SMART GARBAGE SEGREGATION AND MANAGEMENT SYSTEM USING THE INTERNET OF THINGS

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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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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, cameras, 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, paper, 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.

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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Date: February 18, 2024

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

We thank ALLAH ALMIGHTY who helped us to obtain our target. We are grateful to our parents, who always motivated us and provided us with the ultimate help, love, and care. We would also want to thank our supervisor Dr. Saif Ur Rehman for their support and encouragement of my motivation to work very hard and intelligently. When addressing the classification problem in this research project, We found him very supportive. Undoubtedly, his constructive remarks on my project required me to think of innovative methods and concepts in the area of IoT and beyond. We also want to express our appreciation to all the instructors who were very helpful and offered valuable assistance, support, and guidance.

Thank you,

Muhammad Umer

Rana Waleed

Ahmed Ali

Farman Ali Chand

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.

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LIST OF ACRONYMS

CAM	Camera
CNN	Convolutional Neural Network
CV	Computer Vision
DC	Direct Current
E-Waste	Electronic Waste
ESP8266	Extended Simple Platform 8266
GPS	Global Positioning System
GSM	Global System for Mobile Communication
HC	High Conductance
IC	Integrated Circuit
ID	Identification
IFTTT	If This Then That
IoT	Internet of Things
IR	Infrared Rays
KNN	K-Nearest Neighbour
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LEACH	Low-Energy Adaptive Clustering Hierarchy
MATLAB	Matrix Laboratory
ML	Machine Learning
NodeMCU	Node Micro-Controller Unit
PCB	Printed Circuit Board
PIR	Passive Infrared Ray
PV	Photovoltaic
RFID	Radio Frequency Identification
SDG	Sustainable Development Goal
SMS	Short Message Service
UNSDGs	United Nation Sustainable Development Goals
Wi-Fi	Wireless Fidelity
YOLO	You Only Look Once

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 hopper and from the conveyor, various types of garbage will be segregated using sensors and cameras by implementing an object classification technique and the servo-operated barriers will place the garbage in the required bin accordingly.

1.3 Project Overview/Goal

This innovative project revolves around the integration of internet-connected devices, sensors, and cameras to automatically sort and monitor various waste categories, including metallic, wet, paper, 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.

1.4 Proposed Methodology

This system proposed uses internet-connected devices, sensors, and camera to automatically sort and monitor different types of waste, such as metallic, wet, paper, 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 camera 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, paper, and plastic materials. Moreover, the results of segregation are displayed on the LCD. The proposed block diagram of the system is shown in Figure 1.2 and the proposed flowchart of the system is shown in Figure 1.3.

