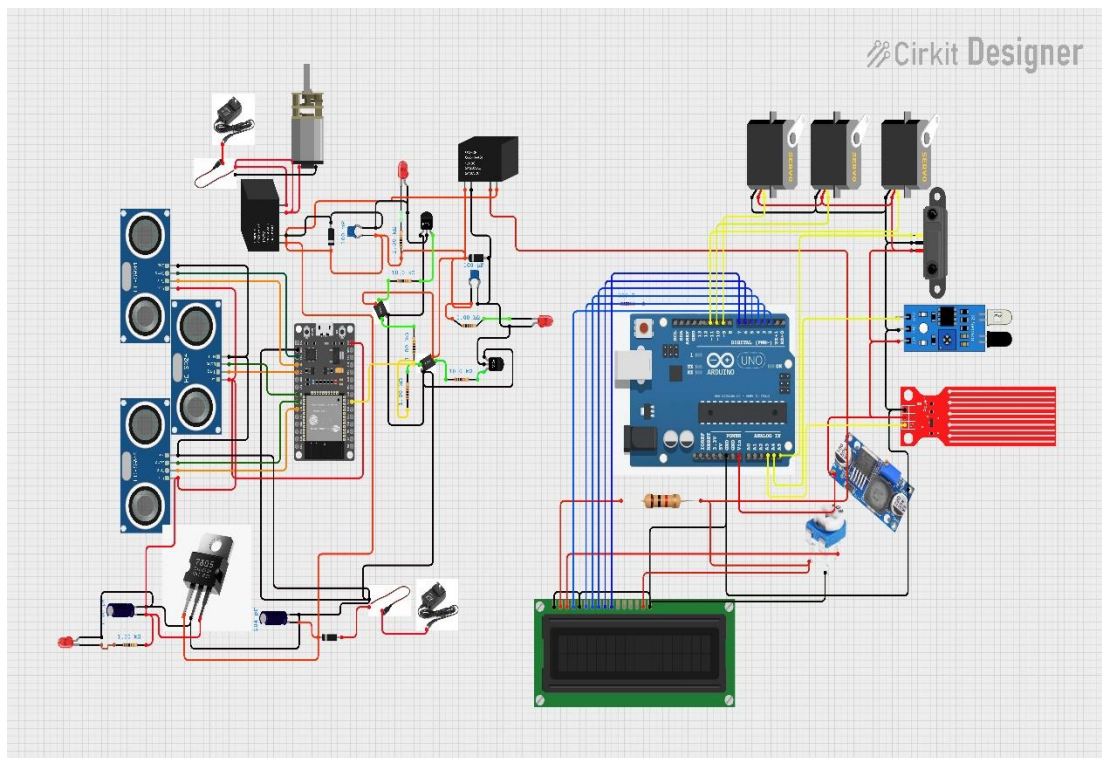


Figure 4. 24: Circuit Diagram of the System

4.4 Hardware Setup

The Smart Garbage Segregation and Management System relies on a combination of physical components and electronic circuitry for its operation. This section will explore the hardware setup with the mechanical aspects that are responsible for waste segregation. We'll delve into the construction and organization of these mechanisms, followed by a detailed examination of the control systems that manage the entire process.

4.4.1 Mechanical Structure of System

The mechanical structure of the Smart Garbage Segregation and Management System is the backbone of the physical waste separation process. The mechanical structure of the system from different views are shown in Figures 4.25, 4.26, and 4.27.

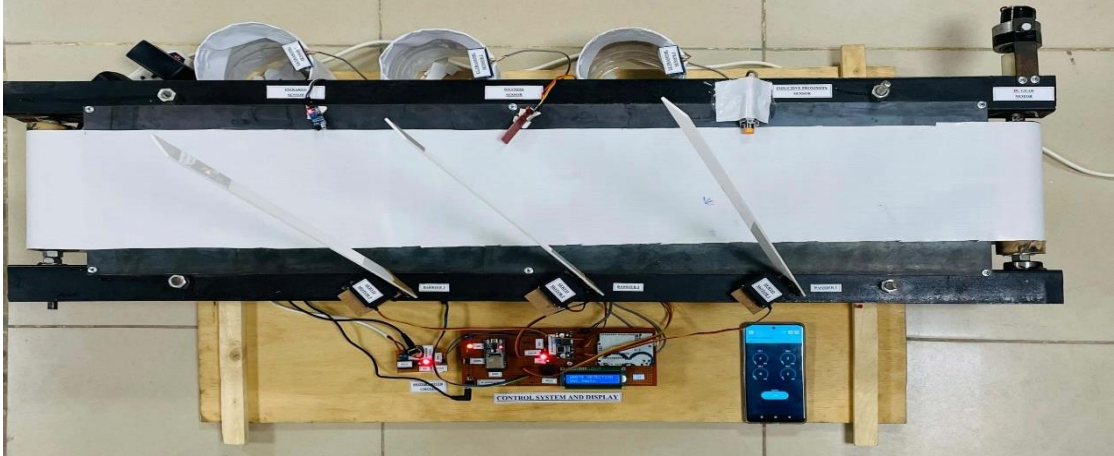


Figure 4. 25: View of Mechanical Structure of System from Top

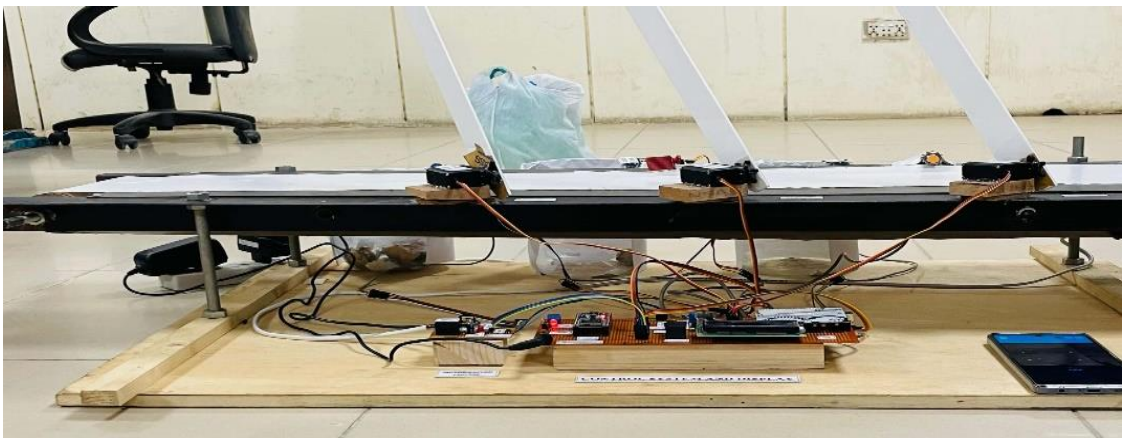


Figure 4. 26: View of Mechanical Structure of System from Front



Figure 4. 27: View of Mechanical Structure of System from Side

4.4.2 Control and Display of System

This system controls the whole working of the Smart Garbage Segregation and Management System and displays the real-time results on screen. It consists of different components as shown in Figure 4.28.

