Final Report Project 2

by UGENDDHIRAN SIVAKUMAR

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POLITEKNIK SULTAN SALAHUDDIN ABDUL AZIZ SHAH

TECH ENHANCED WASTE CONTROL SYSTEM

UGENDDHIRAN SIVAKUMAR

(08DJK22F1047)

ELECTRICAL ENGINEERING DEPARTMENT

SESI 1 2024/2025

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This final report is submitted to the Electrical Engineering Department in fulfilment of the requirements for the award of the Diploma in Electrical Control Engineering

ELECTRICAL ENGINEERING DEPARTMENT

SESI 1 2024/2025

DECLARATION OF PROJECT REPORT AND COPYRIGHT

TECH ENHANCED WASTE CONTROL SYSTEM

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(As a project supervisor at (date): ……………	)	PUAN SURIANI BINTI DAUD

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ABSTRAK

Bayangkan sebuah bandar di mana tong sampah yang melimpah dan pengumpulan sisa yang tidak efisien sudah menjadi perkara lama. Sistem kawalan sisa yang diperkemas dengan teknologi ini merevolusikan bagaimana bandar-bandar menguruskan sisa mereka, menjadikan proses itu lebih efisien, berkos efektif, dan mesra alam. Dengan menggunakan sensor IoT yang dipasang di dalam tong sampah, sistem saya secara berterusan memantau tahap penuh setiap tong sampah secara waktu nyata. Apabila sebuah tong sampah mencapai kapasiti tertentu, sistem secara automatik menghasilkan laluan pengumpulan yang dioptimumkan untuk trak pengurusan sisa. Ini tidak hanya mengurangkan perjalanan yang tidak perlu tetapi juga mengurangkan penggunaan bahan api dan pelepasan karbon, menjadikan proses pengumpulan lebih lestari.

ABSTRACT

Imagine a city where overflowing trash bins and inefficient waste collection are things of the past. This tech-enhanced waste control system revolutionizes how cities handle their waste, making the process more efficient, cost-effective, and environmentally friendly. Using IoT sensors installed in trash bins, our system continuously monitors the fill-level of each bin in real-time. When a bin reaches a certain capacity, the system automatically generates an optimized collection route for waste management trucks. This not only reduces unnecessary trips but also minimizes fuel consumption and carbon emissions, making the collection process more sustainable.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

1.1 Introduction

Imagine a city where overflowing trash bins and inefficient waste collection are things of the past. Introducing the cutting-edge "Tech-Enhanced Waste Control System," a revolutionary solution poised to transform urban waste management practices. In this innovative system, overflowing trash bins and inefficient waste collection become relics of the past. By harnessing the power of IoT (Internet of Things) technology, this "Tech-Enhanced Waste Control System" offers a comprehensive approach to optimizing waste collection processes, ensuring efficiency, cost-effectiveness, and environmental sustainability.

At the heart of this groundbreaking system are IoT sensors meticulously installed in trash bins throughout the city. These sensors continuously monitor the fill-level of each bin in real-time, providing invaluable data that drives intelligent decision-making. When a bin reaches a predetermined capacity threshold, the system springs into action, automatically generating an optimized collection route for waste management trucks. This "Tech-Enhanced Waste Control System" is designed to enhance overall operational efficiency. This system can anticipate fluctuations in waste generation patterns, enabling proactive adjustments to collection schedules and routes. It improves service reliability but also keeps city streets clean by preventing overflowing bins.

1.2 Project Background

Waste management is a critical aspect of urban sustainability, directly impacting public health, environmental quality, and resource conservation. With rapid urbanization and population growth, effective waste management systems are essential to mitigate pollution, reduce landfill usage, and promote circular economy principles. Monitoring waste fill levels in containers plays a crucial role in optimizing waste collection processes, preventing overflow, and minimizing operational costs for waste management authorities.

Current State of Research:

Research in waste monitoring systems has advanced significantly in recent years, driven by advancements in sensor technology, data analytics, and IoT integration. Studies have explored various sensor-based approaches, including ultrasonic, infrared, and weight-based measurement techniques, to accurately assess waste fill levels. Additionally, research has focused on developing predictive models and optimization algorithms to improve collection route efficiency and resource allocation.

Past Studies:

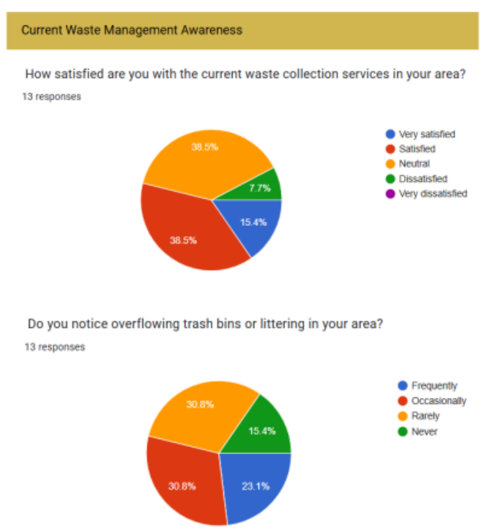
While many studies have demonstrated the effectiveness of sensor-based waste monitoring systems, controversies exist regarding the reliability and scalability of these technologies. Past research has highlighted challenges such as sensor accuracy in different environmental conditions, integration with existing infrastructure, and cost-effectiveness. Clarifying these controversies is crucial for informing the methodology and implementation of future research.

Claims and Assumptions:

Some claims have been made regarding the potential cost savings and environmental benefits associated with waste monitoring systems. However, these claims may need to be clarified through empirical research and case studies. Assumptions about the uniformity of waste generation patterns, the effectiveness of predictive algorithms, and the scalability of monitoring solutions also warrant scrutiny and validation.

Methods and Techniques:

In my study, I adopted a mixed-methods approach, and data analysis, to evaluate the performance and feasibility of a waste fill level monitoring system. I deviate from previous research by integrating real-time sensor data with spatial analytics to optimize waste collection routes dynamically. Additionally, we incorporate user feedback engagement to address implementation challenges and ensure the practicality of our proposed solution. Figure 1.1 shows the user feedback engagement.



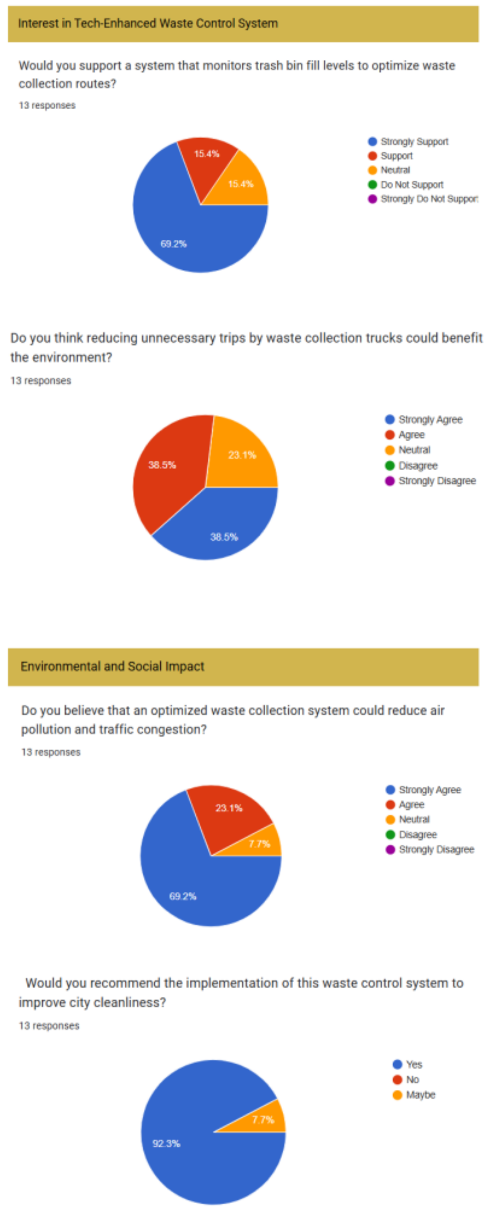
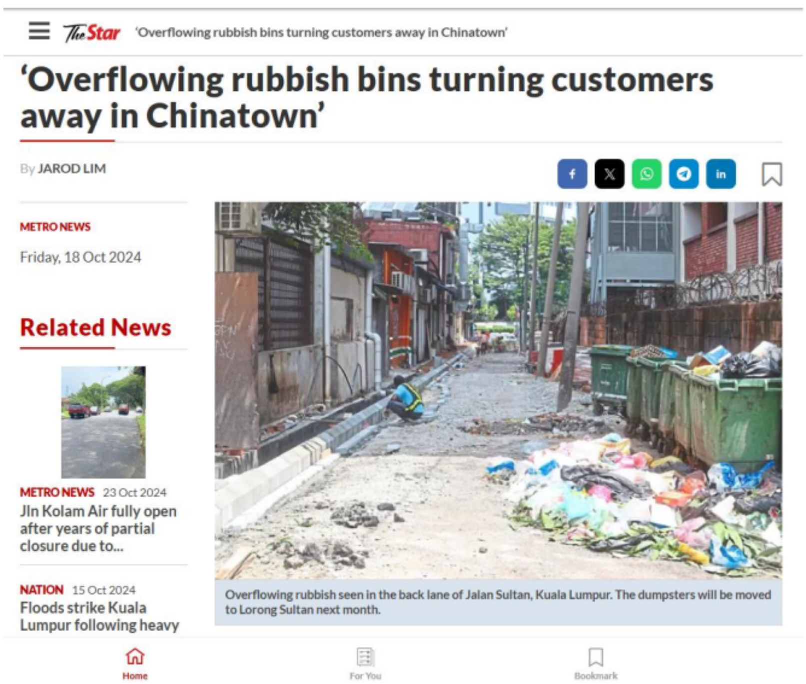


Figure 1.1 user feedback engagement

1.3 Problem Statement

In urban areas, overflowing trash bins and inefficient waste collection routes have become pressing issues, leading to environmental pollution, increased carbon emissions, and unnecessary fuel consumption. Current waste management practices often involve fixed collection schedules, which result in either underutilized or overflowing bins. This not only creates health hazards and unpleasant surroundings but also incurs higher operational costs for waste management authorities.