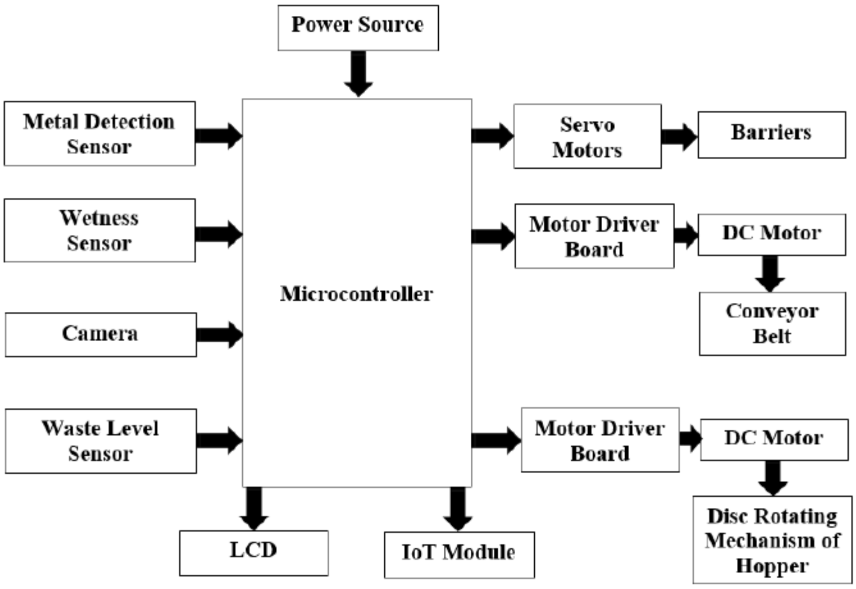

Figure 1. 2: Proposed Block Diagram of the System

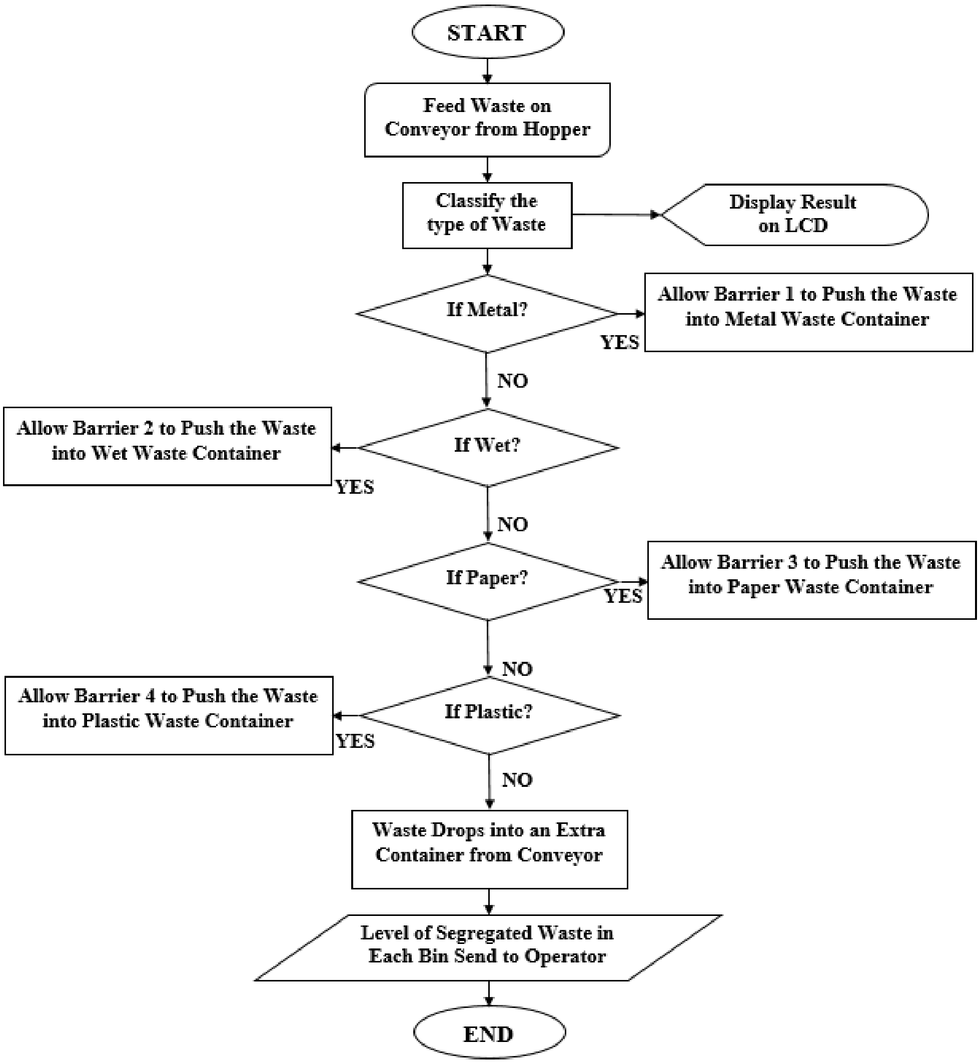

Figure 1. 3: Proposed Flowchart of the System

1.5 United Nations Sustainable Development Goals

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

1.5.1 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

1.5.2 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

1.5.3 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

1.6 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 Data Analysis
2.	Muhammad Umer	Mechanical Structure Design and Documentation
3.	Ahmed Ali	Software Logic Development
4.	Farman Ali Chand	Prototype Assembling

