SMART WASTE MANAGEMENT SYSTEM USING IOT

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Certificate

It is certified that the following students have completed their project work on **"Smart Waste Management System using IoT"** We, hereby declare that this submission is out own work and to the best of my knowledge it contains no materials previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any degree or diploma at adviserAffiliation at school or at any other educational institute, except where due acknowledgement has been made in the thesis. Any contribution made to the research by others, with whom. We have worked at school or elsewhere, is explicitly acknowledged in the thesis. We also declare that the intellectual content of this thesis is the product of our own work, except for the assistance from others in the project's design and conception or in style, presentation and linguistics which has been acknowledged.

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Abstract

Waste handling is a challenging job and is a major source of pollution. It is a global challenge that how waste is disposed of in a timely. A large number of employees is required to handle this issue but due to limited resource-oriented municipalities, it is very difficult to hire manpower to handle waste management. Technological enhancement improves human life standard as well as help societies to perform such task efficiently. To handle waste management, we will propose an **IOT!** (**IOT!**) based system for efficient waste disposal and handling. The waste management system is introduced in which each bin will be embedded in the monitoring system that will notify the corresponding personnel if the bin is full. This system will provide an effective solution to the waste management problem. Therefore, there is a need for an innovative and sustainable approach to waste management.A Smart Waste Management System (SWMS) plays a critical role in managing waste in big cities. It helps improve efficiency, reduce costs, and promote sustainable waste management practices, all of which are essential in ensuring a cleaner, healthier, and more sustainable urban environment. A smart waste management system is an advanced system that integrates the use of sensors, Internet of things (IoT), and other advanced technologies to optimize waste collection, processing, and disposal. These technologies work together to create a smart waste management system that is efficient, cost-effective, and environmentally friendly. The implementation of a smart waste management system can benefit society in several ways. It can reduce the cost of waste management, promote sustainable waste management practices, and help reduce the environmental impact of waste.

In conclusion, a SWMS is an innovative approach to waste management that integrates advanced technologies to optimize the collection, processing, and disposal of waste. It has the potential to revolutionize the waste management industry and contribute to a more sustainable future.

Undertaking

We certify that the work titled “Smart Waste Management System using IoT" is our own work. The work has not, in whole or in part, been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged and referred.

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List of Abbreviations

SWMS	Smart Waste Management System
IoT	Internet of things
GPS	Global Positioning System
RFID	Radio Frequency Identification
SDGs	Sustainability Development Goals
UML	Unified Modeling Language
RN	React Native
ESP	Electronic stability control
GPIO	General Purpose Input/output
RBAC	Role Base Access Control
API	Application Programming Interface
DTA	Decrease Time Algorithm

Chapter 1

Introduction

1.1 Introduction

Waste has become a concern for us as the population is growing rapidly over the past 2 decades. As per studies conducted globally, by 2050, the world is expected to generate 3.40 billion tons of waste annually, increasing drastically from today's 2.01 billion tons which would lead to an approximate cost of 645.5 billion [1]. Waste management is a critical issue that affects the environment and human health. In many cities, the management of solid waste has become a major challenge due to the growing population and the increasing amount of waste generated. The problems identified are the overflowing trash bins, especially in public areas with high population density and the complaints from the residents or public complaints regarding the punctuality of trash collection trucks [2]. Traditional waste management methods are often inefficient, resulting in environmental pollution and health hazards. Therefore, there is a need for an innovative and sustainable approach to waste management.

The SWMS is an emerging technology that integrates the IoT, cloud computing, and data analytics to manage waste efficiently. The system uses sensors and smart bins to monitor and manage waste in real time. The system can track the status of the bins, monitor the level of waste, and optimize waste collection routes. This can lead to significant cost savings and a reduction in the environmental impact of waste management.