According to recent reports, improper waste collection contributes significantly to urban pollution and disrupts efforts toward sustainability (Figure 1.1). To address this, a tech-enhanced waste control system utilizing IoT sensors, GPS modules, and cloud services can offer a more effective solution. By monitoring fill levels of a bin in real-time and generating optimized collection routes, this system aims to reduce unnecessary trips, lower fuel consumption, and minimize carbon emissions, contributing to a more sustainable urban environment.


The Star 'Overflowing rubbish bins turning customers away in Chinatown'

'Overflowing rubbish bins turning customers away in Chinatown'

By JAROD LIM

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Overflowing rubbish seen in the back lane of Jalan Sultan, Kuala Lumpur. The dumpsters will be moved to Lorong Sultan next month.

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Figure 1.2: Online news highlighting issues in current waste management practices and the need for sustainable solutions.

Table 1.1: Comparison of Waste Collection Projects

Aspect	Traditional Waste Collection System	Tech-Enhanced Waste Control System
Monitoring Method	Manual monitoring by waste collection staff	Automated monitoring using IoT sensors in trash bins
Collection Frequency	Fixed schedules regardless of fill level	Dynamic scheduling based on real-time bin fill levels
Efficiency	Low efficiency due to fixed routes	High efficiency with optimized routes generated by GPS and data analytics
Environmental Impact	Higher carbon emissions due to unnecessary trips	Reduced emissions by minimizing collection trips
Cost	Higher operational costs due to inefficient routing	Lower operational costs by reducing fuel usage and optimizing labor
Stakeholders Affected	Municipal waste management and city residents	Municipal waste management, city residents, environmental agencies
Data Availability	Limited or no data available for analysis	Real-time data collected and stored in the cloud for analytics
System Sustainability	Limited scalability and adaptability	High scalability with potential for integration with other smart city systems

1.4 Project Objective

The key objective of this project is to develop an efficient Tech Enhanced Waste Control System (TEWCS) to optimize waste management processes in residential areas.

More precisely, the fundamental objectives of this research are:

1) To design a robust and scalable sensor-based framework for real-time monitoring of waste fill levels in containers.

2) To implement a prototype TEWCS incorporating diverse sensor technologies and wireless communication protocols.

3) To develop advanced algorithms for data processing, trend analysis, and predictive modelling to achieve optimize waste collection routes and schedules based on fill level data.

1.5 Project Scope

The scope of this project is to design and implement a tech-enhanced waste control system aimed at optimizing waste collection in urban areas. The system utilizes IoT technology, including ultrasonic sensors and a GPS module, to monitor trash bin fill levels in real-time and send data to a cloud platform, such as ThingSpeak, for analysis and route optimization. The primary goal is to minimize unnecessary collection trips, reduce fuel consumption, and decrease carbon emissions. This project will include developing a website to display real-time and historical fill-level data and implementing a system that sends location-based alerts when a bin reaches capacity. Currently, the project is limited to monitoring individual bins without an integrated alert system and can only simulate route optimization for a single collection vehicle. Future expansions may involve scaling up for multiple bins and real-time route adjustments for larger fleets.

1.6 Problem Significance

- Addresses inefficient waste collection and overflowing trash bins.
- Utilizes real-time IoT sensors and GPS for optimized waste management.
- Reduces fuel consumption and operational costs for municipalities.
- Promotes environmental sustainability by minimizing carbon emissions.
- Provides valuable data insights on waste generation patterns.

The Tech-Enhanced Waste Control System is designed to improve urban waste management by offering a smart solution to monitor trash bin fill levels in real time. This project specifically contributes to more efficient waste collection by enabling waste management services to optimize collection routes, which helps in reducing unnecessary trips. Municipalities benefit from lower operational costs and fuel consumption, while communities enjoy cleaner public spaces with fewer instances of overflowing bins.

By using data insights on waste generation, this project allows for informed decision-making and better planning for future waste management needs. Overall, this system supports environmental sustainability and aligns with broader goals of reducing carbon emissions, promoting resource efficiency, and improving the quality of life in urban areas.

1.7 Definition of Term or Operation

1) **IoT (Internet of Things)**: Refers to the network of physical devices connected to the internet, capable of collecting and sharing data. In this system, IoT enables trash bins to transmit fill-level data in real-time to the cloud.

2) **Ultrasonic Sensor**: A sensor that uses ultrasonic waves to measure the distance between the sensor and the trash inside the bin. This sensor is use to monitor the filling level of each bin, with data collected in real-time to determine when a bin is near capacity.

3) **GPS Module**: A device that tracks the geographic location of each bin, allowing the system to record and map bin locations. This data is essential for optimizing collection routes.

4) **Fill Level**: Refers to the percentage of space filled in a trash bin, as measured by the ultrasonic sensor. The filling level is recorded in intervals and used to determine when a bin requires collection.

5) **Optimized Collection Route**: A dynamically calculated route for waste collection trucks, generated based on bin locations and fill levels. This route aims to reduce unnecessary trips, fuel consumption, and carbon emissions.

6) **Real-Time Monitoring**: Continuous, instant tracking of the bin's fill level and location through sensors and GPS. This data is sent to the cloud and can be accessed on the website in real-time.

7) **ThingSpeak (Cloud Platform)**: A cloud service that stores, processes, and analyzes data sent from the IoT devices in the bins. ThingSpeak is used to manage and visualize the data from multiple bins.

8) **Sustainability**: The system's contribution to environmental sustainability by minimizing waste-related pollution, reducing fuel usage, and promoting efficient resource allocation through optimized waste collection.

1.8 Summary

Chapter 1 introduces the **Tech-Enhanced Waste Control System (TEWCS)**, a modern approach to addressing inefficiencies in waste collection processes through real-time monitoring and route optimization.

The **Introduction** highlights the system's purpose, which is to transform urban waste management by the involvement of IoT sensors and GPS technology to track bin fill levels and create optimized collection routes.

The **Project Background** emphasizes the significance of waste management for urban sustainability and reviews current research, noting advancements in sensor technology and challenges in scalability and cost-effectiveness.

The **Problem Statement** identifies the issues with traditional waste collection, such as overflowing bins and unnecessary trips, leading to increased operational costs and environmental impact.

This problem connects to the **Project Objectives**, which outline specific goals, including designing a scalable framework for waste monitoring, developing a prototype, and optimizing collection routes using data analysis and predictive modelling.

The **Project Scope** details the limitations of the current system, such as monitoring individual bins and simulating routes for a single vehicle, with future plans to expand to multiple bins and fleets.

The **Problem Significance** section underlines the system's environmental and societal impact, focusing on reducing fuel consumption, minimizing carbon emissions, and improving urban cleanliness.

Lastly, the **Definition of Terms or Operation** provides clear explanations for key terms like IoT, GPS, and real-time monitoring to ensure consistent understanding. Chapter 2 will build on this foundation by detailing the specific methodology and technical approach used in developing and implementing the TEWCS, setting the stage for practical application and testing of the system.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The term "literature" refers to prior research articles and studies that provide context for understanding and investigating a research problem. Literature reviews are essential for positioning new research within a broader field of study, as they survey scholarly articles and other sources relevant to the topic. In the case of this project, a literature review explores IoT technology, sensor-based waste monitoring, GPS-based route optimization, and the environmental impact of waste management systems. This chapter will introduce related studies, theories, and methodologies that have influenced the design and scope of this **Tech-Enhanced Waste Control System**.

2.2 IoT in Waste Management

Using IoT technology in waste management has become increasingly popular due to its potential to automate data collection and improve efficiency. IoT enables continuous monitoring of waste bins by integrating sensors that track fill levels and send data to cloud servers. In their study *"IoT-Based Smart Waste Management System for Urban Sustainability,"* Lee and Jin (2021) demonstrated that IoT systems help optimize collection schedules by reducing the need for routine visits to bins that are only partially filled. Although effective, IoT systems face challenges in network reliability and data processing, especially in dense urban areas. IoT has become essential for real-time data tracking and dynamic adjustment of collection routes, highlighting its significance in modern waste management systems.

2.3 Sensor-Based Waste Monitoring

Waste monitoring is a key component of any smart waste management system. Various types of sensors, including ultrasonic, infrared, and weight-based sensors, are used to monitor bin fill levels. Ultrasonic sensors are commonly chosen for monitoring solid waste due to their high accuracy and non-contact measurement method. In the study *"Performance Analysis of Ultrasonic Sensors for Smart Waste Monitoring,"* Kumar and Zhao (2020) demonstrated that ultrasonic sensors are effective in measuring bin fill levels, though accuracy can vary in outdoor environments with temperature changes. These sensors measure fill levels by calculating the distance to the trash within a bin, providing reliable real-time data to optimize collection schedules. However, the reliability of ultrasonic sensors in different weather conditions remains a noted limitation.