1.7 Thesis Outline

In this thesis, Chapter 1 serves as the foundation, providing a comprehensive introduction to our proposed 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 proposed 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 proposed "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 and Arduino 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 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 proposed 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 proposed 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, paper, 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 Paper Waste

The term "paper waste" refers to a wide range of discarded paper products, such as newspapers, magazines, cardboard, etc as shown in Figure 2.3. While the paper is biodegradable, its production contributes to deforestation and requires significant energy and water resources. Reducing paper consumption, recycling initiatives, and sustainable forestry practices reduce the environmental impact of paper waste.

Figure 2. 3: Discarded Paper Waste

2.2.4 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. 4: 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 Sensors and Actuators in Waste Management

Waste management has evolved significantly in recent years, driven by technological advancements that leverage sensors and actuators to enhance efficiency. The following sensors and actuators are discussed in detail:

2.5.1 Inductive Proximity Sensor

An inductive proximity sensor is also known as a metal sensor. It works by generating an electromagnetic field and detecting changes in the field caused by the proximity of metal objects. It is used to detect metallic objects without contacting them physically. In waste management, these are used to identify metal components in waste materials. In automated sorting systems, they serve as a key component in segregating metallic waste for recycling.

2.5.2 IR Sensor

An IR sensor is a device that detects infrared radiation which is not visible to the human eye. It is widely utilized for waste level monitoring in bins and containers. These sensors detect waste based on infrared radiation. As a result of using IR sensors, waste collection can be managed more efficiently by providing real-time information on bin fill levels, optimizing collection routes, and reducing unnecessary pickups.

2.5.3 Motion Sensor

The motion sensor detects movement within its viewing area. Motion sensors are essential to waste management systems, particularly in public spaces. These sensors can detect movement and activity around waste disposal areas, triggering alerts for collection when waste bins reach a certain capacity. To prevent overflow situations, motion sensors contribute to timely waste removal.

2.5.4 PIR Sensor

A PIR sensor is a type of motion sensor that detects changes in infrared radiation associated with heat signatures. In waste management, it is commonly used to detect heat signatures associated with living beings, identify people near waste bins, and optimize waste collection schedules.

2.5.5 Rain Sensor

The rain sensor detects rain or moisture in the air. During adverse weather, it reduces the need to open waste bins. These sensors can detect rain or moisture levels, triggering protective measures such as closing lids to prevent water ingress and maintain waste integrity.

2.5.6 Soil Moisture Sensor

A soil moisture sensor measures the soil's moisture content. In organic waste management or composting, soil moisture sensors are employed to monitor and regulate moisture content in compost heaps. These sensors ensure optimal conditions for organic matter decomposition, contributing to efficient composting processes.

2.5.7 Ultrasonic Sensor

An ultrasonic sensor uses ultrasonic waves to measure distances and detect obstacles. In waste management, it helps to monitor fill levels in containers and guides automated waste collection vehicles. This reduces operational costs and enhances overall system efficiency.

2.5.8 ESP32CAM and Image Sensor

ESP32CAM is a microcontroller module equipped with a camera and image sensor is a device that captures visual data. ESP32CAM and image sensors are instrumental in waste management systems for visual monitoring and analysis. By capturing images of waste bins or sorting processes, these sensors provide valuable information on waste composition, contaminants, and waste management.

2.5.9 Raspberry Pi Camera

The Raspberry Pi Camera is a camera module designed for use with Raspberry Pi microcomputers. Raspberry Pi cameras are versatile waste management tools that provide high-quality video and images. In combination with image processing algorithms, it helps analyze waste streams, detect anomalies, and facilitate intelligent sorting.

