Smart Garbage Collection System with Route Assistance

RMPMD Rathnayake

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R.M.P.M.D. Rathanayake
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	Supervisor 1	Supervisor 2	Supervisor 3
Name	Prof. KP Hewagamge		
Signature	K. P. Hewagamage		
Date	30/09/2024		

Abstract

The advent of new IoT technologies has highlighted the necessity for intelligent waste management bins. These bins provide remote monitoring of container status, promoting a cleaner environment and enhancing the garbage collection process. For waste collection staff, understanding the appropriate collection sites and schedules is essential to save superfluous trips. Nonetheless, the production of numerous physical smart bins for experimental purposes is costly and difficult, particularly for research teams. This project introduces a smart bin simulator system to tackle this difficulty. This simulator produces data regarding waste fill levels, allocates bins to designated places, and replicates their functionality. It incorporates a scheduling functionality for waste pickup, accounting for intervals of inactivity to replicate real-world situations. Data visualization and recording are facilitated by Node-RED for the municipal council's central dashboard. A mobile application created with Android Studio offers drivers, collectors, and residential customers access to route details, collection timetables, and monthly data. This comprehensive strategy seeks to enhance the efficiency of waste management and the quality of life.

Acknowledgement

I wish to express my gratitude to the several individuals that contributed to the realization of this project. First and foremost, I would like to express my gratitude to my supervisor, Prof. KP Hewagamge, for his substantial assistance, professionalism, and invaluable direction during this research, as well as to the Municipal Council of Dehiwala for their support. I extend my gratitude to my friend Charaka Dushyantha for his assistance with numerous facets of creating this system. I wish to convey my deep appreciation to my husband, Amila Thilakarathna, and my family for their unwavering support and constant encouragement during my academic journey. This achievement would not have been feasible without their support.

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Chapter 01: Introduction

1.1 Project Overview

Garbage is a growing problem in urban areas of Sri Lanka, and this problem is aggravated due to the absence of proper waste management systems in the country. Presently, mixed waste is often collected and disposed of in ecologically sensitive regions, including roadsides, marshlands, low-lying areas, public spaces, forests, wildlife habitats, and waterways, leading to numerous adverse environmental consequences such as groundwater and surface water contamination, as well as air pollution. The Garbage collection in urban areas in Sri Lanka is conducted through the municipal council, and this process contains many issues.

As in normal practice, Garbage Collectors run their process two days per week to collect food waste and other waste separately. But they do not follow a proper schedule or procedure to maintain the whole process, which is causing many issues for people as their arrival is unpredictable. At present, no comprehensive technical guidelines are available in Sri Lanka addressing all important elements of waste management systems. Therefore, this project intends to attempt to fill this gap by initiating or operating a proper solid waste management activity that will minimize the time spent collecting Garbage, provide notification to people when the collection day is stated, as well as give an optimal Route for Garbage Collection.

1.2 Motivation

Since waste management is an essential part of every community's hygiene and sustainability efforts. The motivation behind this project stems from the pressing need for improving waste management practices. Traditional Garbage Collection methods often result in inefficient resource allocation, increased fuel consumption, and environmental pollution. A significant challenge for waste management companies is to collect Garbage efficiently timely, which requires a lot of resources and planning. To address this challenge, this project proposes an IoT-based Garbage Collection control system that includes sensors to identify filling status, spoilage status, and bin tracking to provide optimal route assistance for Garbage Collectors. The main feature of this Smart Bin is that once the Garbage bin is full, it would send a notification to the respective authority to clear the bin. And they will follow by the optimal route to complete the process. This feature prevents overflow of Garbage creating fussy and unclean atmosphere around the bin and avoids time consumption. A cleanly and social Dust Bin would help make Garbage management better than what it is today.

1.3 Objectives

The objectives of this project are as follows:

- To develop a hardware device that will be installed in Garbage bins to monitor their fill level, which is overflow status, spoilage status considering organic bins, and bin location in real time.
- To develop a software platform that will receive and process the data from the hardware devices.
- To integrate the hardware devices and software platform to create a complete IoT-based Garbage Collection System.

- To implement a route assistance that generates the most optimal collection route based on real-time data and factors such as filled level and spoiled trucks or cans.
- To integrate a user-friendly mobile application that provides Garbage Collectors with optimal routes, real-time updates, and other relevant information.
- Evaluate the system's performance through simulations and real-world testing, measuring its impact on efficiency, cost savings, and environmental sustainability.

1.4 Background of the Study

The background study highlights the significance of smart garbage collection systems with route assistance in addressing the inefficiencies of traditional waste management methods. By leveraging technology and data analytics, these systems optimize waste collection routes, reduce costs, and improve overall efficiency. While challenges exist, the benefits of implementing these systems outweigh the associated complexities. Further research and implementation efforts are necessary to refine and expand the application of smart garbage collection systems to create cleaner and more sustainable urban environments.

Smart Garbage Collection System

Smart garbage collection systems leverage various technologies, including the Internet of Things (IoT), sensors, data analytics, and route optimization algorithms. These systems monitor the fill-level of garbage bins in real-time using sensors, enabling efficient waste collection. By collecting data on bin fill levels, traffic conditions, and other relevant factors, these systems can dynamically generate optimized routes for waste collection vehicles. This real-time optimization improves route efficiency, reduces fuel consumption, and minimizes environmental impact.

Benefits of Smart Garbage Collection Systems

Implementing a smart garbage collection system with route assistance offers several benefits:

1. Efficient Routing: By considering real-time data, such as fill-level sensors and traffic information, these systems generate optimized routes that minimize travel time and distance. This leads to improved operational efficiency and reduced costs.
2. Reduced Environmental Impact: Optimal routing minimizes fuel consumption and vehicle emissions, contributing to environmental sustainability.
3. Cost Savings: Smart garbage collection systems optimize routes, reducing fuel and labor costs associated with inefficient routes and unnecessary trips.
4. Improved Service Quality: With real-time data on bin fill levels, waste collection can be scheduled based on demand, ensuring timely pickups and reducing overflowing bins.
5. Enhanced Resource Allocation: By analyzing data on waste generation patterns, these systems enable better resource allocation, ensuring that collection resources are utilized efficiently.

1.5 Scope of the Study

The scope of this project includes the following:

Design and development of hardware devices: The project will involve the design and development of hardware devices (such as ultrasonic sensors, methane sensors etc) that will be installed in garbage bins to monitor their fill level (overflow or not), spoiled status, and bin locations. The hardware devices will be equipped with sensors and wireless communication modules to transmit the data to the software platform as well as a cloud-based platform that provides real-time data and analytics.

Development of software platform: The project will involve the development of a software platform that will receive and process the data from the hardware devices. The software platform will include data analytics tools to provide insights into the garbage collection process.

Integration of hardware and software: The project will involve the integration of the hardware devices and software platform to create a complete IoT-based garbage collection system. The system will be designed to provide real-time data on the fill level, spoiled status, and track locations of the garbage bins and optimize the garbage collection process by providing route assistance to facilitate garbage collectors.

Pilot deployment and evaluation: The project will involve the deployment of the IoT-based garbage collection system considering the bins situated on the university premises. The system will be evaluated in terms of efficiency, effectiveness, and user satisfaction. The evaluation will provide feedback that will be used to improve the system.

The IoT-based garbage collection system is an innovative solution that has the potential to revolutionize the garbage collection process. The successful implementation of the project is led to improved efficiency, effectiveness, and user satisfaction in the garbage collection process.

1.6 Structure of the Dissertation

The structure of the dissertation for the smart garbage collection system with route assistance project is organized as follows:

Introduction:

- Project overview
- Motivation for the project
- Objectives of the research
- Background study of the project
- Scope of the project is defined
- Overview of the dissertation structure

Background:

- Overview of smart garbage collection systems and their evolution
- Review of existing research and studies on route optimization algorithms for waste collection
- Examination of IoT technologies and their application in waste management
- Analysis of related studies on fill-level sensors, data analytics, and real-time data processing in waste collection systems
- Identification of gaps in current literature and areas for further exploration

Methodology:

- Description of the research approach and methodology adopted
- Explanation of the data collection methods, including sensor deployment and data acquisition
- Overview of the software and hardware tools utilized for the implementation of the system
- Outline of the route optimization algorithms employed and their rationale
- Explanation of any simulations or modeling techniques used for evaluation
- Ethical considerations and data privacy measures implemented

Design

- Detailed explanation of the methodology followed
- Detailed explanation of the architecture and components of the proposed system
- Description of the software development process, including database design, data integration, and algorithm implementation
- Overview of the hardware setup, including sensor deployment, communication infrastructure, and vehicle tracking systems
- Presentation of the user interface design for waste collection vehicle operators and administrative personnel
- Discussion of any challenges or issues encountered during the system design and implementation phase

Testing and Evaluation:

- Explanation of the evaluation methodology employed to assess the system's performance
- Presentation and analysis of collected data, including fill-level sensor readings, route optimization results, and operational metrics
- Comparison of the system's performance against predefined benchmarks and existing approaches
- Discussion of the findings in relation to the research objectives and research questions
- Critical examination of the limitations and constraints encountered during the evaluation process

Discussion:

- Interpretation and interpretation of the results in the context of the research objectives
- Examination of the system's effectiveness in optimizing waste collection routes and improving operational efficiency
- Analysis of the impact of the smart garbage collection system on cost reduction, resource allocation, and environmental sustainability
- Consideration of any potential implications, limitations, or constraints in the real-world implementation of the system

- Reflection on the research questions and how they have been addressed through the study

Conclusion:

- Recapitulation of the research objectives and main findings
- Summary of the contributions made by the study to the field of smart garbage collection systems
- Discussion of the practical implications and potential for future research and development
- Final thoughts and recommendations for stakeholders, policymakers, and waste management authorities

Chapter 02: Background

2.1 Introduction

Due to lack of space, the majority live in urban areas displace Garbage through the municipal council. Also, public places such as railway stations, bus stops etc. are equipped with garbage bins so that people can use them wherever they are. The management of waste in urban environments has become a critical issue due to increasing population density and waste generation (D, et al., 2019). Sri Lanka is still using the traditional garbage collection process that often face challenges such as inefficient routing, delayed pickups, and increased costs, etc. Since the technology has been developed now, the concept of a smart garbage collection system with route assistance has emerged as a promising solution to address these issues. This system utilizes technology and data analytics to optimize waste collection processes, reduce operational costs, and improve overall efficiency.

To develop an effective and efficient garbage collection system, it is important to understand the current waste management practices and challenges faced by the municipal council. The background study will include an analysis of the existing literature on waste management and IoT-based systems for garbage collection. The study will also include a survey of the municipal council to understand their current practices and challenges in garbage collection.

2.1.1 The Current Garbage Collection Process

This section aims to provide an understanding of the garbage collection process in urban areas Waste collection is the act of picking up wastes at homes, businesses, institutions, commercial and industrial plants and other locations, loading them into a collection vehicle and hauling them to a facility for further processing or transfer to a disposal site. Collection of waste is the one of the basic elements of any waste management system. of Sri Lanka, highlighting its significance in addressing waste management challenges.

The garbage collection process in urban areas of Sri Lanka is a multifaceted system that involves several key steps as follows:

Collection Points: Municipalities and local authorities establish designated collection points or bins strategically placed throughout urban areas. These collection points serve as convenient disposal locations for the public. The residents' waste is collected from their home premises.

Scheduled Collection: Garbage collection is carried out according to predetermined schedules set by local authorities. Normally collectors come for collection of residential waste twice a week to collect recyclable and non-recyclable waste separately. But, the frequency of collection varies based on factors such as area size and population density.

Collection Vehicles: Specialized garbage trucks equipped with large bins or compactors are used for waste collection. These vehicles are designed to facilitate efficient collection and transportation of garbage.

Collection Process: Garbage collectors follow pre-planned routes, stopping at designated collection points and private residences to collect waste. Since there is no mechanism for collection, when collecting residential waste, normal practice is someone notify people about their arrival (shout louder) so people can keep their waste outside. Garbage collectors unload the garbage from bins or containers into the collection vehicle, ensuring proper segregation of recyclable and non-recyclable waste, if applicable.

Transportation: Once the garbage truck is filled, the waste is transported to a transfer station or landfill. Transfer stations serve as intermediate points where waste from multiple collection vehicles is consolidated before further processing.

Collection of unseparated (commingled) and separated solid waste in an urban area is difficult and complex because the generation of wastes takes place in every house, every apartment building and commercial and individual facility as well as in the streets, parks, and even vacant areas. Therefore, in any waste collection operation it is important to look into; types of waste collection services/systems, type of equipment to be used and associated labour requirements, collection routes etc.

2.1.3 Target Waste

The following municipal waste are considered for the implementation of this project.

- Domestic waste (exclusive of sewage and hazardous waste)
- Commercial waste (Market waste)
- Institutional wastes (schools, hospitals (non-clinical), public offices, etc.)
- Street sweeping and beach cleansing waste
- Wastes collected from drains and water courses in urban areas

Waste collection is the act of picking up wastes at homes, businesses, institutions, commercial and industrial plants and other locations; loading them into a collection vehicle and hauling them to a facility for further processing or transfer to a disposal site. Collection of wastes is the one of the basic elements of any waste management system.