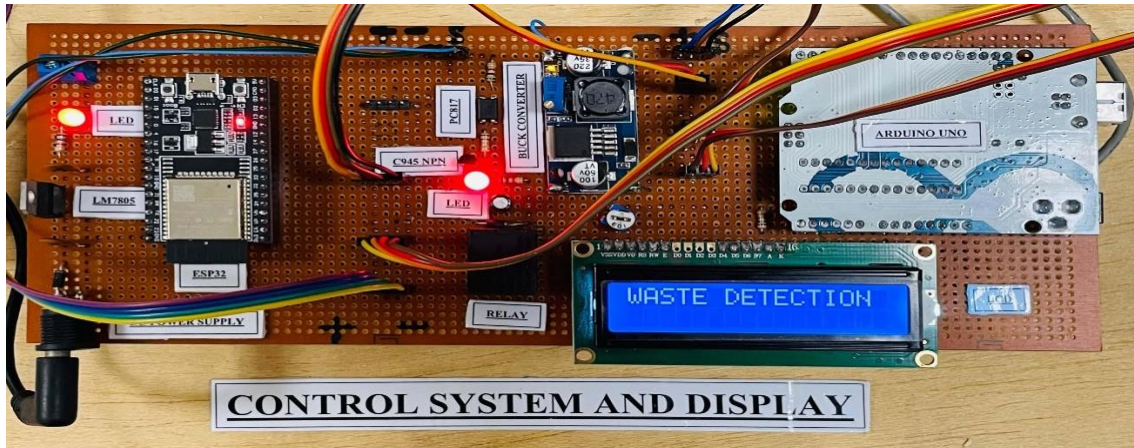


Figure 4. 28: Control and Display of System

4.4.3 Motor Driver Circuit

This circuit is crucial for the mechanical movement and smooth operation of the system. It drives a DC gear motor, which is attached to the conveyor's pulley to move the conveyor belt. The motor driver circuit is shown in Figure 4.29 below.

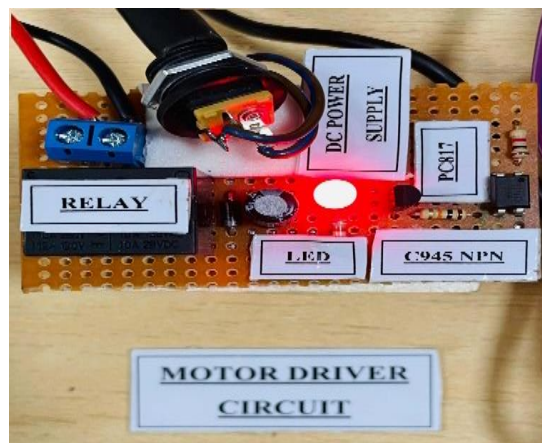


Figure 4. 29: Motor Driver Circuit

4.4.4 Waste Collection Bins Equipped with Ultrasonic Sensor

The waste collection bins are designed to collect segregated waste items. Each bin is equipped with an ultrasonic sensor that sends the waste level to the operator's dashboard in real-time. These bins are shown in Figure 4.30.



Figure 4. 30: Waste Collection Bins Equipped with Ultrasonic Sensor

4.5 Hardware Results

This section presents the results obtained from the hardware setup for all types of waste, including metallic waste, wet waste, and plastic waste.

4.5.1 Metallic Waste Detection

Figure 4.31 illustrates the detection of metallic waste by the inductive proximity sensor. Upon detection, servo-operated barrier 1 closes to drop this waste into Bin 1. Simultaneously, the LCD display shows the result indicating metallic waste, as depicted in Figure 4.32.

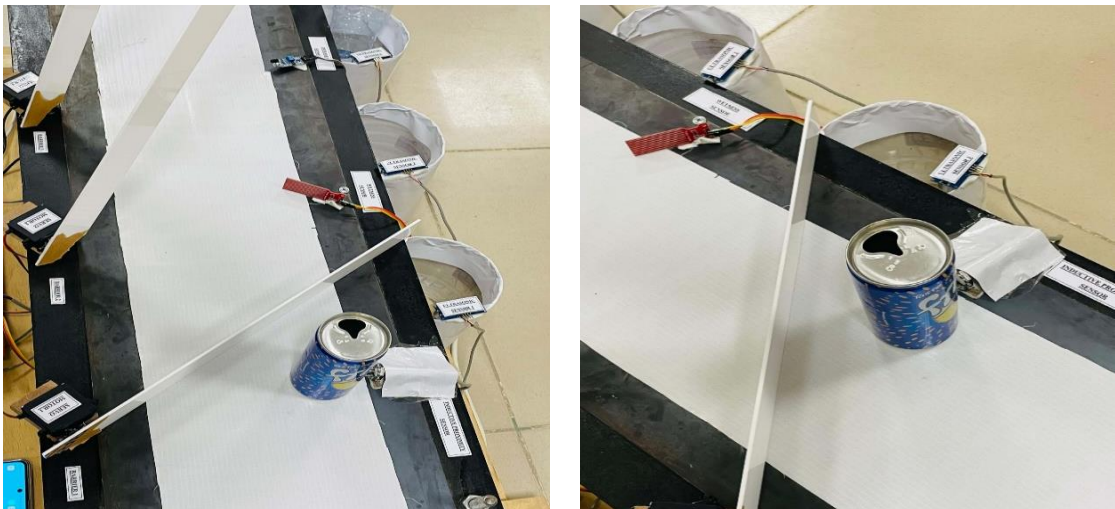


Figure 4. 31: Metallic Waste Detected

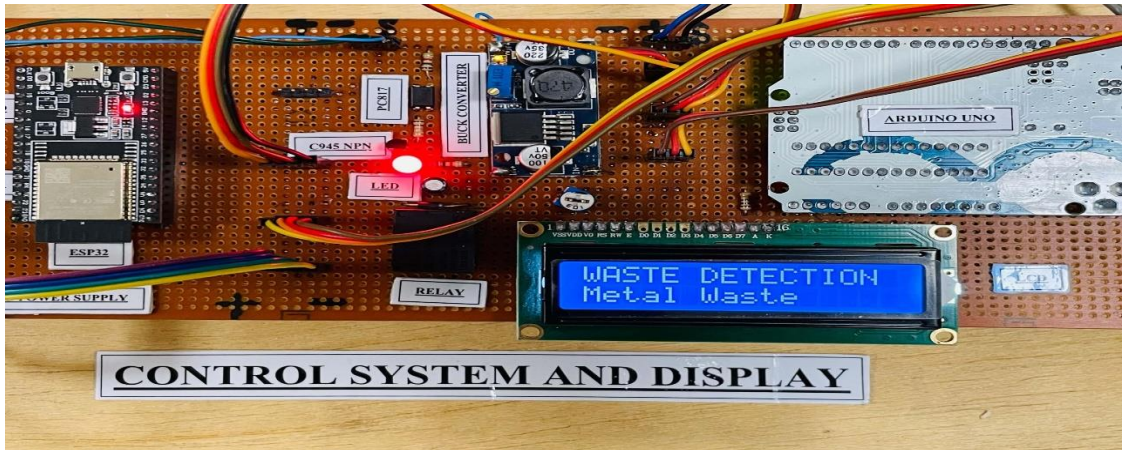


Figure 4. 32: Result of Metallic Waste Detection Display on LCD

4.5.2 Wet Waste Detection

Figure 4.33 illustrates the detection of wet waste by the wetness sensor. Upon detection, servo-operated barrier 2 closes to drop this waste into Bin 2. Simultaneously, the LCD display shows the result indicating wet waste, as depicted in Figure 4.34.