2.5.10 DC Motor and Servo Motor

DC motor and servo motor are types of electric motors. DC motors are commonly used to provide rotational motion and servo motors offer precise control over angular positions. These are essential actuators in waste management systems. Sorting facilities utilize DC motors to power conveyor belts and other mechanisms for waste movement. Servo motors are employed in robotic arms for accurate waste-sorting applications with precise control capabilities.

2.6 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.

2.7 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:

2.7.1 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.

2.7.2 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.

2.7.3 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.

2.7.4 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.

2.7.5 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.

2.7.6 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.

2.7.7 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.

2.7.8 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.

2.8 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 IR 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 PIR, NodeMCU, IR, and Soil Moisture Sensors, as well as DC and Servo Motors, and Capacitive Sensors, to enable precise waste categorization. The IR 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, Metal 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, IR sensor, image sensor, metal 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	Methodology
1.	2023	J. Sigongan et al. [5]	Solar-Powered Smart Garbage Segregation Bins with SMS Notification and ML Image Processing	The authors 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.
2.	2023	S. Prabhakaran et al. [6]	Smart Dustbin Using IoT	The authors propose a smart bin system equipped with ultrasonic and IR 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.
3.	2022	M. W. Rahman et al. [7]	Intelligent Waste Management System Using Deep Learning with IoT	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.
4.	2021	Akanksha et al. [8]	Smart Robot for Collection and Segregation of Garbage	The authors 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.
5.	2021	M. Ashwin et al. [9]	IoT Based Intelligent Route Selection of Wastage Segregation for Smart Cities Using Solar Energy	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.
6.	2021	S. Pandey et al. [10]	Smart Garbage Segregator Using IoT	The authors 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 PIR, NodeMCU,

				IR, and Soil Moisture Sensors, as well as DC and Servo Motors, and Capacitive Sensors, to enable precise waste categorization. The IR sensor monitors bin status and communicates via IFTTT for SMS notifications.
7.	2020	S. Sarker et al. [11]	Energy Saving Smart Waste Segregation and Notification System	The authors 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.
8.	2020	C. Bhangale et al. [12]	Smart Garbage Segregation & Handling System Using IoT	The author’s 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.
9.	2019	S. N et al. [13]	Smart Garbage Segregation & Management System Using IoT & ML	The authors 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, Metal Sensor, Moisture Sensor, Servo Motor, and LCD Display.
10.	2019	E. Johar et al. [14]	IoT Based Intelligent Garbage Monitoring System	The authors 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.
11.	2018	P. Anitha et al. [15]	Smart Garbage Maintenance System Using IoT	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.
12.	2018	S. Paul et al. [16]	Smart Garbage Monitoring Using IoT	The authors 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, IR sensor, image sensor, metal sensor, ultrasonic sensor, and ESP8266 Wi-Fi module.
13.	2018	S. Suryawanshi et al. [17]	Waste Management System Based On IoT	The authors 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.

2.9 Summary

This chapter summarizes the challenges of traditional waste management and recommends modern solutions. The literature review is based on thorough research to propose an advanced garbage management system. It explores various waste types and highlights the need for customized waste management strategies due to the unique challenges. The chapter discusses waste management complexities in the context of urban development and population growth. IoT integration into waste management is highlighted as a transformative solution for increased efficiency and sustainability. Technologies like sensors and actuators, along with integrated cloud computing, play key roles in improving waste management efficiency. This integration of smart technologies into waste management not only aims to enhance efficiency but also contributes to environmental sustainability.

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 proposed Smart Garbage Segregation and Management System. Throughout this simulation, an Arduino controller 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 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.

3.2.3 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.

3.2.4 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.