2.2 Requirement Analysis

Identifying the specific requirements for the system is the most difficult process in the system development life cycle. The requirement collection and analysis are a continuous process that requires domain understanding, with constant input from one action toward to the next.

Generally, the waste collection areas and transport routes, the number and type of the collection vehicles to be used, frequency of waste collection and the schedule for collection and transport are concerned for the implementation. The garbage collection process should ensure regular and timely collection to prevent waste accumulation, which can lead to environmental hazards and health risks. Collection schedules should be well-planned and adhered to, taking into account the population density and waste generation rates of specific areas.

2.2.1 Smart Garbage Bins

Bin Placement: Identify high-traffic and densely populated areas in urban regions of Sri Lanka for the installation of smart garbage bins. Consider factors such as marketplaces, commercial areas, residential neighborhoods, and public spaces where waste generation is high.

Bin Capacity and Sensing Technology: Determine the optimal size and capacity of the smart bins based on the average waste generation rates in regions. Integrate sensors and IoT technology into the bins to monitor fill levels accurately, spoiled condition to ensure a healthy environment and enable efficient waste collection.

Real-time Monitoring and Alerts: Implement a system that continuously monitors the fill levels of smart bins and sends real-time alerts to waste management personnel when bins are nearing capacity. This ensures timely collection and prevents overflow, particularly in areas with irregular collection schedules.

Data Collection and Analytics: Collect data on waste generation patterns, fill levels, spoiled condition and collection frequencies from smart bins. Analyze this data to optimize waste collection routes, identify areas with high waste generation, and evaluate the effectiveness of waste management strategies in different regions.

2.2.2 Route Assistance

Route Optimization: Develop a route planning system that optimizes waste collection routes based on real-time data from smart bins, traffic conditions, and the geographical layout of Sri Lanka's urban areas. Minimize travel distances and time to ensure efficient waste collection and reduce carbon emissions from collection vehicles.

Geographic Information System (GIS): Utilize GIS technology to provide visual mapping of optimized waste collection routes, smart bin locations, and real-time data in Sri Lanka. Enable route adjustments and re-routing to account for factors such as road closures, traffic congestion, or special events.

Navigation and Tracking: Provide waste collection personnel in Sri Lanka with navigation tools, such as GPS devices or mobile applications, to assist in following optimized routes and tracking collection progress. Enable real-time communication between collection teams and the waste management center for coordination and support.

Data Integration and Analysis: Integrate data from smart bins, route planning systems, and collection activities in Sri Lanka. Analyze and evaluate the performance of the waste collection process, including route efficiency, collection frequency, and resource utilization. Use this data to make data-driven decisions for route optimization and resource allocation.

2.2.3 Stakeholder Requirements

Waste Management Personnel: Train waste management personnel in Sri Lanka to effectively use smart bin technology, route assistance tools, and data analysis systems. Provide user-friendly interfaces and clear instructions for navigating optimized routes, collecting waste, and utilizing the technology effectively.

Municipal Authorities: Collaborate with municipal authorities in Sri Lanka to establish guidelines and policies for the implementation of smart garbage bins and route assistance systems. Ensure that the necessary infrastructure, resources, and funding are available to support the implementation and maintenance of the technology.

Residents: Educate residents about the benefits of smart garbage bins, waste segregation practices, and the impact of optimized route planning on efficient waste collection. Provide easily accessible information about waste collection schedules, any changes or disruptions to the regular routine, and avenues for reporting issues or requesting additional services.

2.2.4 Infrastructure and Resources

Smart Bin Infrastructure: Install durable and weather-resistant smart garbage bins in Sri Lanka, equipped with reliable connectivity, sensors, and power sources. Ensure the bins are designed to prevent unauthorized access, tampering, or damage from harsh weather conditions.

Communication Network: Establish a reliable and secure network infrastructure in Sri Lanka to support data transmission between smart bins, route assistance systems, and waste management centers. Ensure uninterrupted connectivity to monitor and manage the smart bin network effectively.

Hardware and Software: Acquire and maintain the necessary hardware, such as sensors, IoT devices, and GPS navigation tools, for the smart bin and route assistance systems in Sri Lanka. Develop or acquire user-friendly software applications or platforms for data analysis, route planning, and real-time monitoring of smart bins and collection activities.

2.2.5 Monitoring and Evaluation

Performance Metrics: Define key performance indicators (KPIs) specific to Sri Lanka to evaluate the effectiveness of smart garbage bins and route assistance systems. Measure metrics such as collection efficiency, route optimization percentage, reduction in collection time and travel distance, and cost savings.

Data Collection and Analysis: Establish a data collection mechanism in Sri Lanka to gather information on smart bin fill levels, collection routes, and operational metrics. Analyze this data to identify trends, patterns, and areas for improvement in the waste collection process.

Regular Assessment and Feedback: Conduct periodic evaluations and seek feedback from waste management personnel, residents, and municipal authorities in Sri Lanka to assess the functionality, usability, and impact of the smart bin and route assistance systems. Incorporate the feedback to refine and enhance the technology and processes.

2.3 Review of Similar Systems

The integration of Internet of Things (IoT) technologies in waste management has gained significant traction in recent years, with researchers exploring various approaches to optimize collection processes and improve urban cleanliness. This literature review examines recent advancements in IoT-based waste management systems, focusing on smart bin technologies, waste detection methods, route optimization strategies, and data analytics in the context of smart cities.

2.3.1 Smart Bin Technologies

Smart bins equipped with sensors form the foundation of IoT-based waste management systems. Pardini et al. (2020) proposed a smart waste bin prototype using ultrasonic sensors to measure fill levels and a load cell to estimate waste weight. Their system demonstrated improved efficiency in waste collection schedules. Similarly, Castro et al. (2021) developed a low-cost smart waste management system using ultrasonic sensors and LoRaWAN technology, enabling real-time monitoring of bin fill levels across a wide area. Fang et al. (2023) highlights the potential of smart garbage bins for increased efficiency, disease reduction, and environmental improvement. However, high implementation costs and environmental factors pose challenges for widespread promotion.

While these studies focus primarily on fill level detection, there is a growing recognition of the need for more comprehensive sensing capabilities. Memon et al. (2019) highlighted the potential of incorporating multiple sensors, including gas sensors, to detect various parameters such as bin tilt, temperature, and harmful gas emissions. This multi-sensor approach aligns with our research's dual-sensing strategy, which incorporates both fill level and spoilage detection.

2.3.2 Waste Detection and Classification

Advanced waste detection methods have been explored to enhance the capabilities of smart waste management systems. Wireless sensor networks have developed quickly, according to Fang et al. (2023). Many studies have examined the use of sensors in trash monitoring, mostly by monitoring the amount of rubbish and then using the network to warn users. Numerous research have documented the application of various machine learning-based techniques to waste management in order to forecast and optimize the generation, detection, collection, classification, and characteristics of municipal solid trash.

Md. Wahidur Rahman proposed a deep learning-based waste classification system using convolutional neural networks (CNNs) to categorize waste into recyclable and non-recyclable materials. This approach demonstrates the potential for automating waste sorting processes, which could be integrated into future iterations of smart bin systems.

The literature does, however, appear to be lacking in information about how to identify waste spoiling in public trash cans. While some research, like that done by Ferrer et al. (2018), has looked into the use of gas sensors in composting systems, there is still much to learn about how these technologies might be used to the management of urban trash. In order to close this gap, our research incorporates methane sensors for spoilage detection. This could lead to new opportunities for prompt waste collection and management, as spoiled environments attract crows, muggets, and other pests that spread disease and odors throughout the surrounding area. Therefore, identifying ruined state early on rather than waiting for the bin to be completely filled ensures that people always live in a healthy atmosphere.

2.3.3 Route Optimization and Collection Efficiency

Optimizing waste collection routes is crucial to improve the efficiency of waste management systems. Ercin et al. (2021) have conducted research and proposed an IoT-based system for route optimization in waste collection systems, utilizing machine learning applications and the Capacitated Vehicle Routing Problem algorithm to control occupancy, minimize fuel consumption, and support sustainability. Our SUTT (Smart Urban Trash Tracker) mobile app builds upon similar concepts, providing collectors with optimized routes that consider both bin status and traffic conditions.

2.3.4 Integrating IoT and Data Analytics

The integration of IoT data with advanced analytics has opened new possibilities for waste management. The study conducted by Ravi el at. (2022) proposes an IoT-based system for managing solid waste in smart cities, allowing monitoring, changeover time, and garbage collection truck routing. The system uses embedded devices to disperse trash cans, and a mobile app for drivers and municipalities to manage collection efficiently. This approach demonstrates the potential of data-driven decision-making in waste management, which is a key feature of the proposed system.

Fatimah et al. (2020) explored the potential of Industry 4.0, including IoT and big data analytics, to create sustainable circular economy approaches for waste management. This research highlights the importance of comprehensive data analysis in achieving development goals, aligning with our system's capability to provide long-term waste generation trends and insights.

2.3.5 Smart Cities and Waste Management

The role of smart waste management in the broader context of smart cities has been extensively discussed in recent literature. Esmaeilian et al. (2018) provided a comprehensive review of future waste management systems in smart and sustainable cities, emphasizing the need for integrated, technology-driven approaches [10]. Their work underscores the importance of our research for contributing to the overall smart city ecosystem.

Bibri and Krogstie (2017) conducted an extensive interdisciplinary literature review on smart sustainable cities, highlighting the crucial role of data-driven solutions in urban management [11]. Our research aligns with their findings by providing a data-centric approach to waste management that can inform broader urban planning and sustainability initiatives.

Overall, there are several IoT-based systems for garbage collection that have been developed and implemented around the world, each with its own unique features and capabilities. The proposed system includes IoT-based smart waste management platform. The platform includes sensors that can be installed in waste bins, as well as a cloud-based platform that provides real-time data and analytics. The system also includes route optimization algorithms that help municipal council to optimize their collection routes.

2.4 Related Technologies

This section explore the related technologies that can be utilized for the implementation of smart garbage bins and route assistance systems in urban areas. These technologies aim to optimize waste collection processes, improve efficiency, and promote sustainable waste management practices.

The report provides an overview of the key technologies, their functionalities, and their applicability in the context of the project.

2.4.1 Internet of Things (IoT) Technology

Definition and Functionality: IoT technology enables the interconnection and communication between physical devices, allowing them to exchange data and perform intelligent actions. In the context of smart garbage bins, IoT sensors can be integrated to monitor fill levels, detect bin status, and provide real-time data for effective waste management.

Applicability: IoT technology is essential for monitoring and managing smart garbage bins. It enables the collection of data on fill levels, bin locations, and operational parameters, facilitating optimized collection routes, timely waste collection, and efficient resource allocation.

2.4.2 Sensor Technology

Definition and Functionality: Sensor technology enables the collection of various data points such as fill levels, temperature, humidity, and weight. For smart garbage bins, sensors can be used to detect fill levels, bin openings, or bin status changes.

Applicability: Sensors play a crucial role in smart garbage bins by providing accurate and real-time data on the fill levels of bins. This information is vital for optimizing collection routes, preventing overflow, and ensuring timely waste collection.

2.4.3 Geographic Information System (GIS) Technology

Definition and Functionality: GIS technology captures, analyzes, and presents geospatial data on maps. It enables visualization, analysis, and manipulation of geographic information for route planning, spatial analysis, and decision-making.

Applicability: GIS technology is essential for optimizing waste collection routes. It helps in visualizing bin locations, traffic patterns, and other spatial factors to design efficient and optimized collection routes. GIS technology also allows for dynamic route adjustments based on real-time data and traffic conditions.

2.4.4 Route Optimization and Navigation Systems

Definition and Functionality: Route optimization systems utilize algorithms to determine the most efficient collection routes based on various factors such as bin fill levels, traffic conditions, and distance. Navigation systems provide real-time guidance and directions to waste collection personnel.

Applicability: Route optimization and navigation systems are crucial for improving the efficiency of waste collection. By identifying the shortest and most optimal routes, these technologies reduce travel time, fuel consumption, and vehicle emissions. They also enable waste collection personnel to navigate routes accurately and efficiently.

2.4.5 Communication and Data Management Systems

Definition and Functionality: Communication systems enable real-time data transmission between smart garbage bins, waste management centers, and collection personnel. Data management systems store, process, and analyze the collected data for route optimization, performance evaluation, and decision-making.

Applicability: Effective communication and data management systems ensure seamless connectivity between smart bins, waste management personnel, and route optimization systems. They facilitate real-time monitoring of bin fill levels, timely alerts, and data analysis to optimize waste collection processes.

Several key technologies contribute to the successful implementation of smart garbage bins and route assistance systems in urban areas. IoT technology, sensor technology, GIS technology, route optimization and navigation systems, and communication and data management systems are essential components for optimizing waste collection processes, improving efficiency, and promoting sustainable waste management practices. These technologies enable real-time monitoring of bin fill levels, route optimization, accurate navigation, and effective data management for informed decision-making in waste collection operations. By integrating these technologies, the project can achieve its objectives of efficient waste collection, reduced environmental impact, and improved overall waste management practices.