2.4 GPS and Data Analytics for Route Optimization

The integration of GPS with data analytics has transformed waste collection logistics by allowing for optimized routing based on data that captured on real-time. In the study *"The Ultimate Guide to Waste Collection Route Optimization,"* Shivangi Singh (2024) examined how GPS-enabled systems reduce fuel consumption and emissions by calculating the shortest route to bins that require immediate collection. They found that advanced route optimization algorithms cut down collection time and minimize unnecessary trips. Seyed Sahand Mousavi, Ali Hosseinzadeh, and Abooali Golzary (2018 to 2022) in their study *"Challenges, recent development, and opportunities of smart waste collection: A review,''* identified issues with GPS accuracy and signal stability in high-density areas, which could impact the reliability of real-time route adjustments. Despite these challenges, GPS integration remains a valuable tool for improving collection efficiency in urban waste management.

2.5 Environmental Impact and Sustainability

Sustainability in waste management focuses on reducing carbon emissions, pollution, and resource waste. The study *"Major Benefits of IoT Waste Management for Smart Cities,"* conducted by Christian Meldgaard (2022), showed that smart waste systems can substantially solve issues at the side of creating a more efficient pathway for garbage trucks. By promoting efficient resource allocation, IoT systems support urban sustainability initiatives and align with global sustainability goals. Their findings confirmed that optimized collection reduces fuel usage and improves the cleanliness of urban areas. Despite the positive outcomes, challenges such as scalability and system integration with existing infrastructure persist, emphasizing the need for adaptable and cost-effective solutions.

2.6 Gaps in Existing Research

Although IoT-based waste management systems demonstrate significant benefits, gaps remain in scalability, sensor reliability, and large-scale implementation. Limited research explores how these systems can be applied on a broader scale in densely populated cities. Additionally, sensor performance in fluctuating outdoor conditions requires further investigation to ensure consistent data accuracy. This project aims to address these gaps by implementing a scalable IoT framework with reliable ultrasonic sensors and GPS modules, ensuring accurate, real-time monitoring and optimized collection in urban environments.

2.7 Related Projects

PROJECT 1

Similar projects have explored smart waste management, but they differ in methodology, tools, and materials. For example, *“IOT Garbage Monitoring Using Raspberry Pi”* by Nevon Projects (2019) used a Raspberry Pi microcontroller for data processing, but the high cost and complexity of the Raspberry Pi make the project less scalable for large cities. In contrast, the present project uses the ESP32 microcontroller, which is cost-effective and provides ample processing power for IoT applications.

PROJECT 2

In another study, *“Smart Garbage Monitoring System Using Internet of Things (IOT),”* Technovation (2017) integrated Arduino microcontrollers with GPS for location tracking. Although effective, the system's limited processing power makes it challenging to handle large-scale data analysis. By using the ESP32 microcontroller and ThingSpeak cloud service, our project offers a scalable and flexible solution that provides real-time data insights and is more adaptable to larger applications.

Comparison	Project 1 (Nevon Projects 2019)	Project 2 (Technovation 2017)	Proposed Project
Microcontroller	Raspberry Pi	Arduino MKR 1000	ESP32
Cost	High (RM 1,500)	Moderate (RM 600)	Low (RM 200)
Data Processing	High capability	Moderate capability	Moderate capability with cloud
GPS Integration	No	Yes	Yes
System Scalability	Limited due to high cost	Moderate	High with cloud and real-time data
Power Supply	Direct Power	Battery	Rechargeable Battery

Table 2.1

Table 2.1 compares the methodologies and scalability of previous projects and highlights the cost-effectiveness and adaptability of the proposed project, which uses the ESP32 microcontroller and solar power options for better sustainability.

2.8 Summary

Chapter 2 reviewed key studies on IoT technology, sensor-based waste monitoring, GPS integration, and sustainable waste management. The literature reveals that while IoT-enabled systems improve waste collection efficiency, challenges remain in sensor reliability, GPS accuracy, and large-scale implementation. By addressing these gaps, the proposed **Tech-Enhanced Waste Control System** aims to provide an adaptable, cost-effective solution to optimize urban waste management. Chapter 3 will outline the specific methodology and technical approach used in developing and testing this system, building on the insights gained from previous studies.

CHAPTER 3
METHODOLOGY

3.1 Introduction

This chapter outlines the methodology used to develop the **Tech-Enhanced Waste Control System**. The methodology section covers the design approach, the hardware and software components, and the system's development process. Key stages include designing the project framework, integrating IoT sensors and GPS modules, setting up data transmission, and testing the system. Additionally, the chapter will detail the block diagram, project flow, and hardware and software used. Each stage contributes to achieving a reliable and scalable waste management system.

3.2 Project Design and Overview

The project design focuses on using IoT sensors, GPS modules, and cloud services to monitor waste filling level in real-time and optimize waste collection routes. The system collects bin fill-level data through ultrasonic sensors, process location data using GPS, and transmits all information to a cloud platform for visualization and analysis.

The overall design is divided into hardware integration, data collection and transmission, algorithm development, and user interface display. The **Gantt chart** in Figure 3.2 outlines the timeline for each phase of the project, from planning to testing.

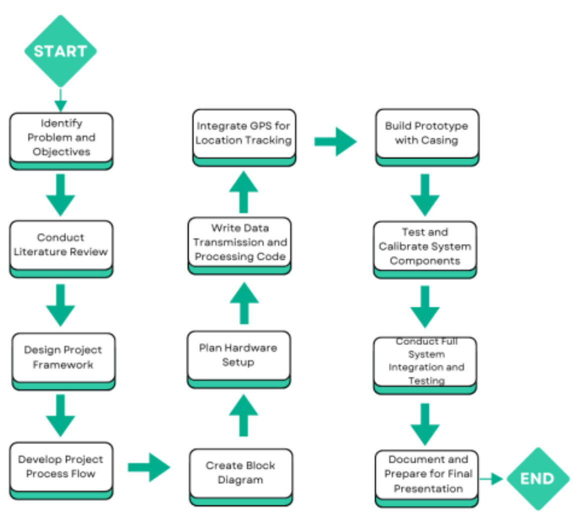
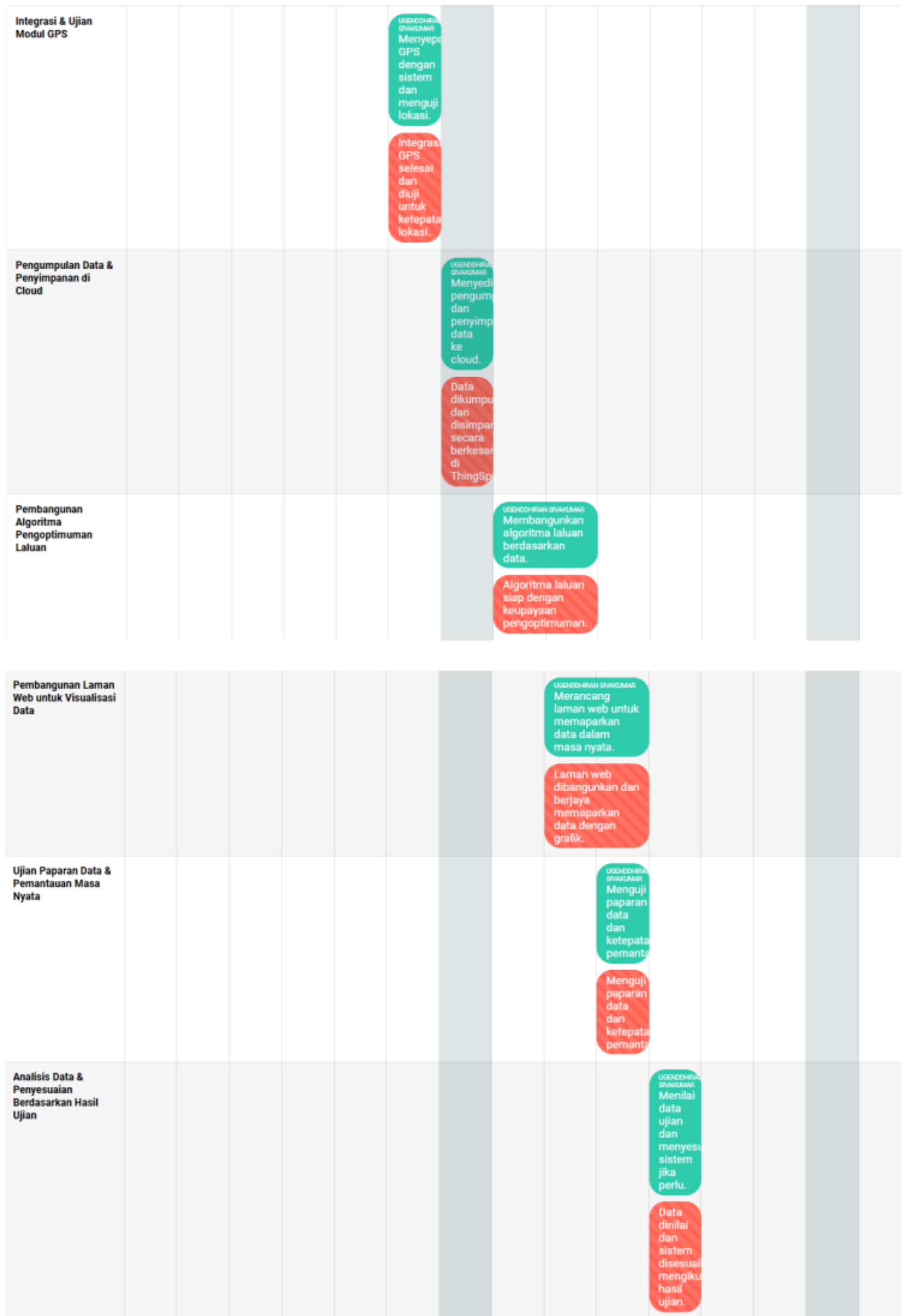


Figure 3.1 Process Flow of The Project



Integrasi & Ujian Modul GPS
GPS dengan sistem dan menguji lokasi.
GPS selesai dan diuji untuk lokasi.
Pengumpulan Data & Penyimpanan di Cloud
dan data ke cloud.
Data dan secara di
Pembangunan Algoritma Pengoptimuman Laluan
Membangunkan algoritma laluan berdasarkan data.
Algoritma laluan siap dengan keupayaan pengoptimuman.
Pembangunan Laman Web untuk Visualisasi Data
Merancang laman web untuk memaparkan data dalam masa nyata.
Laman web dibangunkan dan berjaya memaparkan data dengan grafik.
Ujian Paparan Data & Pemantauan Masa Nyata
Menguji paparan data dan
Menguji paparan data dan
Analisis Data & Penyesuaian Berdasarkan Hasil Ujian
Menilai data ujian dan sistem jika perlu.
Data dinilai dan sistem hasil ujian.