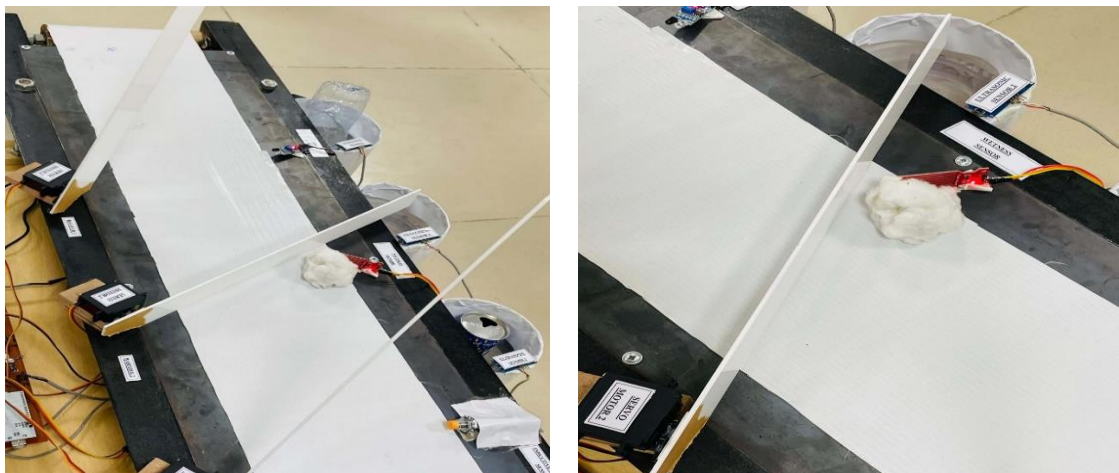


Figure 4. 33: Wet Waste Detected

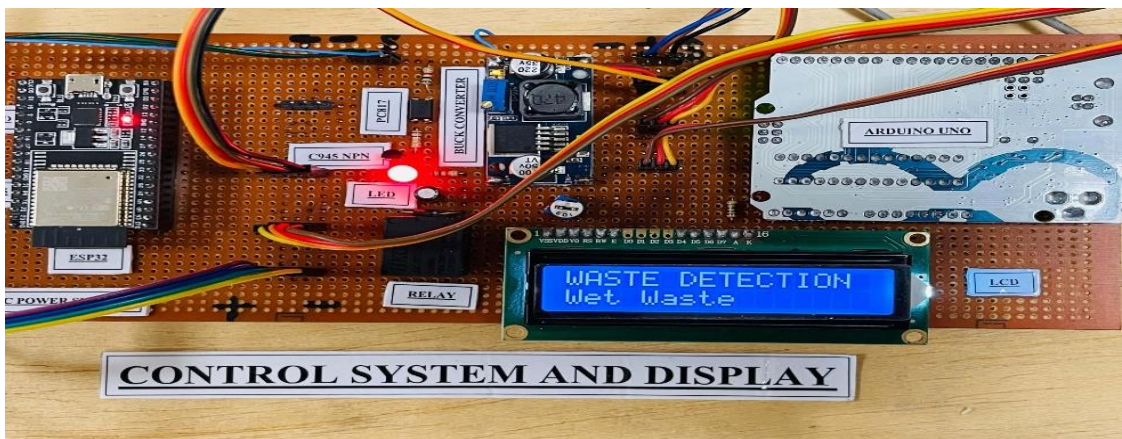


Figure 4. 34: Result of Wet Waste Detection Display on LCD

4.5.3 Plastic Waste Detection

Figure 4.35 illustrates the detection of plastic waste by the infrared sensor. Upon detection, servo-operated barrier 3 closes to drop this waste into Bin 3. Simultaneously, the LCD display shows the result indicating plastic waste, as depicted in Figure 4.36.



Figure 4. 35: Plastic Waste Detected

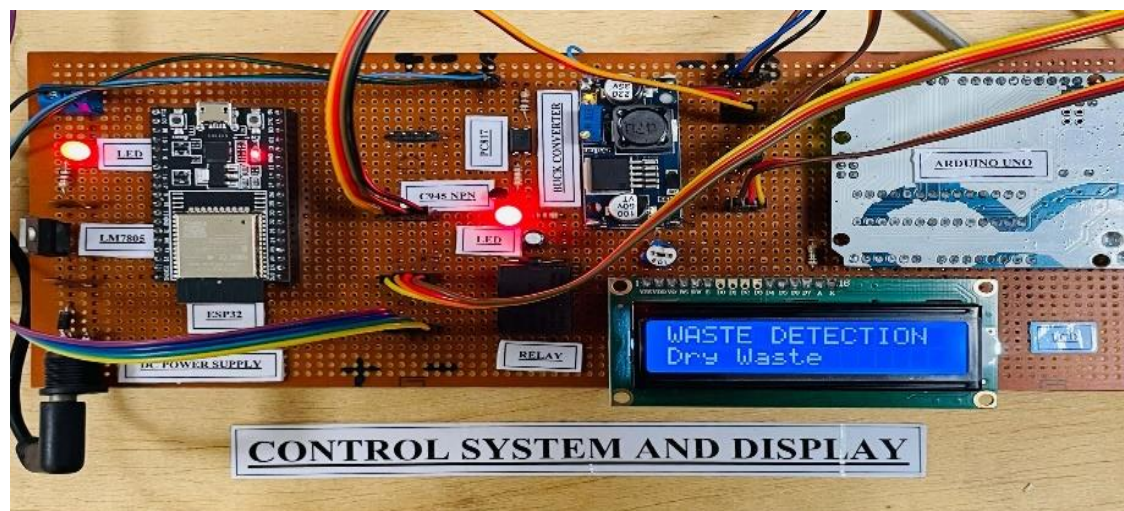


Figure 4. 36: Result of Plastic Waste Detection Display on LCD

4.6 Analysis of Sensors Accuracy

Our system depends extensively on a variety of sensors to operate efficiently. These sensors are crucial for identifying different types of waste, monitoring bin capacities, and optimizing waste management processes. However, it's important to note that no sensor is perfect, and assessing their accuracy is essential for maintaining the system's effectiveness. This section explores the accuracy of the sensors employed in our system, providing data and visualizations to evaluate their performance.

4.6.1 Analysis of Inductive Proximity Sensor Accuracy

The Table 4.2 presents data regarding the performance of the inductive proximity sensor with various types of metallic waste, including output voltage readings and sensor identification accuracy. Moreover, the graphical representation of output voltage and accuracy percentage of the sensor's identification is shown in Figure 4.37 and Figure 4.38 respectively.