Chapter 03: Design Architecture

3.1 Introduction

The "Smart Garbage Bin with Route Assistance" project represents a groundbreaking endeavor designed to tackle the limitations inherent in conventional waste collection systems. These traditional methods have often led to inefficiencies, including overfilled bins, suboptimal collection routes, and unnecessary environmental impacts. In response, this project emerges as a visionary response to transform waste management practices into a smarter, more sustainable, and efficient paradigm.

This chapter serves as a comprehensive guide to the intricate design architecture that underpins this visionary project. It delves into the intricate network of components that comprise the system, ranging from the smart bins themselves to the central server and user interfaces. It elucidates the communication flow that facilitates the seamless exchange of data, transforming sensor measurements into actionable insights. Moreover, it offers insights into the user interaction, unveiling a user-centric approach that empowers individuals to actively engage with waste management processes.

3.2 Related Design Strategies

At its core, this initiative is a manifestation of innovative thinking, fueled by the integration of cutting-edge technologies. Foremost among these technologies is the Internet of Things (IoT), a revolutionary concept that involves the interconnection of everyday objects through the digital realm. In the context of this project, IoT empowers mundane garbage bins to become intelligent agents capable of real-time communication and data sharing. By seamlessly integrating IoT into the waste collection process, the project transcends the confines of traditional methods, ushering in an era of data-driven decision-making and responsiveness.

Another hallmark of this initiative is the utilization of real-time data processing. Unlike the static, pre-scheduled approaches of the past, this project embraces the power of instantaneous data interpretation. As smart bins monitor their fill levels in real time, the data they generate serves as a foundation for dynamic decision-making. This real-time insight enables the system to respond to fluctuations in garbage levels, optimizing collection routes on the fly. By embracing real-time data processing, the project maximizes resource allocation, minimizes waste overflow, and enhances the overall effectiveness of the waste collection process.

The design of the "Smart Garbage Bin with Route Assistance" system draws inspiration from a constellation of forward-thinking strategies, each aimed at maximizing efficiency, reducing waste, and optimizing resource allocation:

3.2.1 Internet of Things (IoT) Integration

The integration of IoT technologies is pivotal to the project's success. By interconnecting physical devices such as smart bins, microcontrollers, and the central server, the system transcends traditional waste management paradigms. IoT empowers the smart bins to become intelligent endpoints, capable of sensing and communicating their fill levels in real time. This real-time data influx fuels informed decision-making and dynamic route optimization, a paradigm shift from conventional scheduled collection routines.

3.2.2 Real-time Data Processing and Analysis

The project leverages real-time data processing to swiftly interpret the incoming sensor data from the smart bins. This nimble data processing capacity enables the system to offer up-to-the-minute information about bin fill levels. This real-time insight facilitates the identification of rapidly filling bins, allowing for immediate adjustments to collection routes and resource allocation. By processing data on the fly, the system minimizes waste overflow and optimizes collection logistics.

3.2.3 Smart Sensors for Accurate Data Collection

The smart garbage bins are equipped with a suite of advanced sensors, including ultrasonic and infrared technologies. These sensors provide accurate and reliable measurements of the garbage fill levels, contributing to the system's efficiency. Ultrasonic sensors emit sound waves to measure the distance between the sensor and the trash, while infrared sensors detect the presence of objects. This multi-sensor approach ensures accurate fill level measurements, minimizing false readings and enhancing the system's reliability.

3.2.4 Route Optimization Algorithms for Efficiency

Central to the system's design is the integration of sophisticated route optimization algorithms. These algorithms analyze a myriad of variables, including bin fill levels, historical collection patterns, real-time traffic data, and geographical considerations. The result is a calculated, optimal route that minimizes travel time, reduces fuel consumption, and decreases the system's overall environmental footprint. By intelligently adapting to ever-changing conditions, the system maximizes efficiency and minimizes operational costs.

3.2.5 User-centric Design and Engagement

The user interface, whether through a mobile app or web portal, embodies a user-centric design philosophy. It empowers users to actively engage with the waste management process. Through the interface, users can monitor the status of nearby smart bins, request timely collections, and receive suggestions for optimal disposal routes. By fostering user engagement and participation, the system aligns with broader sustainability initiatives and encourages responsible waste disposal behaviors.

3.2.6 Environmental Considerations and Sustainability

Beyond mere technological prowess, the design strategies emphasize environmental consciousness and sustainability. By optimizing collection routes, the system reduces vehicular emissions and traffic congestion, contributing to cleaner urban environments. The smart garbage bin system positions itself as a significant step toward smarter, greener waste management practices.

3.3 System Architecture

This section explore the related technologies that can be utilized for the implementation of smart garbage bins and route assistance systems in urban areas. These technologies aim to optimize waste collection processes, improve efficiency, and promote sustainable waste management practices. The report provides an overview of the key technologies, their functionalities, and their applicability in the context of the project.

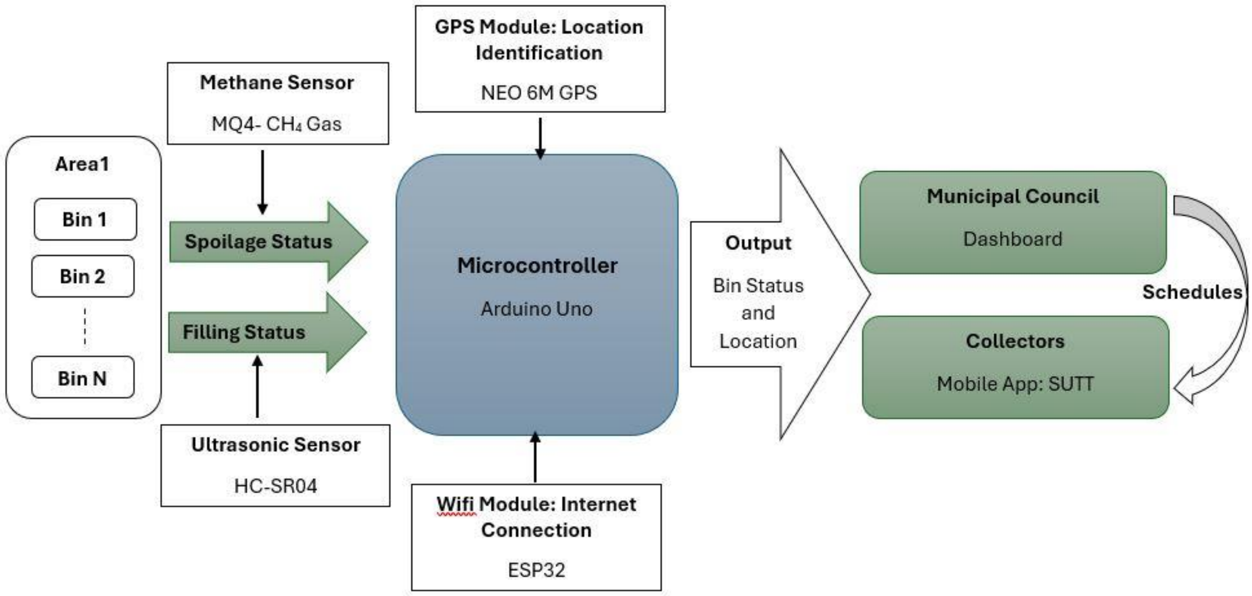


Figure 1:System Architecture

3.3.1 Agile Methodology

There are several process developments models that may be used to lead current software projects, including the Spiral model, Agile approach, Prototyping model, Iterative development model & Rapid Application Development. The Agile model is selected as it can be highly beneficial for a project like the "Smart Garbage Bin with Route Assistance" due to its iterative and collaborative nature. Agile methodologies, such as Scrum or Kanban, are particularly suitable for projects that involve evolving requirements, complex technologies, and a need for constant adaptation (Sharma, et al., 2012).

Iterative Development: Agile encourages breaking down the project into smaller, manageable units called iterations or sprints. Each iteration typically spans a few weeks and results in a potentially shippable product increment. This aligns well with the development of smart garbage bin system, allowing you to focus on specific functionalities, components, or user stories in each iteration. For instance, could have sprints focused on sensor integration, communication modules, user interface design, route optimization, and more.

Adaptive Planning: Given the evolving nature of technology and project requirements, Agile provides a flexible planning approach. The plan and prioritize tasks for each sprint based on the most current information and adjust plan as needed. This is valuable in a project where factors like sensor technologies, communication protocols, or optimization algorithms may require refinement based on real-world testing and feedback.

Continuous Feedback and Improvement: Agile methodologies emphasize regular feedback loops. During each sprint, can gather feedback from stakeholders, users, and team members to ensure that the project is on the right track and that adjustments can be made promptly. This is particularly useful for this project, where user engagement and satisfaction play a critical role.

Collaboration and Cross-functional Teams: Agile promotes collaboration among cross-functional teams. In this project, this could involve software developers, hardware engineers, UX/UI designers, waste management experts, and more. Regular meetings, such as daily stand-ups and sprint reviews, ensure that team members from various disciplines stay aligned and informed.

Emphasis on User-Centric Design: Agile methodologies prioritize delivering value to users early and often. This aligns with the project's goal of providing a user interface that allows users to monitor bin status, request collections, and receive route suggestions. Agile's iterative approach ensures that user feedback is incorporated throughout the development process, resulting in a more user-friendly and effective system.

3.3.2 Modern View Controller Architecture (MVC)

The Model-View-Controller (MVC) architectural pattern is a design framework that divides an application into three interrelated components: Model, View, and Controller. This pattern can be utilized in this project to enhance the system's design, hence improving its maintainability and scalability.
This project can implement the MVC architecture as follows:

Model: The Model encapsulates the fundamental logic and data of your system. The Model in your project will encompass the business logic and data pertinent to the smart garbage bins, sensor information, route optimization, and more elements. It serves as the primary repository of the application's data.

- The Model will oversee communication with smart bins, analyze sensor data, and retain historical records of fill levels.
- It will also incorporate the route optimization algorithm that determines best collection routes based on multiple parameters.

View: The View is tasked with displaying data to users and capturing their interactions. The View in your project encompasses the user interfaces, including mobile applications, web portals, or other platforms.

- The user interface will exhibit real-time bin status, offer options for collection requests, and present route ideas to users.
- It will render the data processed by the Model, facilitating accessibility and comprehension for users.

Controller: The Controller serves as a mediator between the Model and the View. It handles user input from the View, interacts with the Model to obtain or modify data, and subsequently refreshes the View accordingly.

- In this project, the Controller will manage user interactions, including requesting a collection or picking a route recommendation.
- It will interact with the Model to obtain the current bin status, initiate route optimization, and refresh the View with the most recent data.

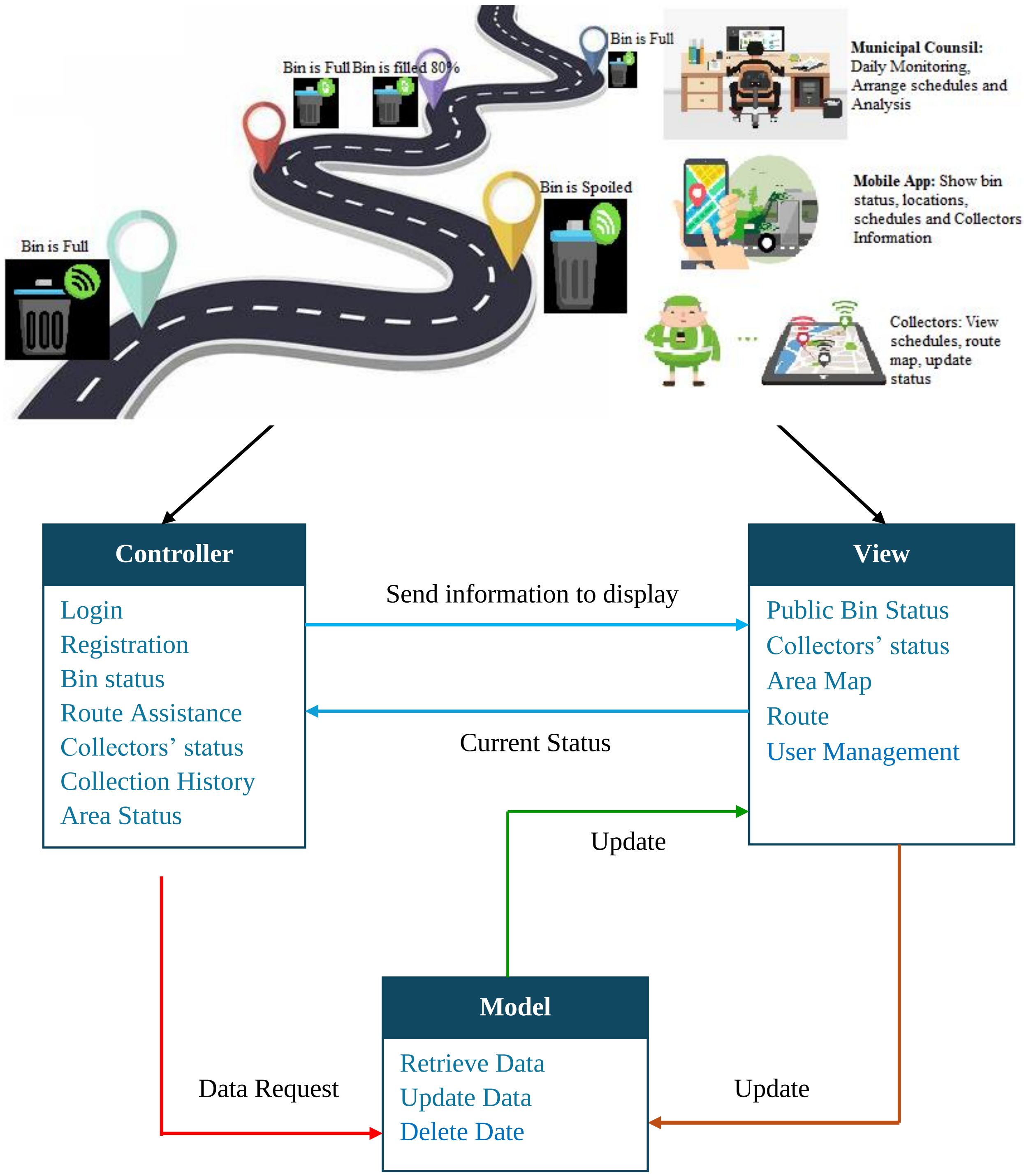


Figure 2: MVC Architecture Approach

3.3.3 Components Overview

Smart Bins: The cornerstone of the system, smart bins are equipped with ultrasonic and infrared sensors. These sensors accurately and continuously measure the fill levels and spoilage status of the bins. Through their sensing capabilities, the smart bins provide essential data that forms the foundation for dynamic waste management decisions.