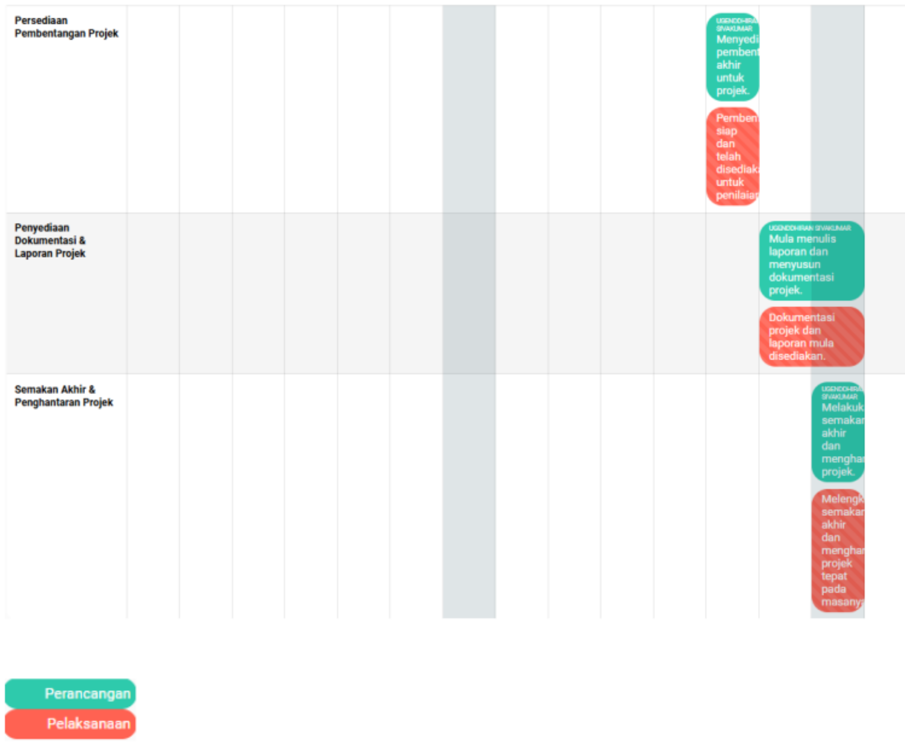


Figure 3.2 Project Gantt Chart

3.3 Block Diagram of The Project

The block diagram represents the system architecture, showing how each component interacts. In this project, the main components include the **ESP32 microcontroller**, **ultrasonic sensor** for bin fill-level monitoring, **GPS module** for tracking, **ThingSpeak cloud platform** for data storage and a **Developed Website** for live monitoring.

The ESP32 collects the real-time data from the sensor, processes it, and forward it to ThingSpeak Cloud and Developd Website via WiFi. When a bin reaches a specific capacity, it triggers an optimized route suggestion. Figure 3.3 illustrates the block diagram.

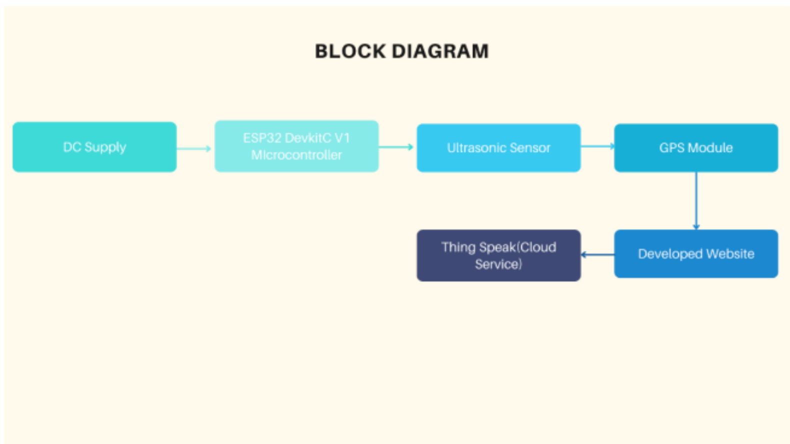


Figure 3.3 Block Diagram of The Module

Block Diagram Explanation

- **Input**: Data from the ultrasonic sensor and GPS module.
- **Processing**: ESP32 will process the collected data and forward it to the cloud.
- **Output**: Data visualized on a website with real-time updates and route suggestions for waste collection trucks.

3.4 Project Flow Chart

The flow chart in Figure 3.4 outlines the operational steps from data collection to route optimization. The process begins with sensor data collection, which is processed and transmitted to the cloud. The system then evaluates bin fill levels and triggers route planning based on predefined thresholds.

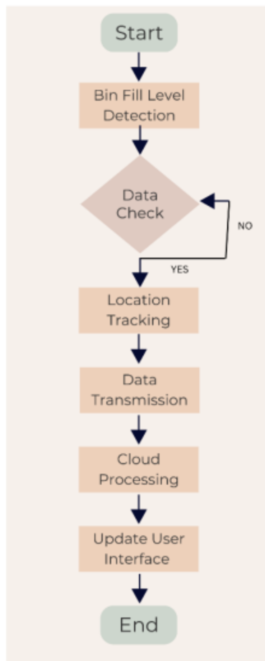


Figure 3.4 Flowchart of The System

Flowchart Explanation

1. **Start**: System initiates with data collection from sensors.
2. **Data Transmission**: Data sent to the cloud via Wi-Fi.
3. **Evaluation**: Bin fill levels are assessed; if a threshold is met, a route alert is generated.
4. **Display**: Data and optimized routes displayed on the user interface.
5. **End**: Continuous monitoring until bins reach threshold again.

3.6 Project Hardware

This section provides details on the hardware used in the project, including the schematic circuit and components involved.

3.6.1 Schematic Circuit

The schematic circuit, shown in Figure 3.5, was created using [Circuito.io] for ESP32 integration with the ultrasonic sensor, GPS module, and WiFi connection. This software was selected for its ease of use and compatibility with various hardware components.

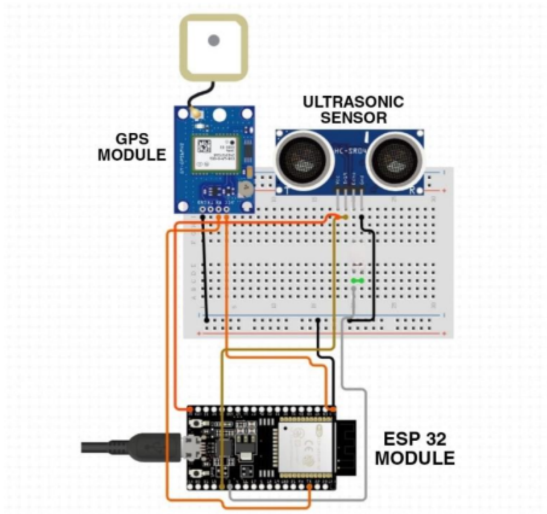


Figure 3.5 Schematic Circuit of The Module

3.6.2 Description of Components

1. **ESP32 Microcontroller**: Manages collected data from the ultrasonic sensor and GPS module, sends data to the cloud.
2. **Ultrasonic Sensor**: Measures bin fill levels by calculating the distance between the sensor and the trash.
3. **GPS Module**: Tracks the location of each bin for optimized route planning.
4. **Power Supply**: Portable power bank ensures continuous operation.

3.6.3 Circuit Operation

The circuit operates by collecting data from the ultrasonic sensor and GPS module, processing this information with the ESP32 microcontroller, and transmitting it via Wi-Fi. When the sensor detects a certain fill level, a notification is sent to the cloud, and a new route is generated for waste collection.

3.4 Project Software

The Tech-Enhanced Waste Control System project utilized various software tools, each playing a critical role in coding, circuit design, data visualization, and real-time monitoring. The following is an overview of the software used and its purpose in the project:

1) **Arduino IDE (Coding)**

   The Arduino Integrated Development Environment (IDE) was used to code the main control logic for the system. This open-source platform allowed us to write, compile, and upload code to the **ESP32 microcontroller**, which manages data collection from sensors and transmits information to the cloud. The Arduino IDE provided a user-friendly interface for code development and debugging, ensuring that the system functioned as intended in real-time.

2) **ESP32 Libraries**

   Specific libraries for the ESP32, such as **WiFi.h** for network connection and **HTTPClient.h** for HTTP requests, were integrated within the Arduino IDE. These libraries enabled seamless communication between the ESP32 and the ThingSpeak cloud platform, allowing the system to transmit fill-level and location data. These libraries were essential for ensuring stable WiFi connectivity and efficient data transfer to the cloud.