Table 4. 21: Analysis of Inductive Proximity Sensor's Accuracy

Sample Number	Metallic Waste Type	Sensor's Output Voltage	Correct Identification
1	Tin Can	0.2 V	Yes
2	Aluminium Foil	4.5 V	No
3	Steel Bottle Cap	0.3 V	Yes
4	Copper Wire	0.2 V	Yes
5	Iron Nail	0.3 V	Yes
6	Metal Spoon	0.4 V	Yes
7	Brass Key	4.2 V	No
8	Aluminium Can	4.4 V	No
9	Metal Paper Clip	0.2 V	Yes
10	Steel Bolt	0.4 V	Yes

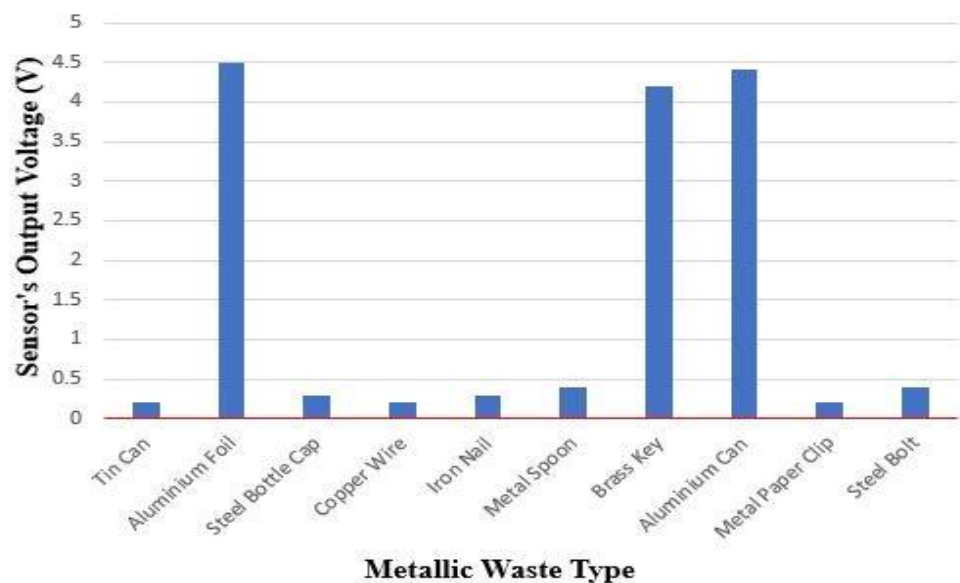


Figure 4. 37: Graphical Representation of Inductive Proximity Sensor's Output Voltage

INDUCTIVE PROXIMITY SENSOR'S ACCURACY

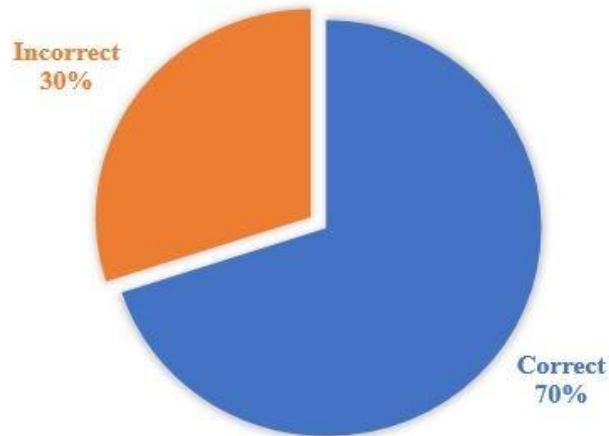


Figure 4. 38: Graphical Representation of Inductive Proximity Sensor's Accuracy

4.6.2 Analysis of Wetness Sensor Accuracy

The Table 4.3 presents data regarding the performance of the wetness sensor with various types of wet waste, including output voltage readings and sensor identification accuracy. Moreover, the graphical representation of output voltage and accuracy percentage of the sensor's identification is shown in Figure 4.39 and Figure 4.40 respectively.

Table 4. 22: Analysis of Wetness Sensor's Accuracy

Sample Number	Wet Waste Type	Sensor's Output Voltage	Correct Identification
1	Food Scraps	2.8 V	Yes
2	Fruit Peels	3.0 V	Yes
3	Vegetable Peels	3.3 V	Yes
4	Used Tea Bags	2.6 V	Yes
5	Coffee Grounds	0.2 V	No
6	Leftover Pasta	2.5 V	Yes
7	Spoiled Meat	0.4 V	No
8	Wet Paper Towels	3.2 V	Yes
9	Cooked Rice	0.3 V	No

10	Dairy Waste	2.9 V	Yes
----	-------------	-------	-----

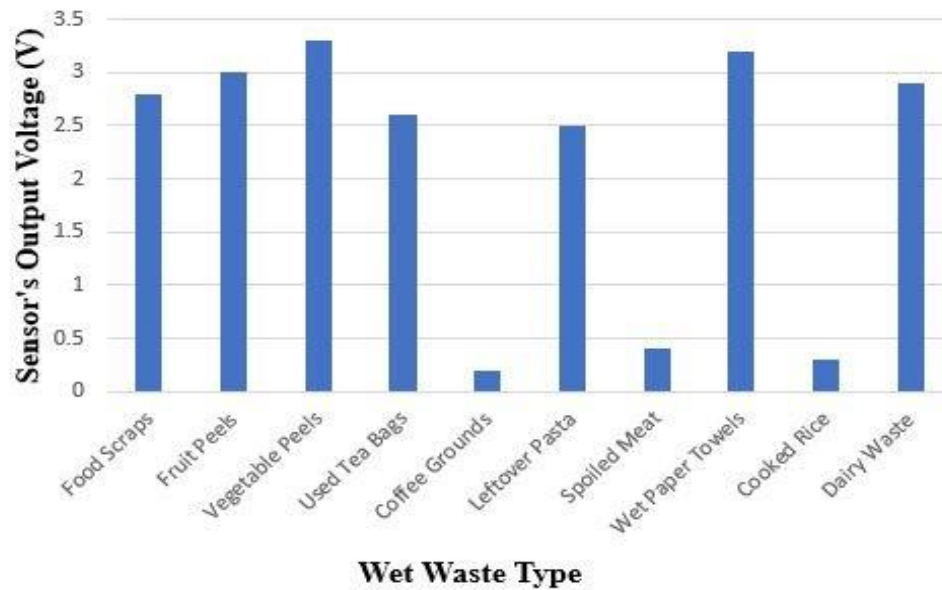


Figure 4. 39: Graphical Representation of Wetness Sensor's Output Voltage

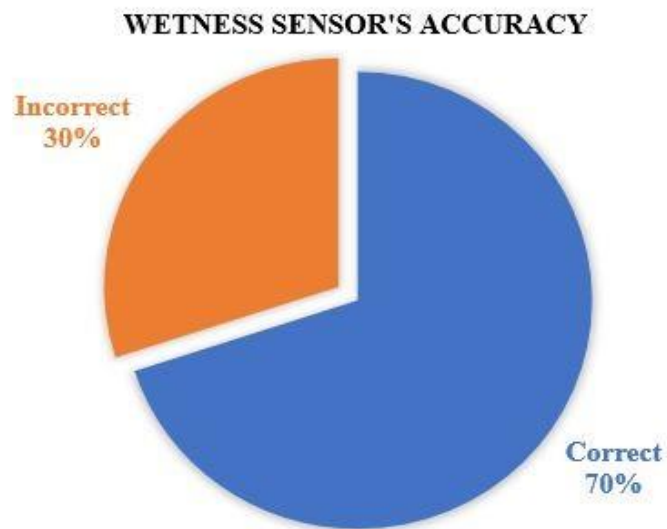


Figure 4. 40: Graphical Representation of Wetness Sensor's Accuracy

4.6.3 Analysis of Infrared Sensor Accuracy

The Table 4.4 presents data regarding the performance of the infrared sensor with various types of plastic waste, including output voltage readings and sensor identification accuracy. Moreover, the graphical representation of output voltage and

accuracy percentage of the sensor's identification is shown in Figure 4.41 and Figure 4.42 respectively.