3.2.5 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
- Inductive Proximity Sensor
- IR Sensor
- Soil Moisture Sensor
- DC Gear Motor
- Servo Motor
- LCD

3.4 Simulation Setup

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

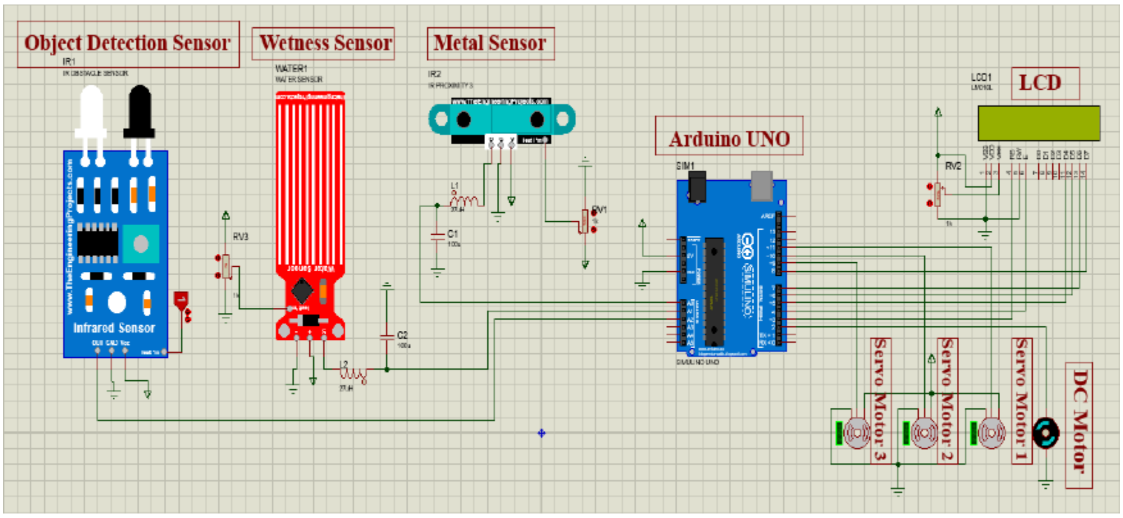

Figure 3. 1: Simulation Setup

3.5 Simulation Results

- As shown in Figure 3.2, simulation is enabled.

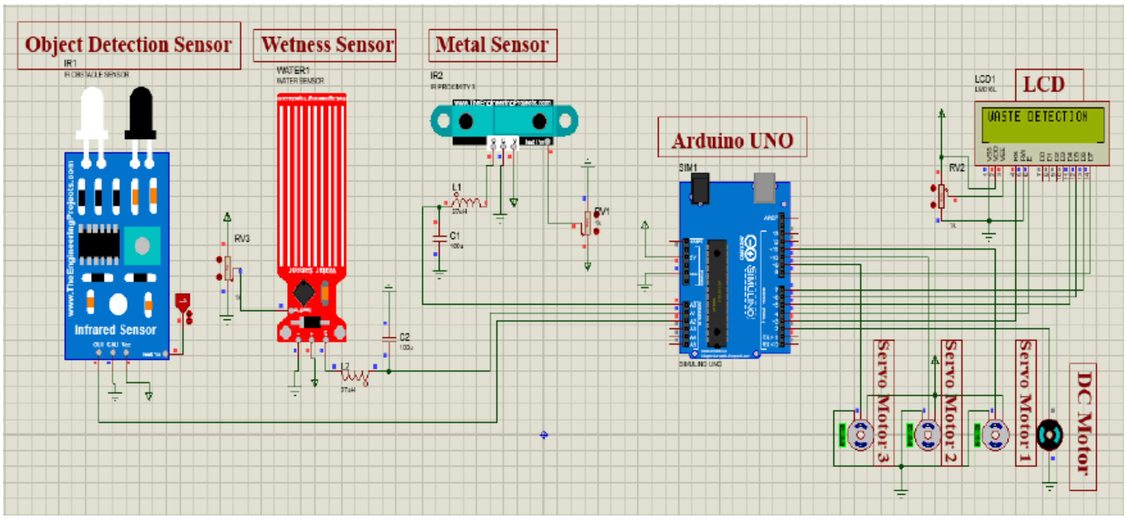

Figure 3. 2: Simulation is Enabled

- In Figure 3.3, the DC motor is temporarily stopped when metal waste is detected, and servo motor 1 is rotated at a specific angle, followed by the DC motor rotating again.