3) **Fritzing (Circuit Design)**

   Fritzing was used for designing the project's circuit layout, providing a clear and organized representation of connections between the ESP32, ultrasonic sensor, GPS module, and power supply. This free, open-source tool allowed us to create schematic diagrams and check for any potential issues before assembling the physical circuit. The diagrams created in Fritzing ensured accuracy in component connections, reducing the risk of errors during setup.

4) **ThingSpeak (Data Visualization and Storage)**

ThingSpeak, a cloud-based IoT platform, was utilized to store and visualize real-time data transmitted from the ESP32. ThingSpeak provides tools for data analysis and graphical visualization, allowing us to evaluate the bin's content level and live location. The platform was instrumental in developing optimized waste collection routes by using collected data to inform decision-making for route planning.

5) **MATLAB (Data Analysis)**

MATLAB was used in conjunction with ThingSpeak for in-depth data analysis and processing. The integration with ThingSpeak allowed us to apply predictive models on bin fill trends, providing insights into usage patterns and enabling proactive adjustments to collection schedules. MATLAB’s powerful analysis tools were essential for generating accurate, data-driven recommendations for route optimization.

6) **Tinkercad (3D Model of System Enclosure)**

Tinkercad, an online 3D modeling tool, was used to design the enclosure for the system components, including compartments for the ESP32, sensors, and GPS module. Tinkercad’s intuitive interface allowed us to create accurate, compact designs, ensuring protection for the components in outdoor installations. The Tinkercad models helped visualize the system’s layout and aided in the final assembly of the enclosure.

3.5 Prototype Development

This section outlines the development of the project prototype, covering the design and layout, PCB process, circuit construction, software development, and casing.

3.5.1 Design and Layout

The design and layout of the prototype were carefully planned to ensure compactness, durability, and ease of integration. Key components, such as the ESP32 microcontroller, ultrasonic sensor, GPS module, and power source, were arranged to minimize space and maximize functionality. The layout was created to facilitate smooth data flow from the sensor to the microcontroller and then to the cloud platform for monitoring. This organized design minimized wiring complexity and helped streamline component connections, enhancing system reliability. Figure 3.6 shows the 3D model and sketch of the model. Figure 3.7 shows the internal component placement.

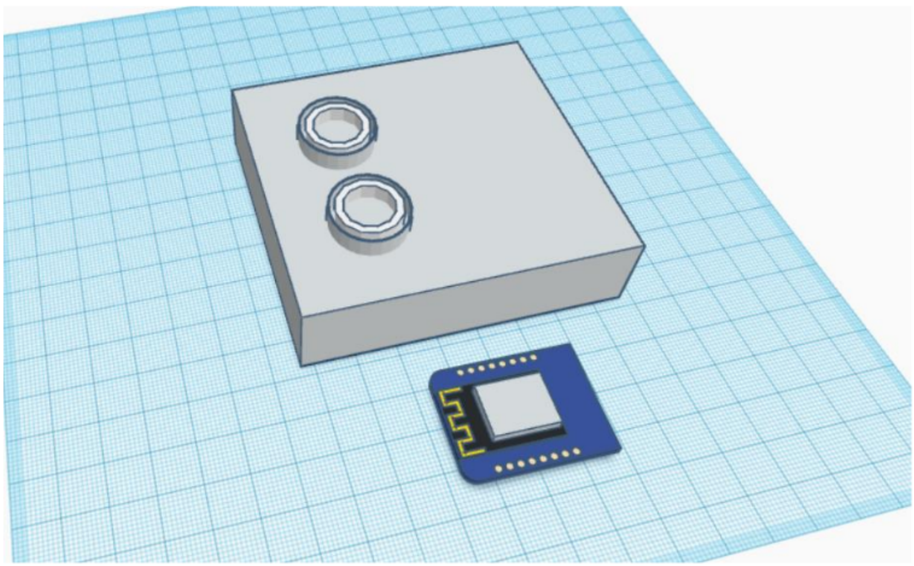


Figure 3.6 3D Model and Sketch of The Model

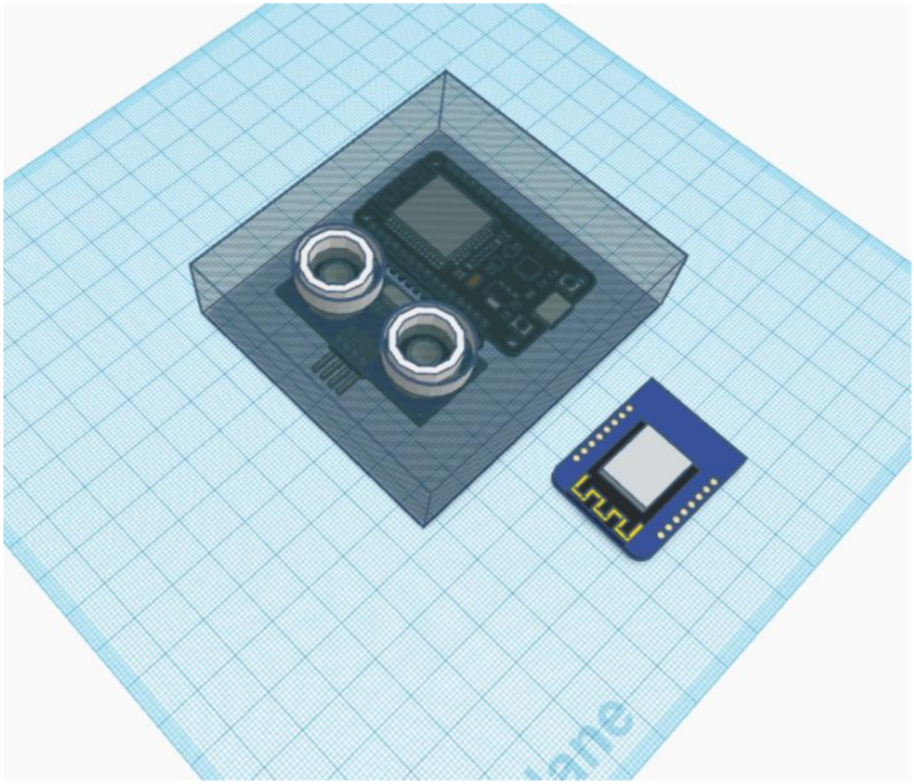


Figure 3.7 The Internal Component Placement.

3.5.2 Circuit Construction

The circuit construction involved soldering only the **receptacle connectors** onto the PCB board. These connectors allowed for secure attachment of the ESP32 and ensured a stable connection without needing to solder the microcontroller directly. For other components, such as the ultrasonic sensor and GPS module, **jumper wires** were used to make flexible connections. This approach allowed for easy adjustments and troubleshooting, as components could be rearranged or replaced if needed.

After assembling the circuit, each connection was carefully tested to verify correct operation. Special attention was given to ensure proper insulation and spacing, reducing the risk of short circuits. Power connections were also checked to confirm a stable voltage supply to the ESP32 and connected sensors. This construction approach enabled a reliable setup, preparing the prototype for operational testing.

3.5.3 Software Development

The software development process was crucial in bringing the hardware components together into a functional system. Using **Arduino IDE**, we developed the code that controls the ESP32 microcontroller. Key functions included reading data from the ultrasonic sensor, capturing GPS coordinates, and sending this information to the ThingSpeak cloud platform via WiFi. Libraries like **WiFi.h** and **HTTPClient.h** were integrated to facilitate data transmission. The code was thoroughly tested and debugged within Arduino IDE to ensure real-time monitoring and reliable data transmission, achieving a stable connection with ThingSpeak.

3.5.4 Mechanical and Product Design

The casing was designed to house the PCB Board, ESP32, Ultrasonic sensor, and GPS module, providing protection against environmental elements while allowing airflow. **Tinkercad** was used to create a 3D model of the casing, ensuring accurate dimensions and structural support. The casing was designed using durable materials that withstand outdoor conditions, with ventilation openings added to prevent overheating. This compact design allows for easy installation on various bins, with mounting points to secure the casing in place. Figure 3.8 shows the casing design of the system.

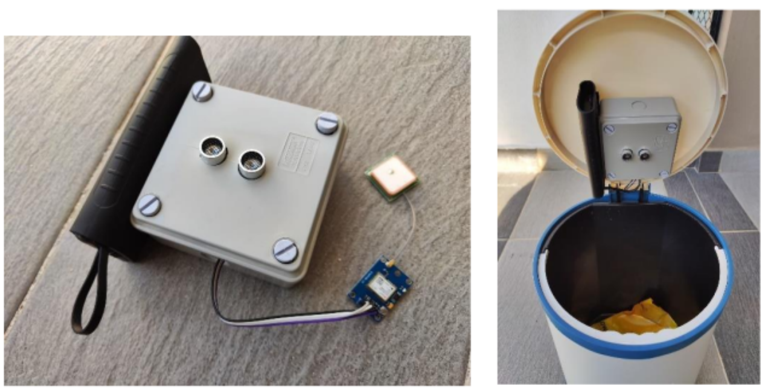


Figure 3.8 Casing Design

3.5.5 System Integration

System integration involved bringing together all the hardware and software components to ensure they operated cohesively as a single unit. The ESP32 microcontroller served as the central processor, coordinating data collection from the ultrasonic sensor and GPS module, and managing communication with the ThingSpeak cloud platform. During this phase, extensive testing was conducted to verify seamless data flow from sensors to cloud storage and to ensure real-time updates on bin fill levels and location tracking.