Table 4. 23: Analysis of Infrared Sensor's Accuracy

Sample Number	Plastic Waste Type	Sensor's Output Voltage	Correct Identification
1	Plastic Bottle	3.3 V	Yes
2	Plastic Bag	2.6 V	Yes
3	PET Plastic	3.2 V	Yes
4	Plastic Films	0.4 V	No
5	Plastic Container	3.3 V	Yes
6	Paper Cup	0.0 V	No
7	Styrofoam	0.2 V	No
8	Plastic Utensil	2.9 V	Yes
9	Plastic Straw	2.7 V	Yes
10	Plastic Wrapper	3.0 V	Yes

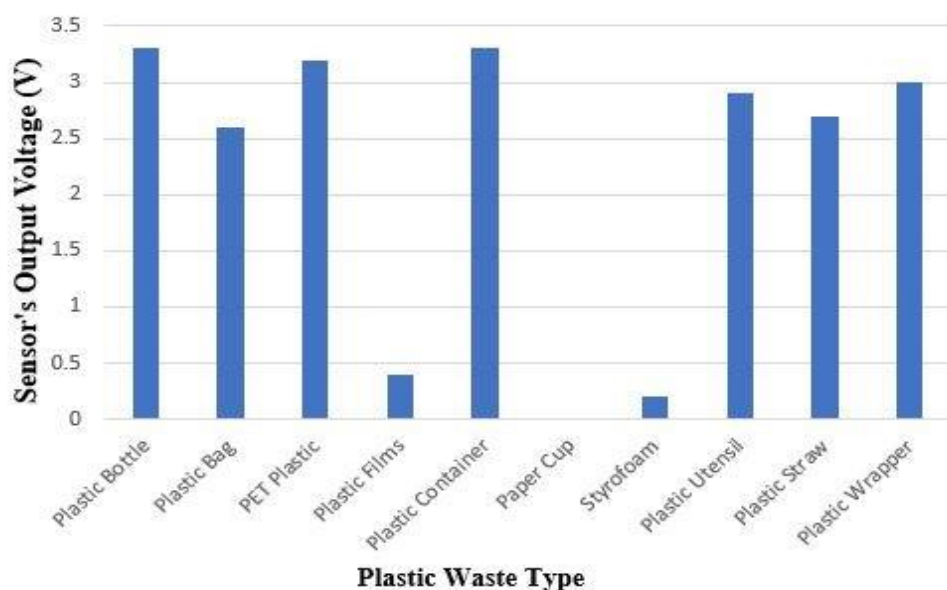


Figure 4. 41: Graphical Representation of Infrared Sensor's Output Voltage

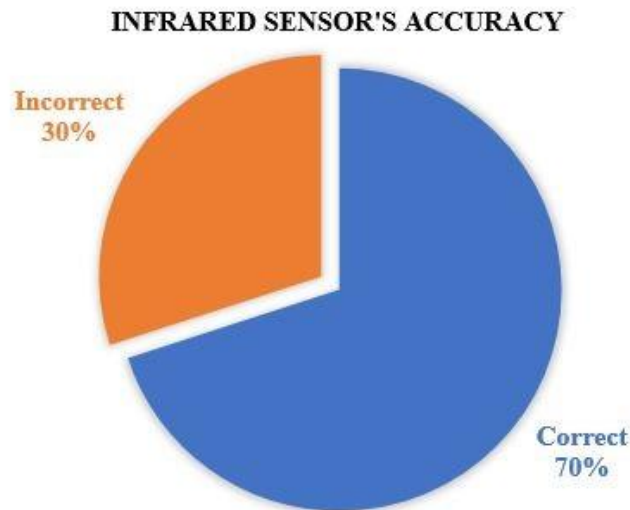


Figure 4. 42: Graphical Representation of Infrared Sensor’s Accuracy

4.7 Graphical User Interface of System

The Smart Garbage Segregation and Management System integrates advanced hardware with a user-friendly Graphical User Interface (GUI), enhancing interaction with the waste management process. Sensor data is instantly accessible via the Blynk website dashboard (as shown in Figure 4.43) or mobile application (as shown in Figure 4.44), providing flexibility in monitoring preferences. A Wi-Fi controller, such as the ESP32, receives and transmits sensor data to the operator's dashboard, enhancing operational oversight. The dashboard visually represents sensor data, including segregated waste levels and system status (ON/OFF), as displayed in Figures 4.43 and 4.44. Control functions are conveniently accessible through the dashboard, facilitating efficient system management. The Blynk platform ensures seamless communication and control, supporting synchronized operation and scalability for future enhancements and practical applications in waste segregation.