Microcontrollers: Acting as the "brains" of the smart bins, microcontrollers process the data acquired from the sensors. They convert raw sensor measurements into usable information, which is then transmitted to the central server for further analysis.

Communication Modules: These modules enable seamless data transmission within the system. They facilitate the exchange of information between the smart bins, microcontrollers, and the central server, ensuring that data flows smoothly and without delay.

Central Server: Positioned as the heart of the system, the central server receives, processes, and manages data from multiple smart bins. It serves as the hub for route optimization, data analysis, and communication with both microcontrollers and user interfaces.

User Interface (App/Web): The user interface offers a tangible point of interaction for system users. Whether accessed through a mobile app or web portal, it allows users to monitor the status of individual smart bins, request collection services, and receive route suggestions based on real-time data.

Route Optimization Engine: At the core of the central server's functionality lies the route optimization engine. This engine processes incoming data from smart bins, traffic conditions, and historical patterns to calculate optimal collection routes. By considering various factors, including fill levels, traffic congestion, and environmental considerations, the engine generates routes that minimize both travel time and fuel consumption.

3.3.4 Communication Flow

In the communication flow of the system, the smart bins play a pivotal role by periodically transmitting crucial fill level data to the microcontrollers. Acting as intermediaries, the microcontrollers then facilitate the seamless relay of this data to the central server utilizing dedicated communication modules. This intricate transmission process ensures the accuracy and integrity of the incoming information. Within the central server, a core component known as the route optimization engine comes into play. This engine undertakes the complex task of processing the accumulated data. It meticulously analyzes factors like fill levels, historical patterns, real-time traffic conditions, and geographical considerations to meticulously calculate the most optimal collection routes. This sophisticated calculation process serves as a cornerstone for enhancing the efficiency of waste collection operations, thereby encapsulating the intricate communication and data processing flow of the system.

3.3.5 Data Collection

The process of sensors and data collection is a fundamental element of the system's functionality. Embedded within the smart bins, ultrasonic and infrared sensors assume a pivotal role by accurately measuring the fill levels of each bin and methane sensors can measure spoilage status of the bin in real time. These sensors provide the system with essential real-time data that drives decision-making processes. As this raw sensor data is collected, microcontrollers step in to preprocess it. This preprocessing stage ensures that the sensor data is both reliable and pertinent to the subsequent decision-making steps. The culmination of this data refinement occurs through communication modules, which facilitate the seamless transmission of the preprocessed sensor data from the microcontrollers to the central server. This intricate process guarantees that the central server is equipped with precise and relevant information, forming the foundation for further analysis and efficient waste management decisions.

3.3.6 Route Optimization Algorithm

The route optimization algorithm stands as a sophisticated and intelligent decision-making mechanism intricately woven into the fabric of the system. It operates by methodically considering a diverse array of variables, each playing a vital role in shaping waste collection strategies. These encompass the present fill levels of the bins, historical records detailing waste generation patterns, up-to-the-moment data on traffic conditions, and any environmental restrictions that may be at play. Meticulously processing this extensive range of inputs, the algorithm orchestrates its computational prowess to generate meticulously optimized collection routes. This intricate orchestration aims to curtail travel time and reduce fuel consumption, a dual impact that tangibly contributes to the overarching efficiency of the entire system.

3.3.7 User Interface

The user interface serves as an essential conduit, accessible via a dedicated app or web platform, facilitating user interaction with the system. Designed for user-friendliness, it acts as a gateway to the underlying functionalities. Within this interface, users gain the ability to monitor the real-time statuses of each smart bin, empowering them with immediate insights into their fill levels. Additionally, users can actively engage with the system by requesting timely waste collection services, streamlining the waste disposal process. Through the user interface, users receive route suggestions that are grounded in the most up-to-date data, ensuring optimal efficiency. The interface also plays a pivotal role in enhancing user engagement, as notifications and recommendations foster a sense of involvement and contribute to responsible waste disposal practices, aligning seamlessly with the project's objectives.

3.4 UML Diagrams

3.4.1 Use Case Diagram

The Use Case diagram captures the interactions and relationships between these actors and the system functionalities. It offers a comprehensive overview of how different entities engage with the smart garbage bin system to optimize waste collection processes, enhance sustainability, and promote responsible waste management practices.

Actors:

1. **Municipal Council**

The Municipal Council assumes a central role in the system as a key actor. They interact with the system to oversee its overall operation, ensure regulatory compliance, and manage the system's efficiency and sustainability.

- **View System Dashboard**: The Municipal Council can access the system's dashboard to gain an overview of all public and domestic bins' status, collection routes, and overall system performance.
- **Adjust System Parameters**: They have the authority to modify system parameters such as collection schedules, environmental constraints, and notification settings.
- **Monitor Environmental Impact**: The Municipal Council can analyze data on fuel consumption reduction and emission reduction achieved by the optimized collection routes, contributing to better waste management practices.

2. **Garbage Collectors**

Garbage Collectors are an essential actor, responsible for the physical waste collection process and interacting with the system to streamline their tasks.

- **Receive Collection Routes**: Garbage Collectors receive optimized collection routes from the system, which guide them to bins that require attention due to high fill levels.
- **Update Collection Status**: Once a collection is complete, the Garbage Collectors update the system, indicating that a specific bin has been serviced and its fill level adjusted.
- **Report Bin Issues**: If they encounter any issues with bins during collection (e.g., damaged bins), they can report these issues through the system for maintenance.

3. **Public Bins**

Public Bins are an integral part of the system, and they interact to provide real-time data on their fill levels, contributing to the efficiency of waste collection.

- **Send Fill Level Data**: Public Bins periodically send real-time fill level data to the system, allowing it to monitor and analyze the status of these bins.
- **Receive Collection Notifications**: Public Bins can receive notifications from the system indicating upcoming collection times, ensuring that bins are prepared for service.

4. **Domestic Bins**

Similar to Public Bins, Domestic Bins contribute to the system's effectiveness by providing real-time fill level data and receiving collection notifications.

- **Send Fill Level Data**: Domestic Bins transmit their current fill level data to the system at regular intervals, enabling timely collection planning.

- **Receive Collection Notifications**: Just like Public Bins, Domestic Bins also receive notifications to ensure that residents are aware of upcoming collection schedules.

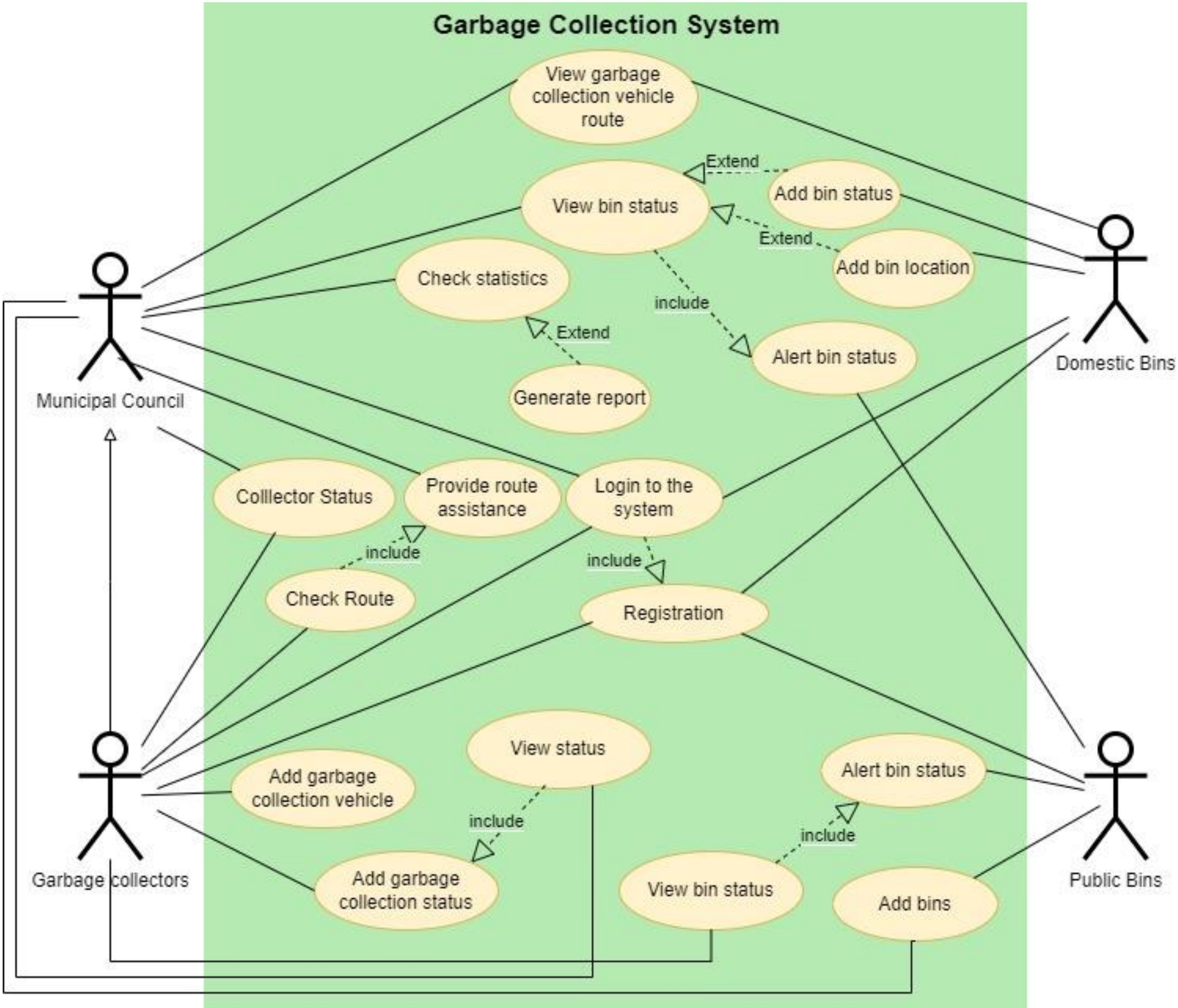


Figure 3: Use Case Diagram of the System

3.4.2 Use Case Narratives

Table 1: Use Case Narrative for view public bin status

Use Case	View public bin status
Description	Admin can view the filling levels and spoilage status of public bins when login to the system. Bin status are alerting automatically to the system.
Primary Actor	Municipal Council
Secondary Actor	None
Pre-Conditions	

1. Admin should login to the system. 2. The sensor model should work properly by sending data to the cloud.
Flow of Event
1. Login to the system as admin. 2. Select Area 3. View the bin status
Post Condition
Go to the dashboard

Table 2: Use Case Narrative for Register to the System

Use Case	Register to the system
Description	Bins need to register to the system for access the functions. Public bin registration is done by the council admin. People can add their smart domestic bins.
Primary Actor	Admin
Secondary Actor	Domestic bins
Pre-Conditions	
Flow of Event	
1. Need to provide initial details to register with the system. 2. Users must provide password and confirm password.	
Post Condition	
Fill the registration details.	

Table 3: Use Case Narrative for View Bin Locations

Use Case	View bin locations
Description	Admin can view the filling levels and spoilage status of bins in any location when login to the system
Primary Actor	Admin

Secondary Actor	None
Pre-Conditions	
1. Admin should login to the system. 2. The login device should connect to the internet	
Flow of Event	
1. Login to the system as admin. 2. Enters to the google map view interface 3. View the filled bins’ locations	
Post Condition	
View the google map	

3.4.3 Class Diagram

The Class Diagram provides a comprehensive representation of the system through classes, including their features and behaviors.