This integration step also included testing the response times, data accuracy, and the effectiveness of the route optimization alerts generated on the user interface. Adjustments were made to enhance system stability, fine-tune sensor readings, and optimize WiFi connectivity, ensuring the final system met performance expectations for urban waste monitoring and management.

3.6 Summary

Chapter 3 outlined the methodology used in developing the Tech-Enhanced Waste Control System, detailing each stage from design to system integration. The project began with defining the system architecture, using IoT sensors, GPS modules, and cloud services to achieve live waste analysis and optimized route planning for waste collection. A Gantt chart was provided to illustrate the timeline for project phases, ensuring an organized approach.

The block diagram and project flowchart were presented, providing a clear visual of data flow, including data collection, processing, and cloud transmission. The hardware components, including the ESP32 microcontroller, ultrasonic sensor, and GPS module, were selected for their compatibility and reliability. Circuit design and layout were planned in **Fritzing** to minimize complexity, while **Tinkercad** was used to design a protective casing, ensuring component safety in outdoor settings.

For software development, **Arduino IDE** was utilized to code the control logic, with libraries like **WiFi.h** and **HTTPClient.h** to facilitate data transmission to the cloud. **ThingSpeak** and **MATLAB** were employed for data visualization, analysis, and predictive modeling to enhance route optimization. System integration then brought all components together, achieving cohesive operation with accurate real-time monitoring.

CHAPTER 4
RESULT AND DISCUSSION

4.1 Introduction

This chapter presents the results of data collection and analysis for the Tech-Enhanced Waste Control System. It includes a detailed evaluation of the finished project, highlighting the advantages, limitations, and challenges encountered during development. Various tests were conducted to assess system reliability, including fill-level detection accuracy, GPS tracking precision, data transmission consistency, and overall system performance. This section also provides insights into testing tools, calibration methods, safety measures, and maintenance procedures used to ensure optimal functionality of the system.

4.2 Results and Analysis

The results are based on data collected during various testing phases. The following subsections outline the tools, methods, and outcomes associated with each test conducted.

4.2.1 List of Testing Tools

1. **Ultrasonic Sensor Tester** – Used to validate the accuracy of fill-level measurements.
2. **GPS Signal Analyzer** – Ensured GPS module precision in tracking bin locations.
3. **Wi-Fi Signal Strength Meter** – Evaluated the strength and stability of the Wi-Fi connection for data transmission.
4. **Multimeter** – Checked circuit continuity and ensured stable voltage supply across components.

4.2.2 Testing and Calibration Methods

1. **Sensor Calibration**: The ultrasonic sensor was calibrated by measuring distances in controlled environments to establish baseline values. Variability in distance measurements was assessed and adjusted in code to ensure accuracy.
2. **GPS Module Testing**: The GPS module's accuracy was tested by placing it in known locations and comparing the recorded coordinates. This test ensured reliable location tracking for optimal route planning.
3. **Data Transmission Check**: Consistency of data transmission was verified by monitoring real-time data on the ThingSpeak platform. Various Wi-Fi strength levels were simulated to test system performance under fluctuating conditions.
4. **System Integration Testing**: The complete system was tested to confirm that data flowed seamlessly from sensors to cloud storage and displayed accurately on the user interface.

4.2.3 Testing Safety/Precautionary Measures

1. **Power Management**: Proper voltage levels were ensured to protect components, especially during prolonged testing sessions.
2. **Environmental Controls**: Testing in outdoor environments included weatherproofing precautions to prevent sensor damage.
3. **Component Isolation**: Electrical components were insulated to prevent short circuits during integration tests.

4.2.4 Preliminary Testing and Calibration Results

In the initial testing phase, the ultrasonic sensor's preliminary results showed minor inconsistencies in fill-level measurements. These inconsistencies were resolved through calibration adjustments in the code, ensuring accurate distance calculations for reliable fill-level detection.

The GPS module encountered issues with obtaining sufficient satellite signals, which affected location accuracy. This limitation, common in system setups, restricted the module's ability to maintain precise tracking. Alternative positioning strategies or enhancements to the GPS module's placement were considered to improve signal reception.

4.2.5 Final Stage Testing Results

In the final stage of testing, the ultrasonic sensor demonstrated consistent and accurate fill-level measurements following calibration adjustments. The sensor reliably detected fill levels with minimal discrepancies, ensuring dependable data collection for real-time monitoring.

The GPS module's performance improved after implementing alternative positioning strategies to enhance satellite signal acquisition. While occasional signal drops persisted in areas with limited satellite coverage, the GPS was generally able to track the bin location with improved precision. This enhancement allowed for more accurate location reporting, although further refinement may be needed for robust urban deployment.

Data transmission over Wi-Fi remained stable during final tests, with the optimized signal sensitivity effectively minimizing disruptions. The system successfully transmitted real-time fill-level and location data to the cloud, allowing for seamless updates on the user interface. Overall, the system met the target specifications for testing, supporting real-time waste monitoring and reliable data flow.

4.3 Discussion

The results from testing indicate that the Tech-Enhanced Waste Control System successfully achieved its objectives. The system provided accurate fill-level monitoring and reliable location tracking, enhancing waste collection efficiency. The data-driven insights from ThingSpeak, analysed in MATLAB, supported predictive modelling for route optimization, aligning with findings in previous research.

Challenges included occasional Wi-Fi connectivity issues and minor sensor calibration adjustments, which were resolved through software adjustments and environmental testing. These findings highlight the importance of robust connectivity and precise sensor calibration in IoT-based waste management systems.

The system's ability to reduce unnecessary collection trips aligns with environmental sustainability goals, reducing fuel consumption and emissions. The results support the potential for broader implementation in urban waste management, demonstrating scalability and adaptability across different environments.

4.4 Summary

Chapter 4 presented the results and analysis of the Tech-Enhanced Waste Control System, providing a comprehensive evaluation of its performance through various testing phases. The initial testing revealed minor inconsistencies in the ultrasonic sensor's fill-level measurements, which were resolved through calibration. GPS challenges related to satellite signal acquisition were partially addressed through adjustments in module positioning, improving location accuracy for the bin's tracking.

Final testing confirmed that the ultrasonic sensor provided consistent and reliable fill-level data, while the GPS module generally achieved improved tracking accuracy. Wi-Fi data transmission remained stable, with optimized sensitivity ensuring seamless real-time updates on the ThingSpeak cloud platform. System performance met the specifications for prototype testing, supporting dependable data flow and real-time monitoring.

The discussion highlighted how the system achieved its primary objectives by enhancing waste collection efficiency and contributing to environmental sustainability. Although challenges with Wi-Fi and GPS were encountered, the project demonstrated the system's scalability and potential for urban implementation, positioning it as a promising solution for optimized waste management.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter provides a conclusion of the Tech-Enhanced Waste Control System project, summarizing how the objectives were achieved. It also presents recommendations for future improvements to enhance the system's functionality and adaptability for broader urban waste management applications.

5.2 Conclusion

The objectives of this project were successfully achieved, as described below:

a) Objective 1

To develop a real time updating system for waste bin filling level using IoT sensors. This objective was accomplished through the integration of an ultrasonic sensor with the ESP32 microcontroller to continuously measure and monitor bin fill levels. Testing and calibration ensured that the sensor accurately detected waste levels, allowing for dependable, real-time data collection. By sending data to the ThingSpeak cloud platform, the system effectively enabled real-time monitoring, which supports timely waste collection and helps avoid bin overflow issues.

b) Objective 2

To implement GPS tracking for location-based monitoring of bins.
The GPS module was successfully integrated with the system to track the bin's location, providing accurate geographical data to support route optimization for waste collection. While there were initial challenges with obtaining sufficient satellite signals, adjustments in module positioning improved accuracy. The integration of GPS tracking in this project fulfils the objective by providing essential location-based data, which can guide waste collection teams in efficiently planning routes.

c) Objective 3

To develop a cloud-based interface for data visualization and analysis.
The system achieved this objective by transmitting real-time data to the ThingSpeak platform, where fill-level and location data were visualized and stored. The ThingSpeak platform also supported data analysis, enabling predictive modelling and route optimization, further enhancing the system's operational efficiency. The cloud-based visualization met the objective by allowing users to monitor the bins remotely, contributing to more proactive waste management practices.

5.3 Future Recommendations

Based on the insights gained during the project, several recommendations are suggested to enhance the system's performance and scalability:

1. **Improve GPS Signal Reception**: Future versions of the system could explore alternative GPS modules or additional positioning strategies, such as multi-antenna setups, to improve signal reception in areas with limited satellite visibility.
2. **Enhance Wi-Fi Connectivity**: To maintain stable data transmission in areas with poor Wi-Fi coverage, incorporating dual connectivity options (e.g., 4G/5G modules) would provide backup connectivity for uninterrupted real-time data flow.
3. **Expand System for Multi-Bin Monitoring**: To scale the project, a multi-bin setup could be implemented, enabling centralized monitoring and optimized routing for several bins across different locations.
4. **Develop Mobile Application Integration**: Creating a mobile app for live monitoring would provide a more user-friendly interface, allowing waste collection teams to access bin data and route optimizations directly on their devices.
5. **Integrate Machine Learning for Predictive Maintenance**: Adding a machine learning model could further enhance route optimization by predicting fill-level trends based on historical data, improving scheduling and reducing unnecessary trips.