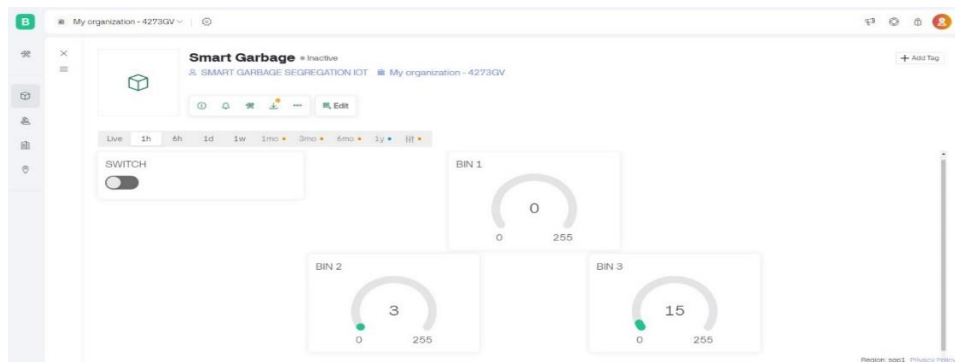


Figure 4. 43: Display of Blynk Website Dashboard

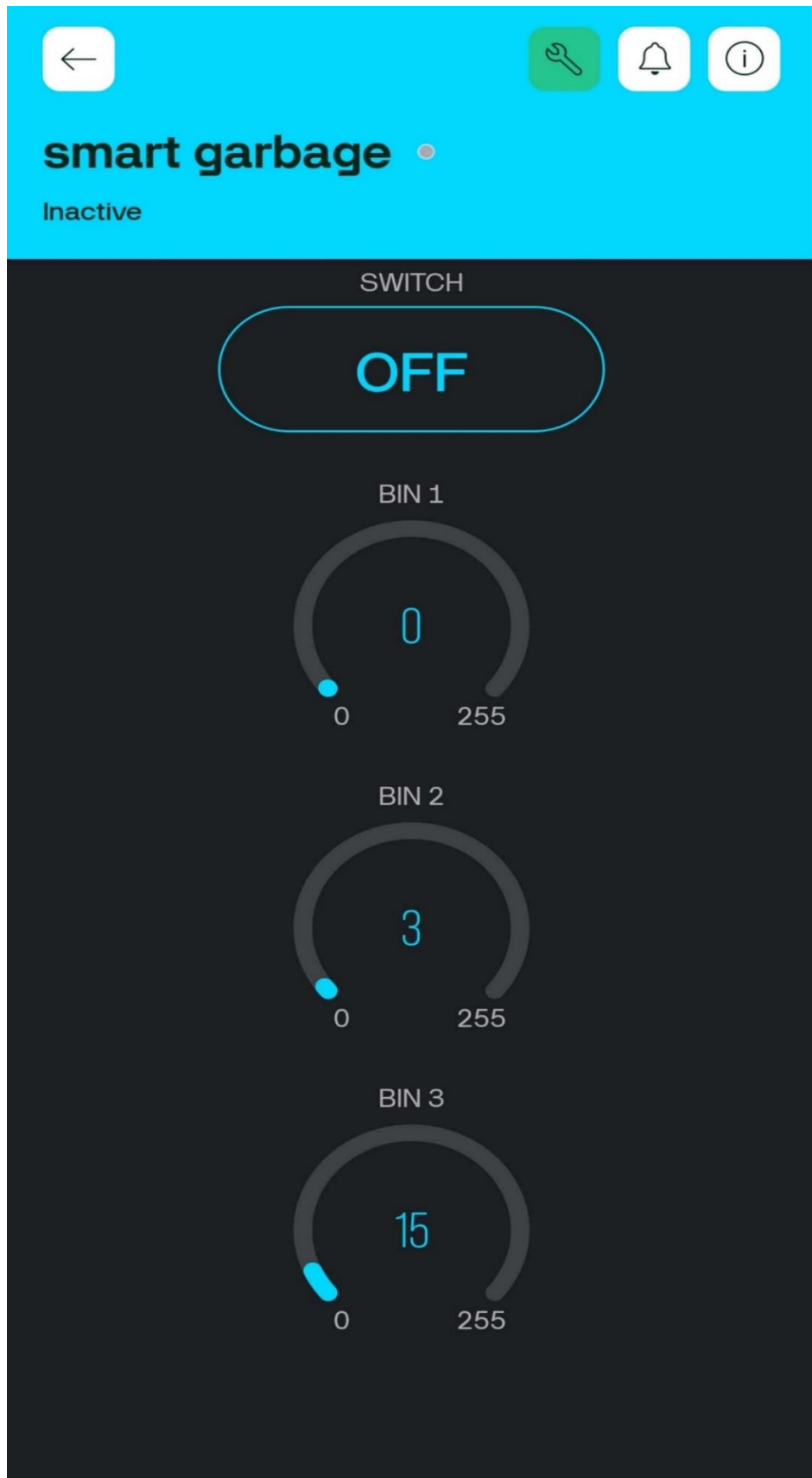


Figure 4. 44: Display of Blynk Mobile Application Dashboard

4.8 Summary

The chapter on “Hardware Implementation” in the project "Smart Garbage Segregation and Management System Using the Internet of Things (IoT)" provides a detailed discussion of the hardware implementation, which is crucial for the project to work effectively. It begins by introducing the project’s aim to automate waste sorting and management using IoT technology, highlighting its importance in tackling modern waste management challenges. The chapter thoroughly details the selection, integration, and functionality of various hardware components essential for the system, such as microcontrollers, sensors, actuators, and power regulators. Each component’s role, specifications, and contributions to the system’s operation are explained, providing a comprehensive understanding of the hardware infrastructure's design and implementation. This detailed exploration ensures the system's accuracy, efficiency, and reliability in effectively segregating waste, demonstrating its potential to revolutionize waste management practices through IoT-driven automation.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

In this thesis, we are presenting the “Smart Garbage Segregation and Management System Using the Internet of Things (IoT)”, which offers a transformative approach to addressing the growing challenges of waste management in urban environments. This project has successfully integrated advanced technologies such as sensors, actuators, and IoT to create a sophisticated system capable of real-time monitoring and intelligent segregation of waste. By leveraging these technologies, the system ensures precise categorization of waste into specific types such as metallic, wet, and plastic wastes, thereby optimizing resource recovery and enhancing recycling rates.

The significance of this project lies in its innovative approach to tackling one of the most pressing issues faced by modern urban centers: effective waste management. Traditional waste management methods have often fallen short in addressing the complexities of waste segregation and recycling, leading to inefficient processes and adverse environmental impacts. The Smart Garbage Segregation and Management System, with its advanced IoT integration, addresses these shortcomings by providing a more streamlined and efficient solution.

The implementation of this system has demonstrated significant improvements in waste management efficiency. The use of IoT allows for continuous monitoring and data transmission to a cloud-based database, ensuring that waste segregation is both accurate and timely. Real-time data collection and processing enable immediate responses to waste accumulation, preventing the overflow of waste bins and reducing the chances of environmental pollution. This real-time aspect is crucial for maintaining urban cleanliness and public health, as it allows waste management authorities to act promptly based on the data received.

The Proteus simulation and Arduino programming have provided a robust platform for testing and validating the system's performance under various scenarios. These tools have been instrumental in simulating real-world conditions, enabling us to refine the system and address potential issues before actual deployment. The simulation results have highlighted the system's potential to minimize physical labor, reduce

environmental pollutants, and mitigate health risks associated with improper waste handling. By automating the segregation process, the system reduces the need for manual sorting, which is often labor-intensive and hazardous.

Furthermore, the hardware implementation has shown the system's capability to function reliably and effectively in real-world settings. The integration of advanced sensors and microcontrollers has enabled the system to detect and sort waste with high accuracy. These sensors can identify different types of waste materials based on their physical and chemical properties, ensuring that each type of waste is directed to the appropriate recycling stream. This precise sorting not only enhances recycling rates but also reduces contamination in recycled materials, improving the overall quality of recycled products.

The practical application of this system has the potential to significantly contribute to the overall goal of creating cleaner, greener, and more sustainable urban environments. By improving the efficiency of waste segregation and management, the system helps in conserving natural resources, reducing landfill use, and lowering greenhouse gas emissions. Additionally, it aligns with global efforts to promote environmental sustainability and supports the United Nations Sustainable Development Goals (UNSDGs), particularly those related to responsible consumption and production, sustainable cities and communities, and climate action.

In conclusion, this thesis represents a significant step forward in the field of waste management. It not only addresses the immediate challenges posed by rapid population growth and urbanization but also aligns with the global need for sustainable and eco-friendly practices. The successful deployment of this smart garbage segregation system demonstrates the feasibility and benefits of integrating IoT into waste management. It paves the way for future advancements in this critical area by showcasing how technology can be harnessed to solve real-world problems. The insights gained from this project provide a foundation for further research and development, encouraging the adoption of smart waste management solutions on a broader scale.

5.2 Future Work

The future work for the "Smart Garbage Segregation and Management System Using the Internet of Things (IoT)" focuses on several key areas to enhance its functionality, scalability, and impact. As we move forward, it is crucial to explore enhancements such

as integrating more advanced sensors, incorporating machine learning algorithms, and expanding the IoT network. These future enhancements are further explained below. By concentrating on these advancements, the Smart Garbage Segregation and Management System will stay at the forefront of innovation, contributing to more sustainable and efficient urban environments worldwide. This will help create a future where waste management is no longer a challenge but a well-orchestrated process that supports a healthy and sustainable planet.