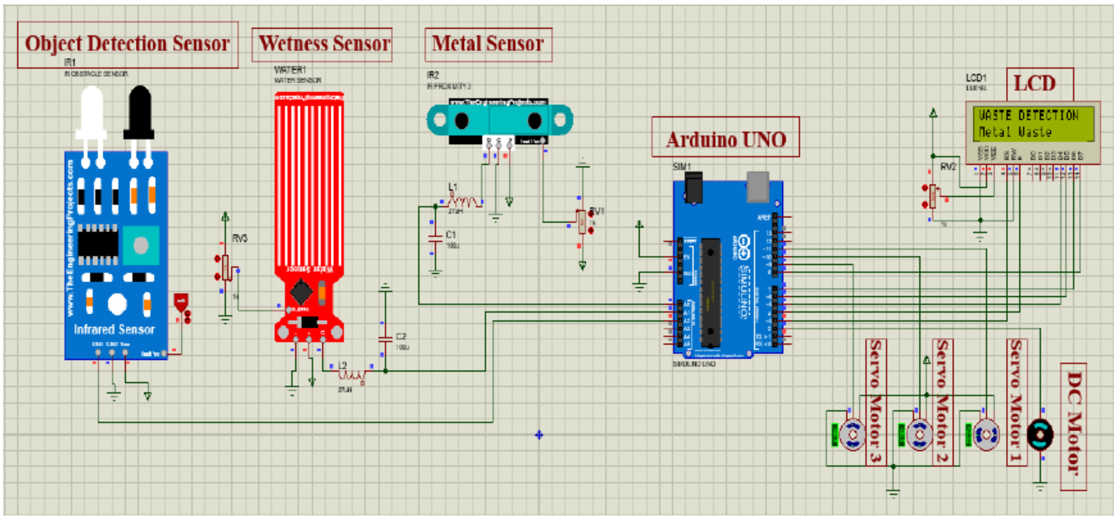

Figure 3. 3: Metal Waste Detected

- In Figure 3.4, the DC motor is temporarily stopped when wet waste is detected, and servo motor 2 is rotated at a specific angle, followed by the DC motor rotating again.