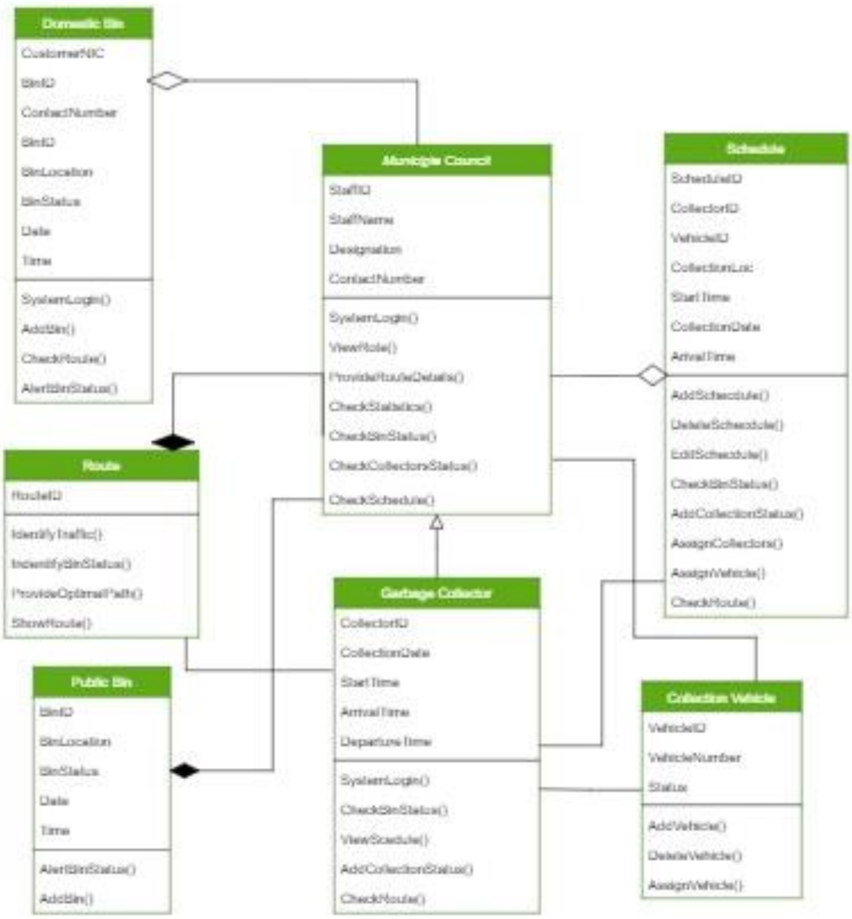


Figure 4: Class Diagram for the proposed system

Chapter 04: Methodology and Implementation

The overall system is consisting of three major parts.

1. Hardware Design
2. Software Design
    - Main System Interface: Municipal Council
    - Mobile App Interface: Domestic, Garbage Collectors
3. Algorithm Design

4.1 Hardware Design

In the hardware design phase, it's essential to outline the specific components used in smart bins. Figure 4 shows the schematic diagram of the hardware system.

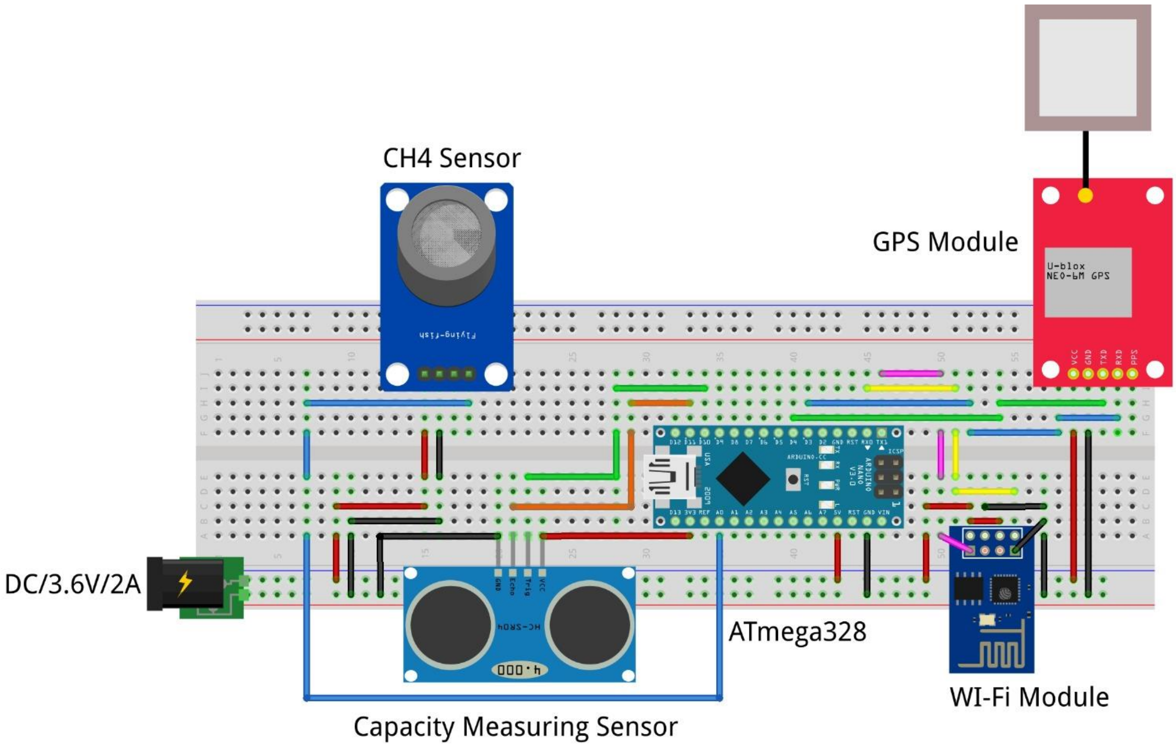


Figure 5: Schematic diagram of the Hardware system

1. Ultrasonic sensor Quantify the volume of refuse in the waste receptacle.

2. Keypad The keypad contains two buttons: Power On and Power Off the System.

3. Microcontroller The microcontroller serves as the central processing unit of the proposed system. The proposed system comprises four microcontrollers. Three ultrasonic sensor inputs are coupled to the microcontroller, with all receiver signals linked to a single microcontroller. The microcontrollers transfer data from waste containers. The other microcontroller receives the data.

4. Global Positioning System (GPS) Specify the location of the bins.

5. Wireless Transmitter and Receiver Transmit and acquire data between the microcontroller and

the website.

6. Website Supervise all waste receptacles and exhibit the most efficient route for identifying waste pickup.

4.1.1 Hardware System Components

1. Ultrasonic Sensor

Ultrasonic ranging module HC - SR04 provides 2cm - 400cm non-contact measurement function, the ranging accuracy can reach to 3mm. The modules includes ultrasonic transmitters, receiver and control circuit. This sensor has been used to check the fill level of the bins.

Figure 6: Ultrasonic Sensor

2. GSM Module

The SIM900 GSM module is a widely used module for adding GSM/GPRS communication capabilities to embedded systems and IoT devices. It supports quad-band GSM/GPRS frequencies, allowing it to work on any GSM network worldwide. The module can make and receive calls, send and receive SMS messages, and connect to the internet using GPRS. It communicates with the host microcontroller via a UART interface and can be controlled using AT commands. The SIM900 module is commonly used in applications such as remote monitoring, asset tracking, and security systems, where reliable cellular communication is required. This module has been used to send SMS alerts to municipal council when a bin is filled.

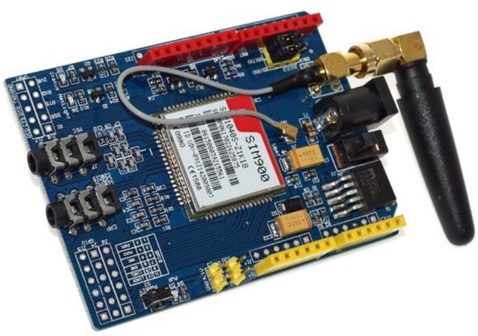


Figure 6: GSM Module

3. GPS Module

The NEO-6M GPS module is a popular and cost-effective GPS receiver module. It features the u-blox NEO-6M GPS chipset, which provides high sensitivity and fast satellite acquisition. The module communicates with a microcontroller or other host device via a serial UART interface, making it easy to integrate into various projects. It typically requires only a 3.3V power supply and consumes very little power, making it suitable for battery-powered applications. The NEO-6M module outputs standard NMEA data messages, including information such as latitude, longitude, altitude, and satellite status, making it suitable for applications such as vehicle tracking, location-based services, and navigation systems.

Figure 7: GPS Module

4. Microcontroller

In this IoT project focusing on garbage collection and route assistance, the Arduino UNO board serves as a crucial component for interfacing the SIM900 GSM module, NEO-6M GPS module, and ultrasonic sensor. The SIM900 GSM module enables communication with the Arduino UNO board over the cellular network, allowing for remote monitoring and control of the system. The NEO-6M GPS module provides accurate location data, enabling real-time tracking of the garbage collection vehicles and route optimization. The ultrasonic sensor is used for detecting the fill level of garbage bins, ensuring timely collection. The Arduino UNO board is ideal for this project due to its ease of use, wide availability of libraries and examples, and compatibility with a variety of sensors and modules. Its low cost and versatility make it a perfect choice for prototyping and implementing IoT solutions like this garbage collection and route assistance system.

Figure 8: Microcontroller

4.1.2 Hardware Implementation

The hardware system will be designed through the Proteus simulation software to verify the system working and then implementation will be conducted. The prototype design of garbage bin is shown in figure 9.

Figure 9: Prototype design of garbage bin

1. Interfacing Ultrasonic Sensor

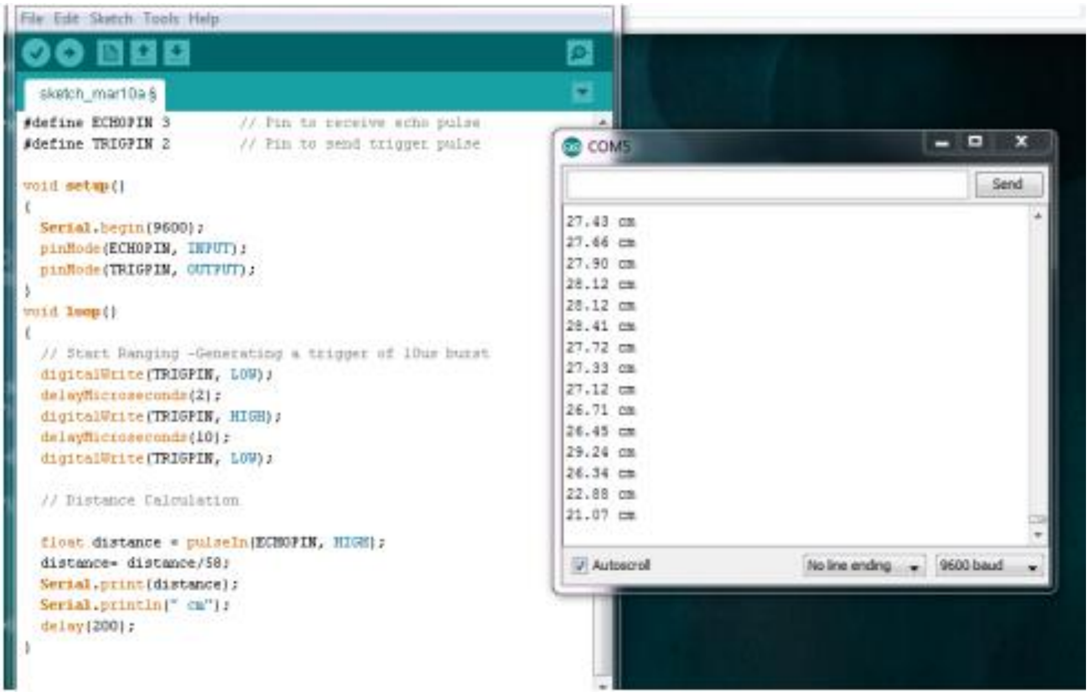
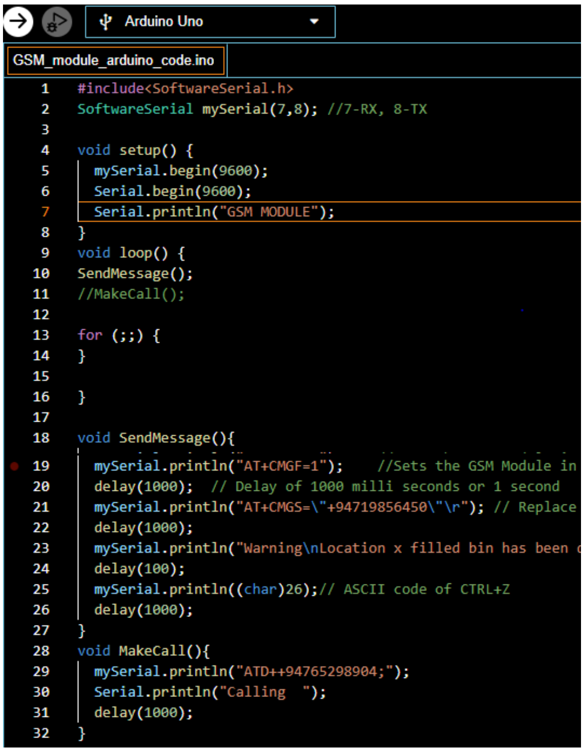