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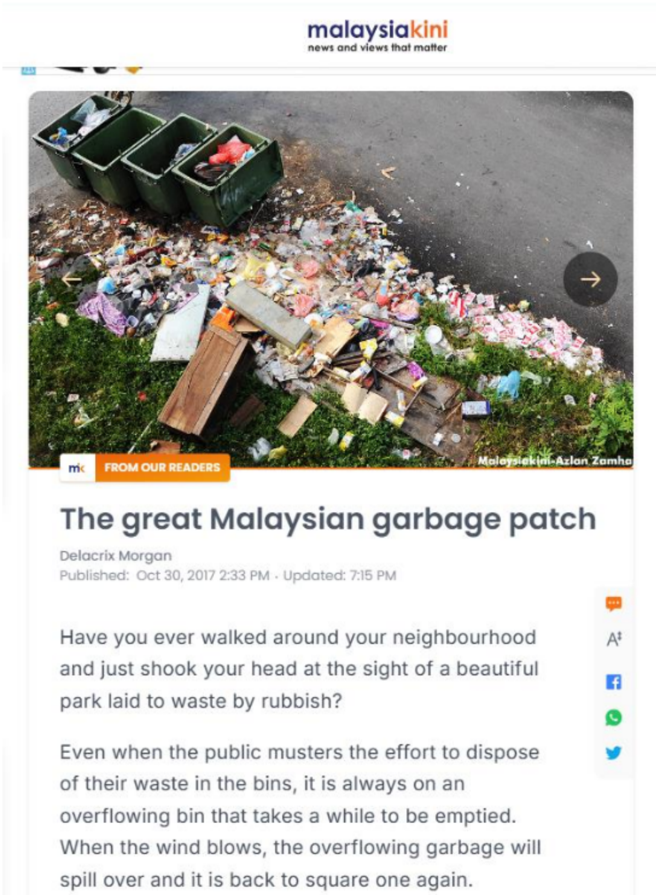
APPENDICES

Appendix A: Research Article & Newspaper

A.1: Newspaper snippets

- Cities around the world are facing a growing waste management crisis as overflowing bins and missed collections have become increasingly common.



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FROM OUR READERS

The great Malaysian garbage patch

Delacrix Morgan
Published: Oct 30, 2017 2:33 PM · Updated: 7:15 PM

Have you ever walked around your neighbourhood and just shook your head at the sight of a beautiful park laid to waste by rubbish?

Even when the public musters the effort to dispose of their waste in the bins, it is always on an overflowing bin that takes a while to be emptied. When the wind blows, the overflowing garbage will spill over and it is back to square one again.

- In Chinatown, overflowing rubbish bins are causing concern among local businesses as waste piles up, creating unpleasant odors and an unsightly atmosphere.

The Star 'Overflowing rubbish bins turning customers away in Chinatown'

'Overflowing rubbish bins turning customers away in Chinatown'

By JAROD LIM

METRO NEWS

Friday, 18 Oct 2024

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Overflowing rubbish seen in the back lane of Jalan Sultan, Kuala Lumpur. The dumpsters will be moved to Lorong Sultan next month.

CENTRALISED rubbish bins in Kuala Lumpur's Chinatown will be moved to a location nearby by next month.

This follows complaints from business owners along Jalan Sultan that the current location of the bins behind their shops had affected business.

A.2: Article Snippet

- Waste management faces multiple challenges worldwide, from overflowing landfills and pollution to inefficient collection systems and high operational costs.

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The Biggest Problems with Waste Management and How to Overcome Them

PUBLISHED JUNE 07, 2023

Waste management is a critical issue that affects our environment and communities. The improper handling of waste can lead to pollution, health hazards, and ecological damage. It is essential to identify and address the biggest problems associated with **waste management** in order to ensure a sustainable future.

Waste Management Problems

→ **Meeting Compliance Regulations**

The Problem: Waste management companies must navigate complex and ever-changing regulations related to waste disposal, recycling, and environmental protection. Staying compliant with these regulations can be challenging and requires ongoing monitoring and adaptation. This can be difficult to do if it's not part of your existing operational routine. Without deliberate mindfulness, these requirements can be easily overlooked, risking high compliance costs.

The Solution: A waste management system has proven helpful in this area. Automation is a great way to complete a task you don't have time to do right manually, but where leaving pieces overlooked is not an option. Waste tracking is a great way to promptly ensure the proper disposal of waste and continue normal operations. This way, if there is an issue leading to compliance concerns, it can be addressed immediately. The data that waste management software provides can also be easily accessed and shared with regulatory bodies, simplifying audits and inspections.

Asset tracking also helps to identify potential safety risks in real time. For example, if a waste container is damaged or compromised, the waste tracking system can immediately notify the relevant personnel, who can take appropriate actions to mitigate the risk. This proactive approach to safety enhances the overall well-being of waste management workers, residents, and the environment.

Appendix B: Project Code

B.1: code for setting up the pin configuration

```
#include <WiFi.h>
#include <HTTPClient.h>
#include <TinyGPS++.h>

// Define the RX and TX pins for GPS module (use hardware serial)
#define GPS_RX_PIN 16  // GPIO16 (RX2)
#define GPS_TX_PIN 17  // GPIO17 (TX2)

#define TRIG_PIN 12  // Trigger Pin for Ultrasonic Sensor
#define ECHO_PIN 13  // Echo Pin for Ultrasonic Sensor

float duration = 0;
int distance = 0;
int maxDistance = 30;  // Maximum distance when bin is empty (in cm)
int minDistance = 5;   // Minimum distance when bin is full (in cm)

// Replace with your Wi-Fi credentials
const char* ssid     = "Xiaomi 12";
const char* password = "wt8cbxqk7b72fha";

// Replace with your server IP or URL (ensure no spaces)
const char* serverName = "http://192.168.70.17/ultrasonic/data.php";

// ThingSpeak Write API Key
const char* thingSpeakAPIKey = "P8ULPRMWPA3GT20X";
const char* thingSpeakServer = "http://api.thingspeak.com/update";

// Create GPS object
TinyGPSPlus gps;

// Create a hardware serial port for GPS (Serial2)
HardwareSerial gpsSerial(2);  // Serial2 on ESP32

void setup() {
  Serial.begin(115200);
  pinMode(TRIG_PIN, OUTPUT);
  pinMode(ECHO_PIN, INPUT);

  // Initialize GPS serial
  gpsSerial.begin(9600, SERIAL_8N1, GPS_RX_PIN, GPS_TX_PIN);

 // Connect to Wi-Fi
 WiFi.begin(ssid, password);
 Serial.print("Connecting to WiFi");
 while (WiFi.status() != WL_CONNECTED) {
   delay(500);
   Serial.print(".");
 }
 Serial.println("");
 Serial.println("WiFi connected.");
 Serial.println("IP address: ");
 Serial.println(WiFi.localIP());
}
```

B.2: code for measures the bin's fill level

- measures the bin's fill level based on distance data from the ultrasonic sensor and calculates the bin’s fill level as a percentage.

```
void loop() {
  // Measure distance using ultrasonic sensor
  digitalWrite(TRIG_PIN, LOW);
  delayMicroseconds(2);
  digitalWrite(TRIG_PIN, HIGH);
  delayMicroseconds(10);
  digitalWrite(TRIG_PIN, LOW);

  duration = pulseIn(ECHO_PIN, HIGH, 30000); // Timeout after 30ms
  if (duration == 0) {
    Serial.println("Echo timeout");
    distance = maxDistance;
  } else {
    distance = duration * 0.034 / 2;  // Convert duration to distance (in cm)
  }

  // Constrain distance within min and max limits
  if (distance < minDistance) distance = minDistance;
  if (distance > maxDistance) distance = maxDistance;

  // Calculate fill level as a percentage
  int fillLevel = map(distance, minDistance, maxDistance, 100, 0);  // Full at minDistance, empty at maxDistance
  fillLevel = constrain(fillLevel, 0, 100);  // Ensure fillLevel is between 0 and 100

  Serial.print("Distance: ");
  Serial.print(distance);
  Serial.println(" cm");

  Serial.print("Fill Level: ");
  Serial.print(fillLevel);
  Serial.println("%");
```

B.3: code for GPS module and ThingSpeak

- reads data from the GPS module, sends both bin fill level and location data to a server, and then posts the fill level data to the ThingSpeak cloud platform