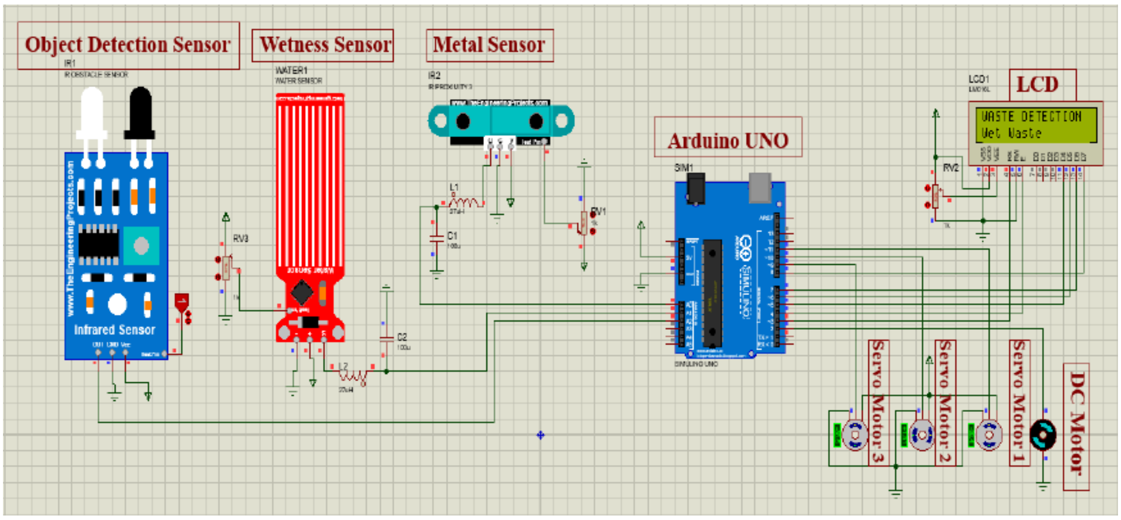

Figure 3. 4: Wet Waste Detected

- In Figure 3.5, the DC motor is temporarily stopped when dry waste (i.e., plastic or paper waste) is detected, and servo motor 3 is rotated at a specific angle, followed by the DC motor rotating again.

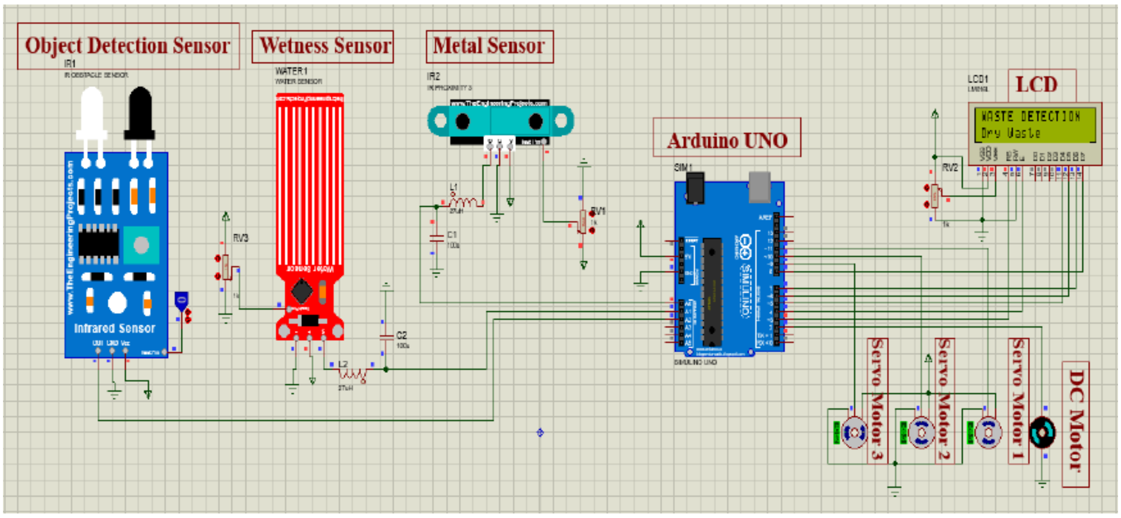

Figure 3. 5: Dry Waste Detected

3.6 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 proposed system is performed in Proteus, utilizing Arduino programming to control an array of sensors and actuators. 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.

REFERENCES

[1] A. K. Lingaraju *et al.*, “IoT-Based Waste Segregation with Location Tracking and Air Quality Monitoring for Smart Cities,” *Smart Cities*, vol. 6, no. 3, pp. 1507–1522, Jun. 2023, doi: 10.3390/smartcities6030071.

[2] M. Eriksen, A. Lusher, M. Nixon, and U. Wernery, “The plight of camels eating plastic waste,” *J Arid Environ*, vol. 185, p. 104374, Nov. 2021, doi: 10.1016/j.jaridenv.2020.104374.

[3] P. Kanade, P. Alva, J. P. Prasad, and S. Kanade, “Smart Garbage Monitoring System using Internet of Things(IoT),” in *Proceedings - 5th International Conference on Computing Methodologies and Communication, ICCMC 2021*, Institute of Electrical and Electronics Engineers Inc., Apr. 2021, pp. 330–335. doi: 10.1109/ICCMC51019.2021.9418359.