5.2.1 Integration of Advanced Sensors

Integrating more advanced sensors will improve the system's ability to accurately detect and categorize various waste types, including complex materials like electronic waste and hazardous substances. This refinement will enhance the segregation process and improve recycling rates.

5.2.2 Incorporation of Machine Learning Algorithms

Incorporating machine learning algorithms will enable predictive analysis, allowing the system to forecast waste generation patterns and optimize waste collection schedules. This predictive capability will enhance operational efficiency, reduce costs, and ensure timely waste disposal.

5.2.3 Expansion of the IoT Network

Expanding the IoT network to cover larger areas will increase the system's reach and effectiveness, making it possible to implement this smart waste management solution in more urban environments. This expansion can be complemented by the development of edge computing capabilities to process data locally at the source, reducing latency and bandwidth usage, and improving real-time monitoring and decision-making.

CHAPTER 6

BUSSINESS DESCRIPTION

6.1 Form of Business

The form of our business will be Sole Ownership. A sole proprietorship is a type of business structure where a single individual owns and operates the entire business. This form is chosen for its simplicity, ease of establishment, and full control over business decisions.

6.1.1 Team/Organizational Structure

All business starts on a small scale and grows over time. Similarly, we will begin our business on a small scale by developing a few prototypes of our system and aim to implement them within a specific time period. As our business grows, we expect to achieve a reasonable profit. The following are the positions that will be assigned to the members of the company:

- **Ahmed Ali** will be the owner and Director of the company.
- **Muhammad Umer** will manage the company and oversee marketing.
- **Rana Waleed** will handle the technical development and implementation of the system.
- **Farman Ali Chand** will focus on research and development, ensuring the system stays innovative and effective.

6.1.2 Vision

Our vision is to revolutionize waste management in Pakistan through the implementation of a Smart Garbage Segregation and Management System using IoT. This system will use real-time data from sensors to efficiently segregate waste, reducing the burden on landfills and promoting recycling. The data collected will be transmitted to a central controller via a wireless module, enabling precise management of waste segregation, collection schedules, and resource allocation.

6.1.3 Mission

- To contribute to socio-economic development by improving waste management practices.
- To promote environmental sustainability through efficient waste segregation and reduced landfill usage.
- To reduce air pollution by decreasing the need for incineration and landfilling of waste.

6.1.4 Goal and Objective

The primary objective of our Smart Garbage Segregation and Management System is to optimize waste management by leveraging IoT technology. This system aims to enhance sustainability and efficiency in waste handling compared to traditional methods. The key goals include:

- **Improved Waste Segregation:** The system will use sensors to automatically segregate waste, reducing manual effort and increasing accuracy.
- **Environmental Protection:** Efficient segregation and management of waste will help reduce landfill usage and associated pollution, contributing to a cleaner environment.
- **Reduced Operational Burden:** Automating the segregation and management process will decrease the reliance on manual labor, allowing for more streamlined and scalable waste management operations.

6.2 Industry and Marketing Analysis

6.2.1 Industry Analysis

After conducting extensive research and industry visits, we have gained valuable insights into the demand for our Smart Garbage Segregation and Management System. This product is relatively new in Pakistan, so we relied on various sources to gather information about similar systems in other countries. Our findings revealed that while several industries are working on similar products, many have faced challenges and have not achieved significant success. This provided us with crucial information on how to improve our product, identify necessary changes, and determine which features to enhance. Here are some key aspects we investigated based on industry reports:

- **Selection of Sensors:** The system heavily relies on sensors, making their selection critical to the system's performance and accuracy.
- **Other Issues:** Monitoring, handling, and dealing with emergency situations are additional critical challenges that need to be addressed to ensure the system's reliability and effectiveness.

6.2.2 Competitive Analysis

As mentioned, there are many companies globally working on similar products, with significant contributions from industries. However, by utilizing the SCAMPER (Substitute, Combine, Adapt, Modify, Put to another use, Eliminate, and Reverse) technique, we believe our product stands out. This method allows us to innovate and improve upon existing solutions, placing us at the forefront of this market. Since this type of system is not widely implemented in Pakistan, we see a significant opportunity to meet market demands. By continuing to grow and innovate, our company aims to provide convenient and cost-effective waste management solutions to both Pakistani and global markets.

6.2.3 Purpose

Our purpose is to develop a system that addresses the following problems:

- **Efficient Waste Management:** Implementing an advanced system for segregating and managing waste to reduce environmental impact.
- **Resource Optimization:** Ensuring optimal use of resources by improving waste collection and segregation processes.
- **Environmental Sustainability:** Promoting recycling and reducing the need for landfilling and incineration, thereby protecting the environment.

6.3 SWOT Analysis

6.3.1 Strengths

- It significantly improves waste management practices, contributing to the socio-economic development of a country.
- It reduces environmental pollution by promoting efficient waste segregation and recycling.

- It minimizes the need for manual labor in waste segregation, enhancing overall efficiency.

6.3.2 Weaknesses

- Communication errors may occur over time, affecting system performance.
- The system requires a constant and reliable Wi-Fi connection to function effectively.

6.3.3 Opportunities

- The introduction of innovative technology will attract attention and interest from both the public and private sectors.
- There is a growing demand for modern, efficient waste management solutions in urban areas.
- The potential for expanding the system to other regions and markets, both domestically and internationally.

6.3.4 Threats

- Concerns about the accuracy and reliability of automated waste segregation systems.
- Resistance from stakeholders with a conventional mindset towards waste management practices.
- Potential regulatory hurdles and the need for compliance with local waste management policies.

6.3.5 Marketing Objectives Follow

- Utilize social media platforms for effective, powerful, and economical advertising of our product.
- Leverage electronic media, including news channels, as an attractive and convincing source for promoting our system.
- Target municipal corporations and private waste management companies for project promotion.
- Engage with government bodies to highlight the system's benefits and how it can address their waste management needs.

6.4 Marketing Communication

In the following aspects of public communications, we consider the inherent strengths and shortcomings and how they are incorporated and applied to our situation. Utilizing social and electronic media, which are currently the most powerful and effective sources for promotion and advertisement, will be key to our strategy. Our marketing communication strategy aims to effectively reach and engage our target audience, highlighting the benefits and innovative features of our Smart Garbage Segregation and Management System.

6.4.1 Advertising

Advertising serves as an informal and sponsored means of educating consumers through radio, news media, online portals, etc., about our goods and services. It is one of the most commonly used marketing tactics, effectively conveying information about our business's goods and services to a broad target audience.

6.4.2 Personal Selling

Marketing involves selling our project through videos and portals. We will demonstrate to our customers how our Smart Garbage Segregation and Management System can meet their needs and help make waste management more convenient, efficient, and economical.

6.4.3 Direct Marketing

The efficacy of direct marketing can be directly measured. By leveraging this technology, businesses can use emails, faxes, and cell phones to connect with potential clients directly, without involving intermediaries.

6.5 Financial Plan

6.5.1 Resources Required

The following resources are required to start the Smart Garbage Segregation and Management System business:

- All basic resources needed for starting a business (i.e., machinery, electronic equipment, a proper place, etc.).
- Accessories.

- Human resources.
- Electricity (etc.).