Figure 10: Interfacing Ultrasonic Sensor

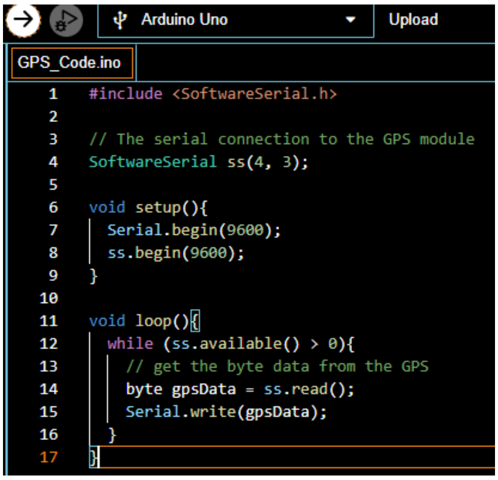
2. Interfacing GSM Module



```
Arduino Uno
GSM_module_arduino_code.ino
#include<SoftwareSerial.h>
SoftwareSerial mySerial(7,8); //7-RX, 8-TX

void setup() {
  mySerial.begin(9600);
  Serial.begin(9600);
  Serial.println("GSM MODULE");
}
void loop() {
SendMessage();
//MakeCall();

for (;;) {
}

}

void SendMessage(){
  mySerial.println("AT+CMGF=1");    //Sets the GSM Module in
  delay(1000);  // Delay of 1000 milli seconds or 1 second
  mySerial.println("AT+CMGS=\"+94719856450\"\r"); // Replace
  delay(1000);
  mySerial.println("Warning\nLocation x filled bin has been
  delay(100);
  mySerial.println((char)26);// ASCII code of CTRL+Z
  delay(1000);
}
void MakeCall(){
  mySerial.println("ATD++94765298904;");
  Serial.println("Calling  ");
  delay(1000);
}
```

Figure 11: Interfacing GSM Module

3. Interfacing GPS Module



```
Arduino Uno    Upload
GPS_Code.ino
#include <SoftwareSerial.h>

// The serial connection to the GPS module
SoftwareSerial ss(4, 3);

void setup(){
  Serial.begin(9600);
  ss.begin(9600);
}

void loop(){
  while (ss.available() > 0){
    // get the byte data from the GPS
    byte gpsData = ss.read();
    Serial.write(gpsData);
  }
}
```

Figure 12: Interfacing GPS Module

4. Full Setup

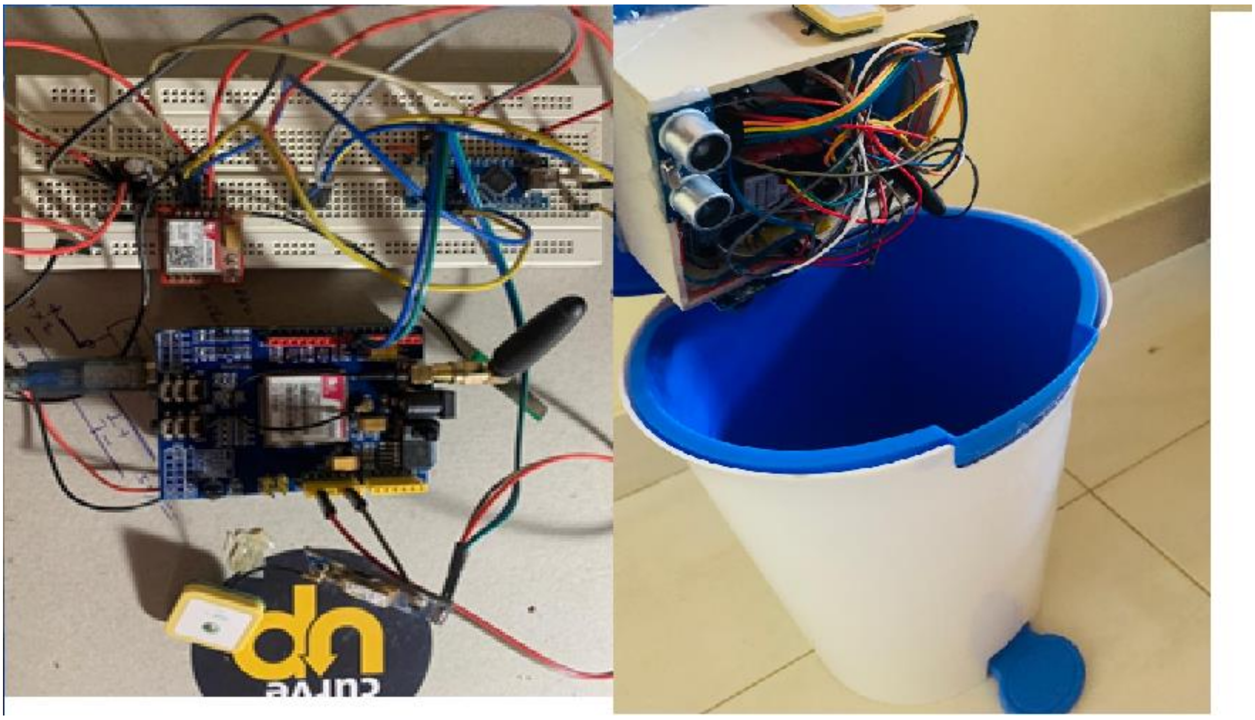


Figure 13: Final Hardware Setup

4.2 Software Design

Software design is focused on municipal council who do the monitoring and controlling, domestic users who need timely update of garbage collection process, garbage collectors who follow the schedules to collect the garbage with the help of optimal route. Therefore, the software design consists of two parts: Central Interface and Mobile App.

4.2.1 Central Interface

The authorization is provided only for municipal council staff. The full control over public bins has been given to the council.

1. Login Page
2. Dashboard
    - Public Bins Details
    - Domestic Bin Details
    - Garbage Collectors Details
    - Collection Vehicle Details
    - Route Details
    - Schedules
    - Statistics

4.2.2 Mobile App

Mobile App is customized for the users according to their type.

1. Garbage Collectors
    - View Schedules
    - View Route

- ➢ View Bin status
- ➢ View Vehicle details
- ➢ Attempt Collecting

2. Domestic Users

Domestic users can register to the system and add their smarts bins status to the system such as notifying when it is filled. Then, council can identify the status and add the location to examine the route.

- ➢ View collecting vehicle route
- ➢ Add bins
- ➢ Send notifications or alerts

4.2.3 Software Implementation

The following languages and technologies have been used for system development.

5. Central Interface: Node-Red Flows

Node-Red is a visual programming tool used for wiring the IoT. It offers a browser-based editor that simplifies the process of connecting flows by using a variety of nodes in the palette. These flows can be deployed to its runtime with just a single click.

The development of the dashboard visually combines hardware and software using Node-RED flows. Therefore, visual interfaces are created that interact with both physical devices (hardware) and digital processes (software), all managed through Node-RED's flow-based programming. Because Node-RED can design interactive dashboards that display real-time data from sensors, control actuators, and interact with other software systems, all within a single visual environment.

➢ **Login Page**

The following interface (Figure:14) is used to login to the system dashboard who are the authorized staff from the municipal council. The Node-Red flow of the page is given in the figure 15.

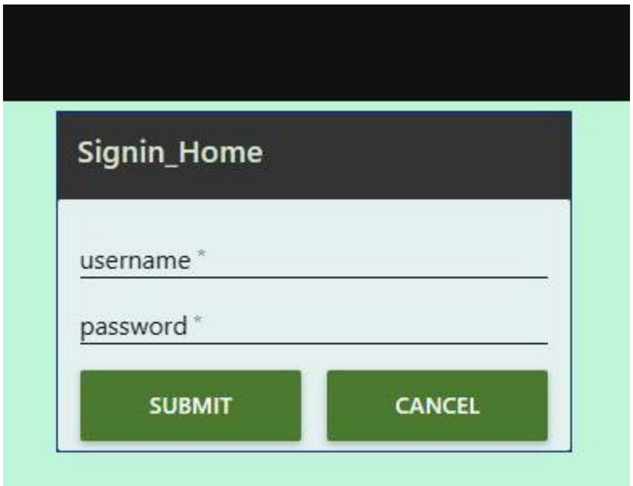


Figure 14: Login Page

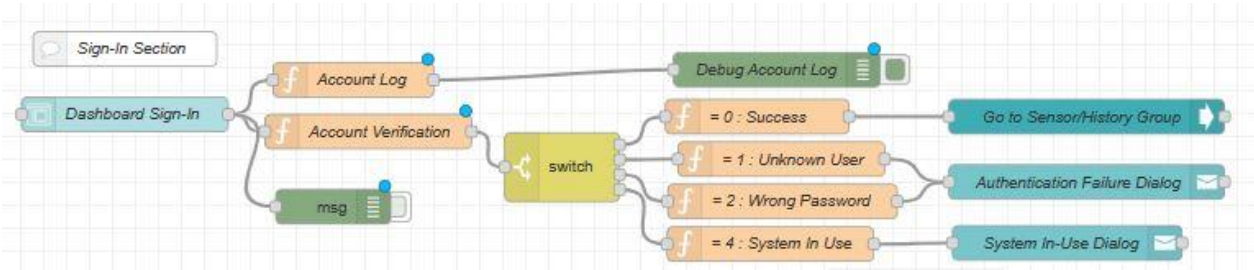


Figure 15: Node-Red Flow_Login Page

➢ Home

The homepage contains all the visual information of route map of bin locations, and Schedules. Information about garbage collection including data on collectors and vehicles. The following figure 16 shows the Node-red flow of the homepage design and the figure 17 shows the homepage interface.