[4] S. Shetty and S. Salvi, “SAF-Sutra: A Prototype of Remote Smart Waste Segregation and Garbage Level Monitoring System,” in *2020 International Conference on Communication and Signal Processing (ICCSP)*, 2020, pp. 363–367. doi: 10.1109/ICCSP48568.2020.9182408.

[5] J. Sigongan *et al.*, “GULP: Solar-Powered Smart Garbage Segregation Bins with SMS Notification and Machine Learning Image Processing,” *International Journal of Computing Sciences Research*, vol. 7, pp. 2018–2036, Jan. 2023, doi: 10.25147/ijcsr.2017.001.1.142.

[6] S. Prabhakaran, Y. M, S. M, and D. Kumar S M, “Smart Dustbin using IOT,” *The Scientific Temper*, vol. 14, no. 02, pp. 412–417, Jun. 2023, doi: 10.58414/scientifictemper.2023.14.2.27.

[7] M. W. Rahman, R. Islam, A. Hasan, N. I. Bithi, M. M. Hasan, and M. M. Rahman, “Intelligent waste management system using deep learning with IoT,” *Journal of King Saud University - Computer and Information Sciences*, vol. 34, no. 5, pp. 2072–2087, May 2022, doi: 10.1016/j.jksuci.2020.08.016.

[8] Akanksha, M. Gupta, and M. M. Tripathi, “Smart robot for collection and segregation of garbage,” in *Proceedings of International Conference on Innovative Practices in Technology and Management, ICIPTM 2021*, Institute of Electrical and Electronics Engineers Inc., Feb. 2021, pp. 169–173. doi: 10.1109/ICIPTM52218.2021.9388369.

[9] M. Ashwin, A. S. Alqahtani, and A. Mubarakali, “Iot based intelligent route selection of wastage segregation for smart cities using solar energy,” *Sustainable Energy Technologies and Assessments*, vol. 46, Aug. 2021, doi: 10.1016/j.seta.2021.101281.

[10] S. Pandey, S. Makkena, and S. Sachdeva, “SMART GARBAGE SEGREGATOR USING IOT,” 2021. [Online]. Available: www.ijcrt.org

[11] S. Sarker, S. Rahman, M. Jahirul Islam, D. Sikder, and A. Alam, “Energy saving smart waste segregation and notification system,” Nov. 2020, pp. 275–278. doi: 10.1109/TENSYMP50017.2020.9230949.

[12] C. Bhangale, S. V. Ganesh, P. R. Vijaybhai, P. R. Shaileshbhai, R. Anjana, and U. G. Student, “Smart Garbage Segregation & Handling System Using IoT,” 2020. [Online]. Available: www.ijcrt.org

[13] S. N, M. F. Peer, R. R, and K. Prakash, “Smart Garbage Segregation & Management System Using Internet of Things(IoT) & Machine Learning(ML),” Nov. 2019, pp. 1–6. doi: 10.1109/ICIICT1.2019.8741443.

[14] E. Johar, R. Mishra, P. Redij, S. Patil, and J. Mali, “IoT Based Intelligent Garbage Monitoring System,” Nov. 2019.

[15] P. Anitha *et al.*, “Smart Garbage Maintenance System Using Internet of Things,” in *2018 3rd International Conference on Communication and Electronics Systems (ICCES)*, 2018, pp. 1084–1086. doi: 10.1109/CESYS.2018.8724041.

[16] S. Paul, S. Banerjee, and S. Biswas, “Smart Garbage Monitoring Using IoT,” in *2018 IEEE 9th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON)*, 2018, pp. 1181–1185. doi: 10.1109/IEMCON.2018.8614896.

[17] S. Suryawanshi, R. Bhuse, M. Gite, and D. Hande, “Waste Management System Based On IoT,” *International Research Journal of Engineering and Technology*, [Online]. Available: www.irjet.net