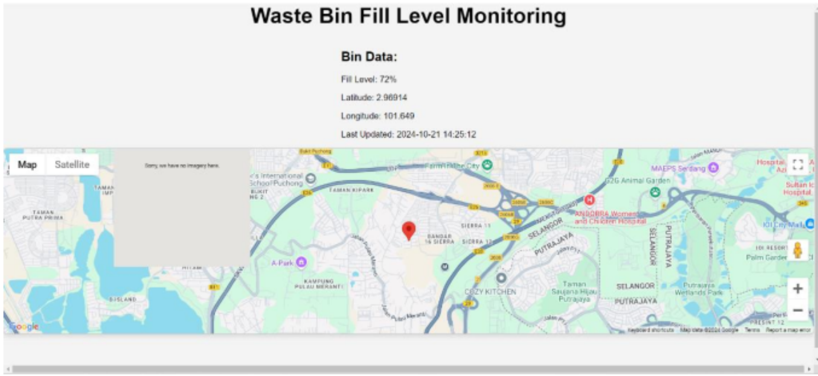
```
  // Read GPS data
  while (gpsSerial.available() > 0) {
    char c = gpsSerial.read();
    gps.encode(c);
    Serial.write(c);  // Print raw GPS data for debugging
  }

  // Variables to hold GPS data
  double latitude = 0.0;
  double longitude = 0.0;

  if (gps.location.isValid()) {
    latitude = gps.location.lat();
    longitude = gps.location.lng();

    Serial.print("Latitude: ");
    Serial.println(latitude, 6);  // Print latitude to 6 decimal places

    Serial.print("Longitude: ");
    Serial.println(longitude, 6);  // Print longitude to 6 decimal places
  } else {
    Serial.println("Waiting for valid GPS signal...");
  }

  // Send data to the server
  if (WiFi.status() == WL_CONNECTED) {  // Check if Wi-Fi is connected
    HTTPClient http;

    // Form the data to send using POST to your server
    String postData = "fillLevel=" + String(fillLevel) + "&latitude=" + String(latitude, 6) + "&longitude=" + String(longitude, 6);

    // Debugging: Print the POST data
    Serial.print("POST Data: ");
    Serial.println(postData);

    // Send data to your server
    http.begin(serverName);
    http.addHeader("Content-Type", "application/x-www-form-urlencoded");

    int httpResponseCode = http.POST(postData);

    if (httpResponseCode > 0) {
      String payload = http.getString();
      Serial.print("HTTP Response code: ");
      Serial.println(httpResponseCode);
      Serial.print("Payload: ");
      Serial.println(payload);
    } else {
      Serial.print("Error on sending POST: ");
      Serial.println(httpResponseCode);
    }

    http.end();  // Close the connection

    // Now send data to ThingSpeak
    String thingSpeakData = "api_key=" + String(thingSpeakAPIKey) + "&field1=" + String(fillLevel);

    http.begin(thingSpeakServer);  // Initialize the HTTP connection to ThingSpeak
    http.addHeader("Content-Type", "application/x-www-form-urlencoded");

    int thingSpeakResponseCode = http.POST(thingSpeakData);

    if (thingSpeakResponseCode > 0) {
      String thingSpeakPayload = http.getString();
      Serial.print("ThingSpeak HTTP Response code: ");
      Serial.println(thingSpeakResponseCode);
      Serial.print("ThingSpeak Payload: ");
      Serial.println(thingSpeakPayload);
    } else {
      Serial.print("Error on sending data to ThingSpeak: ");
      Serial.println(thingSpeakResponseCode);
    }

    http.end();  // Close the connection to ThingSpeak
  } else {
    Serial.println("WiFi Disconnected");
  }

  delay(10000);  // Send data every 10 seconds
}
```

B.4: code for design web application

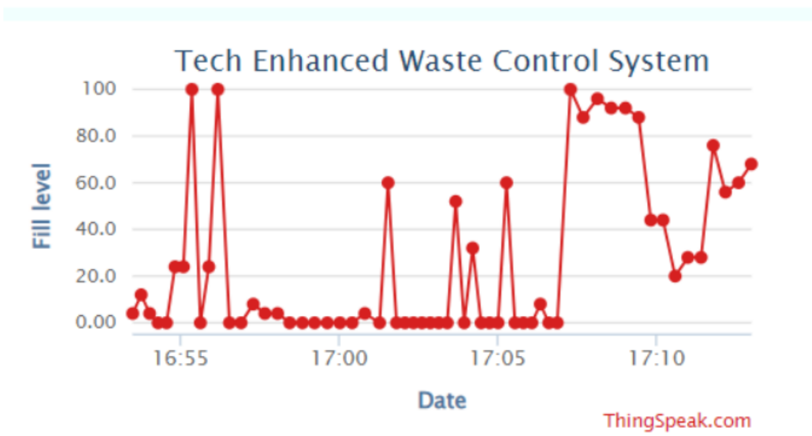
```html
<!DOCTYPE html>
<html lang="en">
<head>
    <meta charset="UTF-8">
    <meta name="viewport" content="width=device-width, initial-scale=1.0">
    <title>Waste Monitoring System</title>
    <link rel="stylesheet" href="style.css"> <!-- Link to your CSS file -->
    <style>
        #map {
            height: 400px;
            width: 100%;
        }
        #binDataContainer {
            margin-top: 20px;
        }
        #loading {
            font-style: italic;
            color: grey;
        }
        #status {
            color: red;
            font-weight: bold;
        }
    </style>
    <!-- Include the Google Maps API -->
    <script src="https://maps.googleapis.com/maps/api/js?key=AIzaSyAk-wxeWg9J8xjKZWJIdXE4D9I6s8hpBkY"></script>
</head>
<body>
    <h1>Waste Bin Fill Level Monitoring</h1>

 <div id="binDataContainer">
     <h2>Bin Data:</h2>
     <p>Fill Level: <span id="fillLevel">Loading...</span>%</p>
     <p>Latitude: <span id="latitude">Loading...</span></p>
     <p>Longitude: <span id="longitude">Loading...</span></p>
     <p>Last Updated: <span id="timestamp">Loading...</span></p>
     <p id="loading">Fetching data...</p>
     <p id="status"></p> <!-- For error messages -->
 </div>

 <div id="map"></div>

 <script>
     var map;
     var marker;

     // Initialize Google Maps with default location or provided coordinates
     function initMap(latitude = 0, longitude = 0) {
         var options = {
             zoom: 14,
             center: { lat: latitude, lng: longitude }
         };
         map = new google.maps.Map(document.getElementById('map'), options);
         marker = new google.maps.Marker({
             position: { lat: latitude, lng: longitude },
             map: map
         });
     }
    // Fetch bin data from the server and update map with location and fill level
    function fetchBinData() {
        var xhr = new XMLHttpRequest();
        xhr.open('GET', 'get.php', true);
        xhr.onload = function () {
            if (xhr.status == 200) {
                try {
                    var response = JSON.parse(xhr.responseText);

                    if (response.status === 'success') {
                        var latestData = response.data;

                        document.getElementById('fillLevel').textContent = latestData.fill_level;
                        document.getElementById('timestamp').textContent = latestData.timestamp;
                        document.getElementById('latitude').textContent = latestData.latitude;
                        document.getElementById('longitude').textContent = latestData.longitude;

                        // Update map with bin's location
                        updateMap(parseFloat(latestData.latitude), parseFloat(latestData.longitude));

                        document.getElementById('loading').style.display = 'none';
                        document.getElementById('status').textContent = '';
                    } else {
                        console.error('Error:', response.message);
                        document.getElementById('status').textContent = 'Error: ' + response.message;
                        document.getElementById('loading').style.display = 'none';
                    }
                } catch (e) {
                    console.error('Invalid JSON response');
                    document.getElementById('status').textContent = 'Invalid response from server.';
                    document.getElementById('loading').style.display = 'none';
                }
            } else {
                console.error('Error fetching data:', xhr.status);
                document.getElementById('status').textContent = 'Error fetching data. Status Code: ' + xhr.status;
                document.getElementById('loading').style.display = 'none';
            }
        };
        xhr.onerror = function () {
            console.error('Request failed');
            document.getElementById('status').textContent = 'Request failed.';
            document.getElementById('loading').style.display = 'none';
        };

        document.getElementById('loading').style.display = 'block';
        xhr.send();
    }

    // Update the map with the bin's location
    function updateMap(latitude, longitude) {
        if (map && marker) {
            var newLatLng = new google.maps.LatLng(latitude, longitude);
            marker.setPosition(newLatLng);
            map.setCenter(newLatLng);
        } else {
            initMap(latitude, longitude);
        }
    }

    window.onload = function() {
        fetchBinData(); // Fetch bin data from the server and update location
    };

      // Fetch bin data every 10 seconds
      setInterval(fetchBinData, 10000);
   </script>
</body>
</html>
```

Appendix C: Software development

C.1: Web application

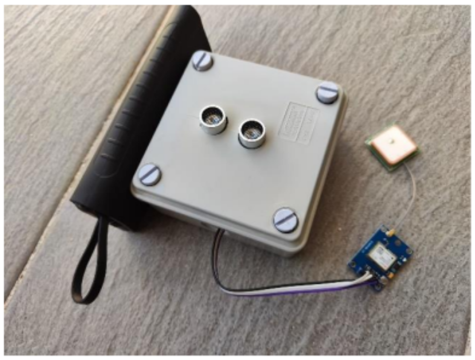


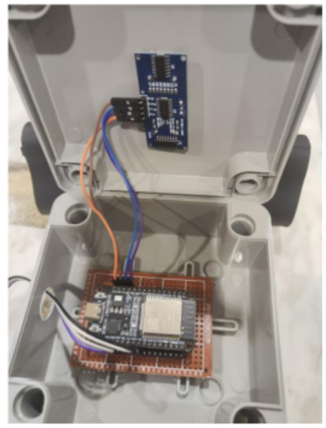
C.2: Collected Data



Appendix D: Photograph and Visuals

D.1: Project Images

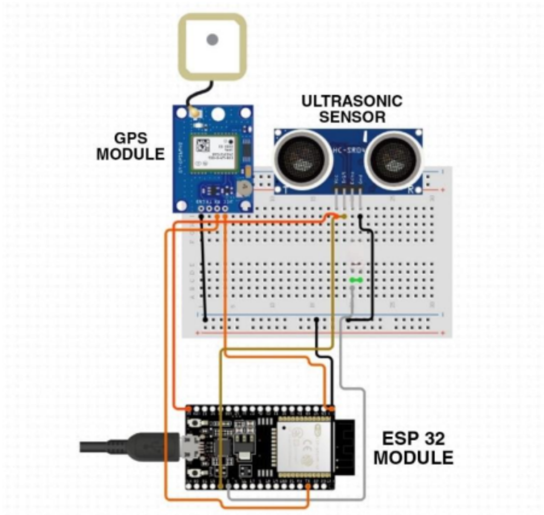




Appendix E: Circuit Diagram

E.1: Tech Enhanced Waste Control System Circuit Diagram

- A complete wiring diagram of the Tech Enhanced Waste Control System. Components include the ESP32, Ultrasonic Sensor and GPS Module.



Final Report Project 2

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