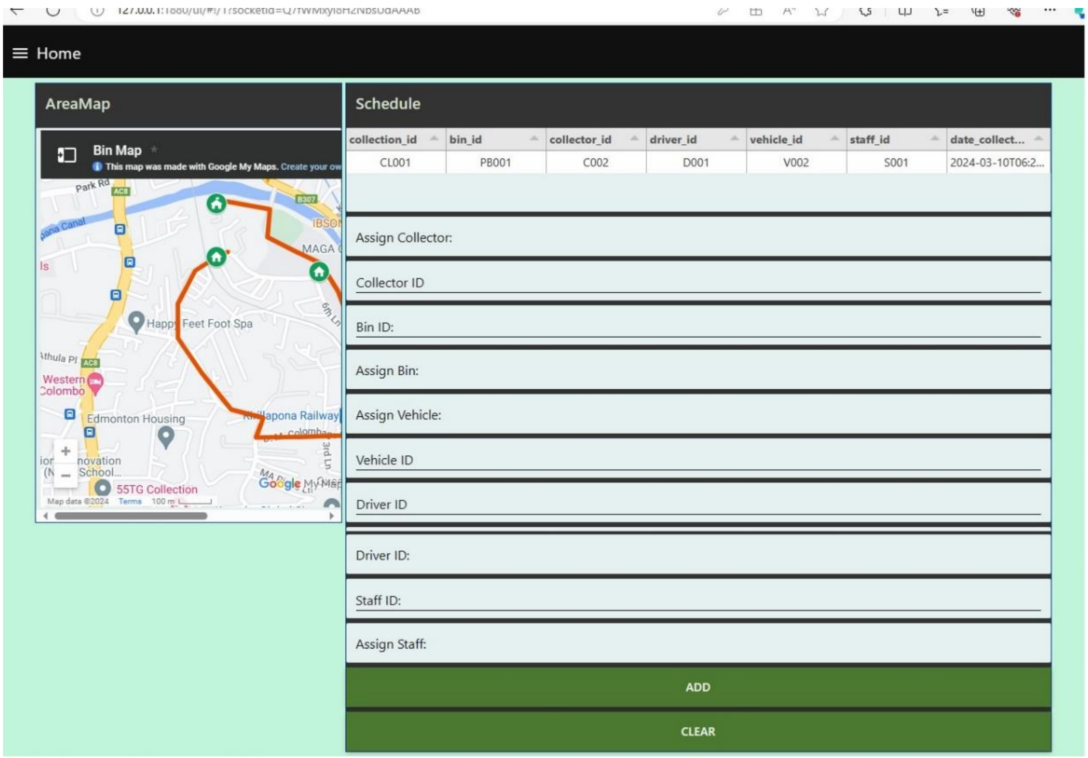


Figure 16: Home Page

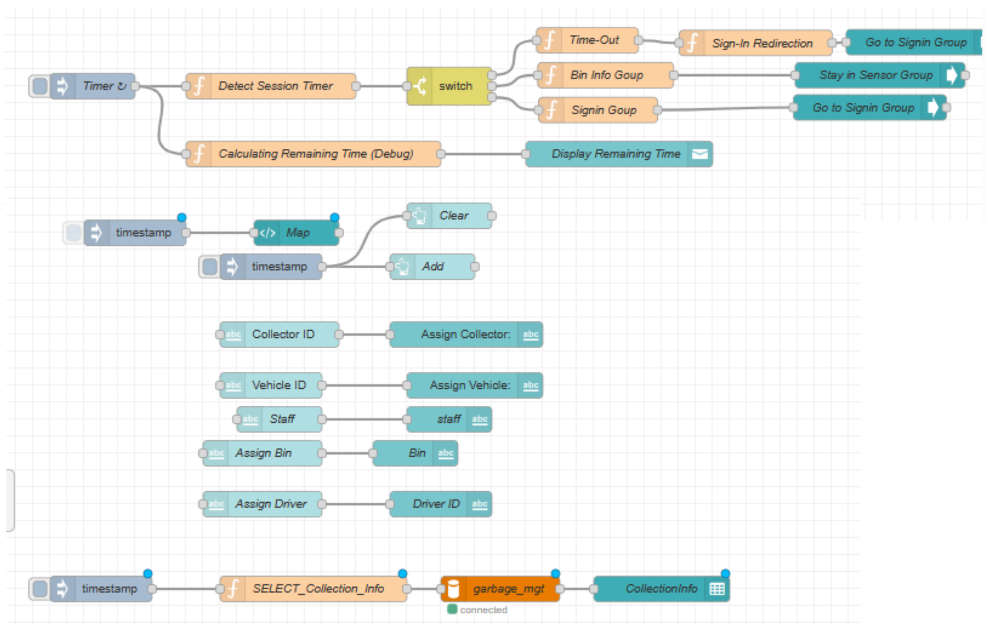


Figure 17: Node-Red Flow_Home Page

➢ BinInfo

The bin status contains all the visual information of public bins and private bins. The status of fill level status is visually represented in the interface. Also, statistics can be obtained from this section. The following figure 18 shows the Node-red flow of the bin interface design.

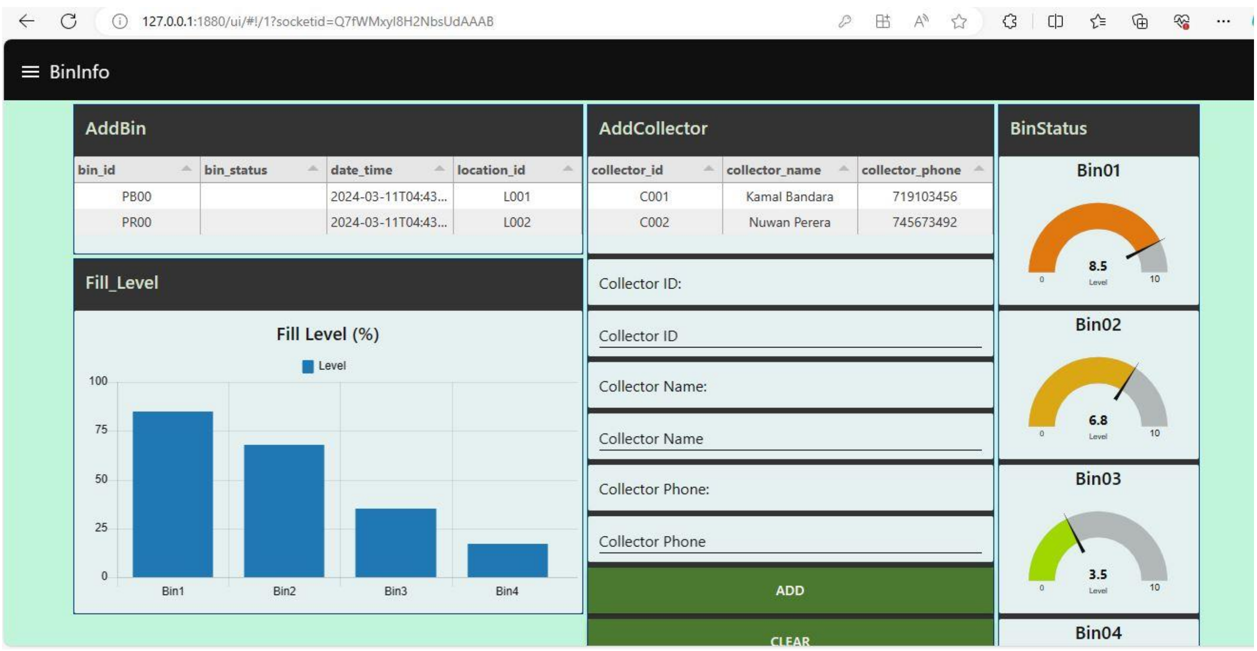


Figure 18: Bin Information Page

6. Mobile App: AndroidStudio

To bridge the gap between planning and execution, a mobile application named SUTT (Smart Urban Trash Tracker (SUTT) was developed using Android Studio software for waste collectors. This application serves as the interface between the optimized collection plans generated by the central system and the on-ground execution by collection teams. The SUTT app provides collectors with real-time schedules, optimized route maps, and turn-by-turn navigation, ensuring that the carefully planned collection routes are followed accurately

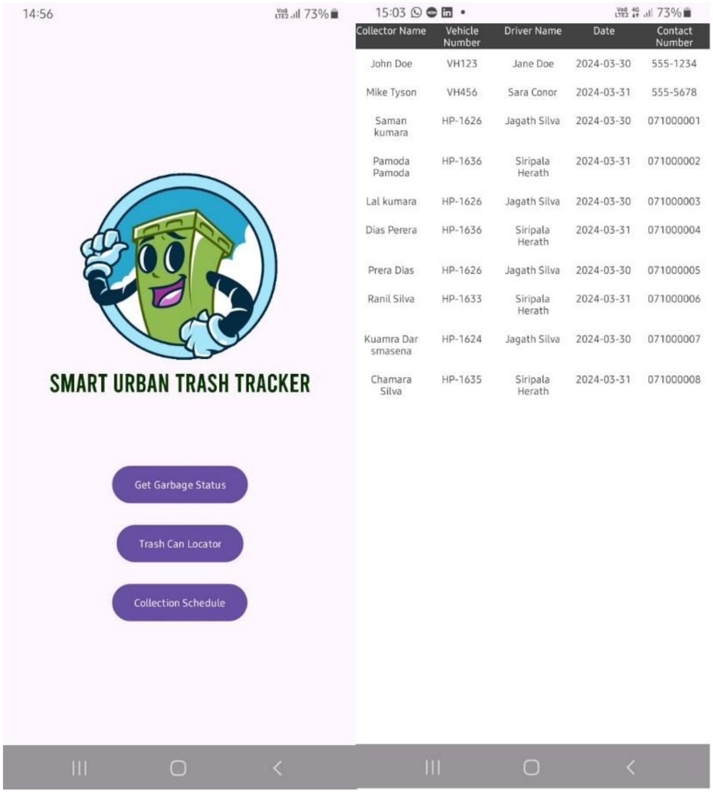


Figure 19: SUTT Android App

7. Database: XAMPP

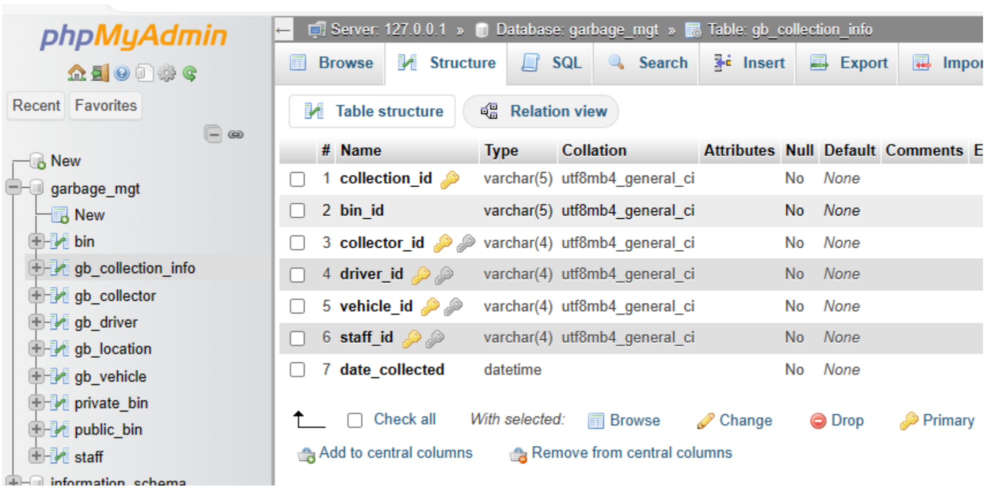


Figure 20: Database Design

4.3 Algorithm Development

The system's intelligence extends to automated scheduling and route optimization for waste collection. When alert thresholds are triggered, the system initiates a scheduling process that assigns collectors, allocates appropriate vehicles, and generates optimized route maps. The route optimization algorithm is a sophisticated component that considers multiple parameters, including bin locations' geographical coordinates (longitude and latitude), distance from the municipal council, and real-time traffic conditions and bin status (when the capacity is above 80% or the level is spoiled beyond 70%).

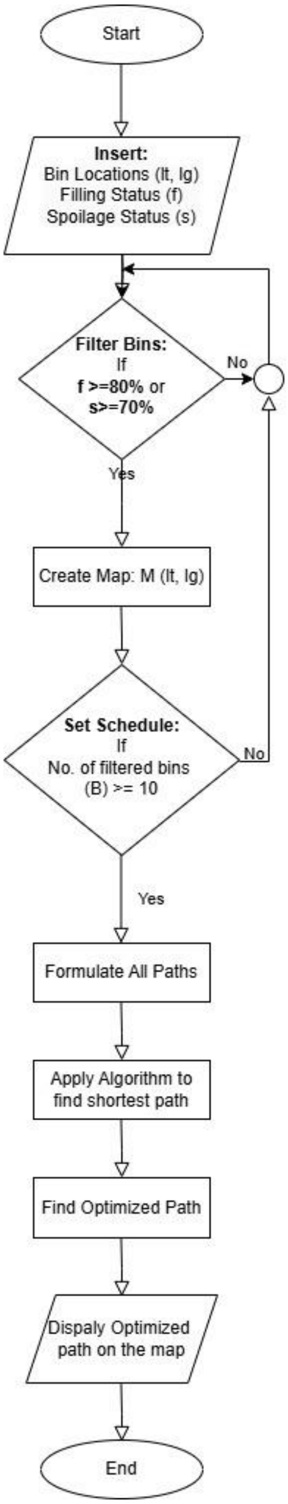


Figure 21: Flow of the Route Optimization

To enhance waste collection efficiency, our route optimization system leverages real-time data acquired from Google Maps. This study presents a novel approach that combines bin fill levels, decaying state, and accurate traffic data to generate an optimum collection route. Presented below is a comprehensive explanation of the algorithm:

1. Data Acquisition and Filtering:

Obtain information regarding the bin locations (longitude, latitude), fill levels, and spoiled status of all bins. and Filter bins according to predetermined criteria for fill level (80%) and spoiled status (70%).

2. Integration with Google Maps:

Google Maps API was used to acquire the current traffic statistics for the designated area, including the filtered categories. Then analyze the current traffic circumstances to identify the optimal path between each pair of filtered bins.

3. Generate Map:

A map is generated by M[lt, lg] by taking into account the depot and the maximum number of filtered containers. The shortest paths from Google Maps are employed to calculate the edges between nodes. A composite score measure is employed to allocate edge weights.

4. Sub Algorithm:

The algorithm u ↞ vertex in Q with min dist[u] involves finding the vertex u in the vertex set Q that has the lowest value of dist[u]. The function length(u, v) calculates the length of the edge connecting the two neighboring nodes u and v, expressed as the distance between them. The variable alt on line 18 represents the linear distance between the root node and the neighboring node v, assuming that the path passes through u. In the event that this route is shorter than the shortest route currently documented for v, the present route is substituted with this alternative route. The previous array is configured with a pointer to the "next-hop" node on the source graph in order to determine the most efficient path to the source.

```
1   Function OptimalPath(Map, source):
2       Q ← set of all nodes in Map
3       dist[source] ← 0
4       prev[source] ← undefined
5       for each node v in Q:
6           if v ≠ source:
7               dist[v] ← INFINITY
8               prev[v] ← undefined
9       while Q is not empty:
10          u ← node in Q with minimum dist[u]
11          remove u from Q
12          for each neighbor v of u:
13              alt ← dist[u] + Graph.weight(u, v)
14              if alt < dist[v]:
15                  dist[v] ← alt
16                  prev[v] ← u
17      return dist[], prev[]
```

Figure 22: Algorithm for Finding Optimal Path

5. Apply Distance Equation

The optimal route is determined using the following modified distance formula.

$$Optimal\ Path = \frac{\sqrt{(lg_2 - lg_1)^2 + (lt_2 - lt_1)^2}}{Traffic\ Density} \qquad (1)$$

Where;

lg_1 , lt_1: The longitude and latitude of the current bin.

lg_2 , lt_2: The longitude and latitude longitude and latitude of the subsequent bin.