Table 6. 1: Initial Budget Expenses

Sr. No.	Capital Nature	Expenses Amount (PKR)
1.	Laptop (46,000 x 1)	46,000/-
2.	Equipment (60,000 x 1)	60,000/-
	Revenue Nature Expenses	
1.	Internet (4000 x 12)	48,000/-
2.	Misc. Expenses (3,000 x 12)	36,000/-
3.	Electricity (20,000 x 12)	240,000/-
4.	Purchase of Raw Material (15,000 x 10)	150,000/-
Total Initial Expenses (Budgeted)		= 580,000/-

6.6 Notes

6.6.1 Note-1

All expenses and revenue are estimated.

6.6.2 Note-2

Raw materials include sensors such as Arduino, Relay, Wi-Fi controllers, and other electrical equipment required for the system.

6.6.3 Note-3

Variable overhead costs, such as electricity, vary with production and depend on the number of units produced in the year.

6.6.4 Note-4

All calculations are based on assumptions, so there is a chance of discrepancies in these calculations.

6.7 Summary

This “Business Description” chapter provides a comprehensive overview of the business strategy and financial plan for the Smart Garbage Segregation and Management System project. It outlines the form of business as a Sole Ownership, detailing key roles within the organization, vision, mission, and objectives, emphasizing its goal to revolutionize waste management in Pakistan through IoT technology. Through industry, marketing, and SWOT analysis, the chapter provides valuable insights into market dynamics, competition, and potential challenges. Marketing objectives prioritize effective promotion via social and electronic media, targeting relevant stakeholders. Additionally, the financial plan highlights initial resource requirements and budget breakdown. Ultimately, the chapter aims to provide a clear understanding of the project's strategy, financial implications, and social impact for readers.

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APPENDIX

A. Program of ESP32

```
#define BLYNK_TEMPLATE_ID "TMPL6lzAViFaB"
#define BLYNK_TEMPLATE_NAME "smart garbage"
#define BLYNK_AUTH_TOKEN "XiCOltW7imukcWtT5nno-iLgp1No8HoW"
char auth[] = BLYNK_AUTH_TOKEN;
char ssid[] = "Galaxy A51 B875";
char pass[] = "12345678";
#define BLYNK_PRINT Serial
#include <WiFi.h>
#include <WiFiClient.h>
#include <BlynkSimpleEsp32.h>
BlynkTimer timer;
#define INTERVAL 1000L
#define relay_pin 33
const int trigPin1 = 0;
const int echoPin1 = 15;
const int trigPin2 = 4;
const int echoPin2 = 5;
const int trigPin3 = 19;
const int echoPin3 = 18;
long duration1 , duration2, duration3;
int distanceCm1, distanceCm2, distanceCm3;
int distanceInch1, distanceInch2, distanceInch3;
int rev_distanceCm1, rev_distanceCm2, rev_distanceCm3;
BLYNK_WRITE(V4)
{
int relay = param.asInt();
Serial.println (relay);
if(relay == 1)
{
digitalWrite(relay_pin,HIGH);
}
}
```

```

else
digitalWrite(relay_pin,LOW);
}
void setup()
{
pinMode(relay_pin, OUTPUT);
pinMode(trigPin1, OUTPUT);
pinMode(echoPin1, INPUT);
pinMode(trigPin2, OUTPUT);
pinMode(echoPin2, INPUT);
pinMode(trigPin3, OUTPUT);
pinMode(echoPin3, INPUT);
Serial.begin(115200);
Blynk.begin(auth, ssid, pass);
}
void loop()
{
//***** Sensor 1*****
digitalWrite(trigPin1, LOW);
delayMicroseconds(2);
digitalWrite(trigPin1, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin1, LOW);
duration1 = pulseIn(echoPin1, HIGH);
distanceCm1= duration1*0.034/2;
distanceInch1 = duration1*0.0133/2;
//***** Sensor 2*****
digitalWrite(trigPin2, LOW);
delayMicroseconds(2);
digitalWrite(trigPin2, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin2, LOW);
duration2 = pulseIn(echoPin2, HIGH);
distanceCm2= duration2*0.034/2;

```

```

distanceInch2 = duration2*0.0133/2;
//***** Sensor 3*****
digitalWrite(trigPin3, LOW);
delayMicroseconds(2);
digitalWrite(trigPin3, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin3, LOW);
duration3 = pulseIn(echoPin3, HIGH);
distanceCm3= duration3*0.034/2;
distanceInch3 = duration3*0.0133/2;
Serial.print("Distance Cm1: ");
Serial.print(distanceCm1);
Serial.print(" Distance Inch1: ");
Serial.print(distanceInch1);
Serial.print(" Distance Cm2: ");
Serial.print(distanceCm2);
Serial.print(" Distance Inch2: ");
Serial.print(distanceInch2);
Serial.print(" Distance Cm3: ");
Serial.print(distanceCm3);
Serial.print(" Distance Inch3: ");
Serial.print(distanceInch3);
Blynk.virtualWrite(V0, String(distanceCm1));
Blynk.virtualWrite(V1, String(distanceCm2));
Blynk.virtualWrite(V2, String(distanceCm3));
{
Blynk.run();
timer.run();
}
}

```

B. Program of Arduino UNO

```
#include <Servo.h>
#include <LiquidCrystal.h>
Servo myservo1;
Servo myservo2;
Servo myservo3;
const int rs = 2, en = 3, d4 = 4, d5 = 5, d6 = 6, d7 = 7;
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);
int metal_waste = A5;
int wet_waste = A3;
int dry_waste = A4;
int metal_state = 0;
int wet_state = 0;
int dry_state = 0;
int pos = 0;
void setup()
{
  Serial.begin(9600);
  pinMode(metal_waste, INPUT_PULLUP);
  pinMode(wet_waste, INPUT_PULLUP);
  pinMode(dry_waste, INPUT_PULLUP);
  lcd.begin(16, 2);
  myservo1.attach(9);
  myservo2.attach(10);
  myservo3.attach(11);
  lcd.setCursor(0, 0);
  lcd.print("WASTE DETECTION ");
  lcd.setCursor(0, 1);
  lcd.print(" ");
  myservo1.write(45);
  myservo2.write(45);
  myservo3.write(45);
}
```

```

void loop()
{
metal_state = digitalRead(metal_waste);
wet_state = analogRead(wet_waste);
dry_state = digitalRead(dry_waste);
if(metal_state == 0)
{
lcd.setCursor(0, 1);
lcd.print("Metal Waste   ");
Serial.println(metal_state);
myservo1.write(135);
delay(1000);
myservo1.write(45);
lcd.setCursor(0, 1);
lcd.print("           ");
}
if(wet_state > 150)
{
lcd.setCursor(0, 1);
lcd.print("Wet Waste   ");
Serial.println(wet_state);
myservo2.write(135);
delay(1000);
myservo2.write(45);
lcd.setCursor(0, 1);
lcd.print("           ");
}
if(dry_state == 0)
{
dry_state = 1;
delay(1000);
dry_state = digitalRead(dry_waste);
if(dry_state == 0)
{

```

```
lcd.setCursor(0, 1);  
lcd.print("Dry Waste ");  
Serial.println(dry_state);  
myservo3.write(135);  
delay(1000);  
myservo3.write(45);  
lcd.setCursor(0, 1);  
lcd.print(" ");  
}  
}  
}
```