F: Constant computed from bin fill levels

S: Constant computed from bin fill spoilage level

Table 4: Verbal Fill levels vs F

Verbal Fill Level	**F Value**
0% to 19%	10
20% to 49%	20
50% to 79%	40
80% to 100%	50

Table 5: Verbal Spoilage Levels vs S

Verbal Spoilage Level	**S Value**
0% to 19%	2
20% to 49%	4
50% to 79%	8
80% to 100%	10

The route will begin at the municipal council and will be planned based on the traffic conditions, which are classified and assigned weights based on road types such as main streets, side streets, and narrow streets. This allows the algorithm to optimize efficiency while also considering practicality in urban environments. This approach not only minimizes fuel consumption and collection time but also reduces the environmental impact of waste collection activities.

Chapter 5: Testing and Evaluation

The testing and evaluation phase of the project with route assistance was conducted in two main stages: hardware testing, focusing on module performance, and software testing, assessing the functionality of the central dashboard and mobile app.

Hardware testing involved a rigorous assessment of key components such as the SIM900 GSM module, NEO-6M GPS module, and ultrasonic sensor. Each module was tested for its individual functionality and compatibility with the Arduino UNO board. The SIM900 GSM module was evaluated for its ability to establish communication, while the NEO-6M GPS module was scrutinized for its accuracy in location tracking. The ultrasonic sensor underwent thorough testing to ensure precise measurement of garbage bin fill levels under various environmental conditions. These tests were essential to validating the reliability and performance of the hardware components in real-world scenarios.

Software testing focused on evaluating the central dashboard and mobile app. The central dashboard was tested for its capability to display real-time data, including garbage bin fill levels and vehicle locations, and to provide route suggestions based on this data. The mobile app was tested for its user interface, compatibility with different devices, and functionality in providing route assistance to garbage collection vehicles. These tests were crucial in ensuring that the software components functioned seamlessly and met the requirements of the project.

The testing and evaluation phase provided valuable insights into the performance and reliability of the smart garbage monitoring system. The results of these tests will be used to further refine and optimize the system, ensuring its effectiveness in improving garbage collection efficiency and route optimization.

5.1 Hardware Testing

The hardware testing phase of the smart garbage monitoring system with route assistance involved testing the various modules used in the system, including the SIM900 GSM module, NEO-6M GPS module, and ultrasonic sensor.

- **SIM900 GSM Module Testing**: The SIM900 GSM module was tested for its ability to make and receive calls, send and receive SMS messages, and establish a GPRS connection for internet access. The module was also tested for its compatibility with the Arduino UNO board and its power consumption characteristics.
- **NEO-6M GPS Module Testing**: The NEO-6M GPS module was tested for its ability to acquire satellite signals and provide accurate location data. The module was tested under various conditions to evaluate its performance in different environments and its power consumption characteristics.
- **Ultrasonic Sensor Testing**: The ultrasonic sensor was tested for its ability to accurately measure the fill level of garbage bins. The sensor was tested with different types of garbage bins and under different lighting conditions to evaluate its performance and reliability.

5.2 Software Testing

The software testing phase of the smart garbage monitoring system with route assistance involved testing the central dashboard and mobile app used to monitor the system and provide route assistance.

5.2.1. Central Dashboard Testing

The central dashboard was tested for its ability to display real-time data from the garbage monitoring system, including fill levels of garbage bins and location data of garbage collection vehicles. The dashboard was also tested for its ability to generate route suggestions based on the data received from the system.

Test Case 01: Employee Authentication

Table 6: Test Cases for Employee Authentication

TC ID	Priority	Severity	Description	Test Steps	Expected Result
#1	P1	S1	Confirm that the user can log in using a valid username and password.	1. User navigates to the login page. 2. Input a valid login and password 3. Select the login button	The user can access the dashboard by logging in.
#2	P1	S1	Confirm that the user is unable to log in with an incorrect username and an incorrect password.	1. User navigates to the login page. 2. Input an invalid login and password 3. Select the login button	1. User unable to authenticate. 2. An error message should be appeared.
#3	P1	S1	Confirm the status when both the username and password fields are empty.	1. User navigates to the login page. Leave the username and password fields empty. 3. Select the login button.	1. User unable to access account 2. An error message should be appeared.
#4	P2	S1	Verify the messages for erroneous login attempts.	1. User navigates to the login page. Leave the username and password fields empty. 3. Select the login button.	The content of the error message must be accurate.
#5	P4	S4	Verify the user interface of the Login page.	1. User navigates to the login page.	The user interface of the page must be appropriately positioned, scaled, and colored.

Test Case 02: Adding a Customer

Table 7: Test Cases for Adding a Customer

TC ID	Priority	Severity	Description	Test Steps	Expected Result
#1	P1	S1	Confirm user can input customer name	1. User navigates to the registration page. 2. Incorporate name	The user is able to input the customer's name.
#2	P1	S1	Confirm user can input contact No	1. User navigates to the registration page. 2. Incorporate contact no	The user is able to input the customer's contact No
#3	P1	S1	Confirm user can input email	1. User navigates to the registration page. 2. Incorporate email	The user is able to input the customer's email
#4	P1	S1	Confirm user can input address	1. User navigates to the registration page. 2. Incorporate address	The user is able to input the customer's address
#5	P1	S1	Confirm user can input longitude	1. User navigates to the registration page. 2. Incorporate longitude	The user is able to input the customer's longitude
#6	P1	S1	Confirm user can input latitude	1. User navigates to the registration page. 2. Incorporate latitude	The user is able to input the customer's latitude
#7	P3	S3	Confirm the functionality of the clear button	1. User navigates to the registration page. 2. Incorporate content 3. Select the clear button.	Field data must be reset.
#8	P1	S1	Confirm validations for mandatory fields	1.User navigates to the registration page. 2. Verify mandatory field validation for all requisite fields.	1. Cannot proceed ahead if mandatory fields are incomplete 2. The validation message should be displayed.
#9	P1	S1	Confirm that the staff can view the customer profile after its creation.	1.Access the staff login portal. 2 Proceed to the customer. 3. Access the added profile	Staff can access the generated profile with accurate information.

#10	P1	S1	Confirm that a user may log in after creating a profile.	1. Create a profile 2. Access the system via the established profile credentials.	User can access the profile by logging in.

Test Case 03: Adding a Bin (Public Bin)

Table 8: Test Cases for Adding a Bin (Public Bin)

TC ID	Priority	Severity	Description	Test Steps	Expected Result
#1	P1	S1	Staff can add a bin for location	1. login to system (Central) 2. go to binStatus 3. click on add a bin button 4. fill the form & save details	1. chose bin should shows under customer my bins window 2. newly added bin details should show in bin allocation details page 3. bin status should shows as pending
#2	P2	S1	View allocated bins	1. login to system 2. go to binStatus page 3. click on view button	1. all the allocated bin details should show
#3	P1	S1	Add a bin	1. go to add bin page	1. bin status should change to active
				2. click on activate bin button 3. enter activation code received	2. customer able to start using the bin
#4	P1	S1	Try to activate bin by wrong activation code	1. go to my bin page 2. click on activate bin button 3. enter invalid activation code	1. validation message should be appears 2. bin should be in pending status
#5	P1	S1	Active a bin by staff	1. go to binStatus page 2. click on active button	1. staff should be able to activate bin without activation code
#6	P1	S1	Deactivate a bin by staff	1. go to binStatus page 2. click on Deactivate button	1. staff should be able to deactivate bin

Test case 04: Adding a vehicle

Table 9: Test cases for adding a vehicle (Truck)

TC ID	Priority	Severity	Description	Test Steps	Expected Result
#1	P1	S1	Add a new truck into the system	1. Navigate to the Vehicle Management page. 2. Select "Add a Vehicle." Complete the form and submit it.	A new truck must be incorporated into the system.
#2	P1	S2	Incapable of adding the identical vehicle on two occasions.	1.Navigate to the Vehicle Management page. 2. Select "Add a Vehicle." 3. Complete the form utilizing the previously entered information and submit it.	1. The validation notice should appear. 2. Incapable of adding the identical vehicle on two occasions.
#3	P1	S1	Examine the added vehicle (Truck) information.	1. Navigate to the Vehicle Management page. 2. Select the see vehicle button.	Capable of viewing truck information.
#4	P2	S2	Revise vehicle information.	1. Navigate to the Vehicle Management page. 2. Select the update vehicle button.	Capable of modifying and preserving vehicle information.
#5	P1	S2	Delete vehicle	1. Navigate to the Vehicle Management page. 2. Press the Delete Vehicle button.	The vehicle should be removed from the system.

5.2.2. Mobile App Testing

The mobile app was tested for its ability to display real-time data from the garbage monitoring system and provide route assistance to garbage collection vehicles. The app was tested on different mobile devices to ensure compatibility and usability.

Test Case: User Login (SUTT App)

Table 10: Test Cases for User Login (SUTT App)

TC ID	Priority	Severity	Description	Test Steps	Expected Result
#1	P1	S1	Confirm that the user can log in using a valid username and password.	1. User navigates to the login page. 2. Input a valid login and password 3. Select the login button	The user can access the dashboard by logging in.
#2	P1	S1	Confirm that the user is unable to log in with an incorrect username and an incorrect password.	1. User navigates to the login page. 2. Input an invalid login and password 3. Select the login button	1. User unable to authenticate. 2. An error message should be appeared.
#3	P1	S1	Confirm the status when both the username and password fields are empty.	1. User navigates to the login page. Leave the username and password fields empty. 3. Select the login button.	1. User unable to access account 2. An error message should be appeared.
#4	P2	S1	Verify the messages for erroneous login attempts.	1. User navigates to the login page. Leave the username and password fields empty. 3. Select the login button.	The content of the error message must be accurate.
#5	P4	S4	Verify the user interface of the Login page.	. User navigates to the login page.	The user interface of the page must be appropriately positioned, scaled, and colored.

5.3 Evaluation

To evaluate the obtained results, the behavior of one of the bins in each distribution area was monitored over a period of four weeks. This data was then visualized and analyzed using the statistics page on the central dashboard. The statistics page provides the council with valuable insights into the usage patterns of the bins, helping them determine the number of bins needed for each area and how regularly they should be cleaned.

The statistics page displays information such as the fill level of the monitored bin over time, indicating how quickly it fills up and when it needs to be emptied. This data allows the council to optimize their waste collection schedule, ensuring that bins are emptied at the right time to prevent overflow.

Additionally, the statistics page can provide information on the peak usage times for the bins, helping the council allocate resources more efficiently. For example, if certain bins tend to fill up quickly on weekends or during specific events, the council can adjust their collection schedule accordingly.

Chapter 6: Conclusion

This system has been successfully developed and implemented. Each module in the system transmits the data between each other and finally displays the data to the end users. The users can access the website and server designed from everywhere (outside of local network), since this software has been uploaded to the internet. This system's software can be accessed from pc, laptop, as well as tablets, as long as the device has the capability to browse the web services. Thus, the real time monitoring for each garbage bin in the area can be achieved. Along the way of developing this system, there definitely exist some difficulties that I have faced. There are 2 kinds of difficulty, one is related to psychological or mentally challenges, and one is the technical challenges. For the technical challenges, the most challenging one during the development stage is the ability to grasp new information and learn to apply them into the real system. Learning the new information and how to apply the information can be another challenge. For an example when develop my algorithm, some theories seems simple and can be done easily, however, when implemented in the system, they did not function together. This is one of the biggest challenge in the technical aspect of the developing stage. Besides that, researching time spent during the development stage is tremendous. Countless hours of researching and implementing have been performed to make sure that the system is working as expected. The implementation area cover from hardware perspective to software. All this require both mentally and technical skills, which I'm lacked of On the other hand, the mentality shall be skilled enough to be able to develop a system, the determination and the commitment to oneself shall always be applied. Also, time managing stands a big role in developing a system, a self-proposed due date shall always be met, which to me is kind of a big challenge. During the development stage of the system, tremendous amount of skills and knowledge have been learned and applied. Though there is hard time during the development, the outcomes are always cherishing. Developing a system is not an one day-work, a step-by step developing stage need to be strictly followed. A big task shall be broken up into several smaller parts where it is more applicable and implementable, then only a system can be developed. Skills such as time managing, self-discipline have also been learnt. Though these are not the skills that are required for developing a system, however, it stands a big role in the stable product development and also self-development. Various technologies and skills have also been learnt, from the low level programming design to high level design - software design (configuration of existing software). After completed this project, it helped me learn that both hardware programming skills and software programming skills are needed. By completing this project, it is hoped that this system will help to improve the quality of life of human, by creating a more efficient garbage collection system and technology. This can be the keystone to the era of smart cities and it is a crucial development, when everything demands for efficiency and speed in managing the cities. Garbage is always one of the top aspects when considering about the proper development and management of a city, hence, this project could help to improve that. However, it is hoped that someday it will, to see if this system really improve the efficiency of the traditional garbage collecting schedule.

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