1.2 Goals

SWMS aim to optimize waste collection processes and minimize the impact on the environment. By reducing the amount of time and resources spent on waste collection and decision-making, a SWMS can help save costs associated with waste management. By monitoring waste levels in bins and containers, a smart waste management system can optimize resource utilization and reduce the number of trucks needed for waste collection. Improving the accuracy of waste data collection and reporting for better decision-making. This can be achieved through the use of sensors, smart bins, and other technologies that enable real-time monitoring of waste levels and efficient routing of waste collection trucks.

1.3 Motivation

We are developing the SWMS project to provide a sustainable and efficient solution for managing waste, reducing environmental impact, and improving the quality of life for residents. By using real-time data on bin fill levels, optimized collection routes, and predictive maintenance, these systems reduce unnecessary collection trips, lower fuel consumption, and minimize labor costs. This results in substantial cost savings for municipalities and waste management companies. By promoting technological innovation and sustainable waste management practices, the project can contribute to addressing environmental challenges and improving the quality of life for residents worldwide.

Traditional waste collection methods often involve fixed collection schedules that may result in either under-utilized or overfilled bins [3] Smart systems help reduce the environmental impact by minimizing emissions from collection vehicles due to optimized routes and reducing the number of vehicles on the road. This translates into lower carbon emissions and improved air quality. By using data analytics and real-time monitoring, smart waste systems can allocate resources more effectively. They ensure that collection crews are dispatched only when necessary, leading to efficient resource management and a reduced environmental footprint.

1.4 Method

The SWMS project will use a combination of hardware and software components, including sensor technology, IoT, data analytics, mobile applications, cloud computing, and Agile software development. SWMS employ various methods and technologies to enhance the efficiency and stainability of waste collection and disposal. One key method involves the use of fill-level sensors installed within waste bins. These sensors employ technologies like ultrasonic. By continuously monitoring fill levels, the system can send real-time alerts to waste collection crews when bins are nearing capacity, optimizing the scheduling of collection routes and minimizing unnecessary trips. Another crucial component is the utilization of Global Positioning System (GPS) technology. This enables real-time tracking of the location of waste collection vehicles [4]. Advanced route optimization algorithms take into account variables such as bin locations, fill levels, traffic conditions, and historical data to plan the most efficient routes for collection trucks. Furthermore, the integration of data analytics plays a pivotal role. The data collected from sensors and vehicles are subjected to analysis using data analytic tools. This analysis yields valuable insights into waste generation patterns, route efficiency, and predictive maintenance requirements.

1.5 Application areas

Smart waste management systems find application in various sectors and urban environments where efficient and sustainable waste collection and disposal are essential. Here are some of the key application areas of SWMS:

1.5.1 Urban environment

In densely populated urban areas, efficient waste collection is crucial. Smart systems optimize collection routes, reduce collection costs, and minimize.

1.5.2 Waste management companies

Waste collection and disposal companies can use SWMS to optimize their operations. These systems help in route planning, real-time monitoring of collection vehicles, and efficient resource allocation. By offering these solutions, waste management companies can enhance their service offerings and reduce operational costs.

1.5.3 Technology providers

Companies specializing in IoT sensors, data analytics, and software development can create and market smart waste management solutions as stand-alone products or as part of a broader suite of IoT services. These technologies enable them to enter the growing smart cities and waste management markets.

1.5.4 Municipalities and local governments:

Municipal governments can implement smart waste management systems to improve the efficiency of public waste collection services. Companies can develop customized solutions for municipalities, offering not only the technology but also ongoing maintenance and support services.

1.5.5 Environmental services

Environmental consulting and service firms can offer smart waste management solutions as part of their stainability services. These systems help clients reduce their environmental footprint and meet stainability goals.

1.5.6 Recycling centers

Recycling centers can use smart waste systems to optimize the collection and sorting of recyclable materials. These systems promote recycling efforts and improve the efficiency of recycling operations.

1.6 Final year project mapping with bloom taxonomy

Bloom's taxonomy is a classification of learning objectives that can be used to design educational activities and assess student learning. The taxonomy categorizes thinking skills into six hierarchical levels, from lower-order thinking skills to higher-order thinking skills as shown in fig 1.1 In the context of Bloom's taxonomy, we are working at the creation level. We are designing and

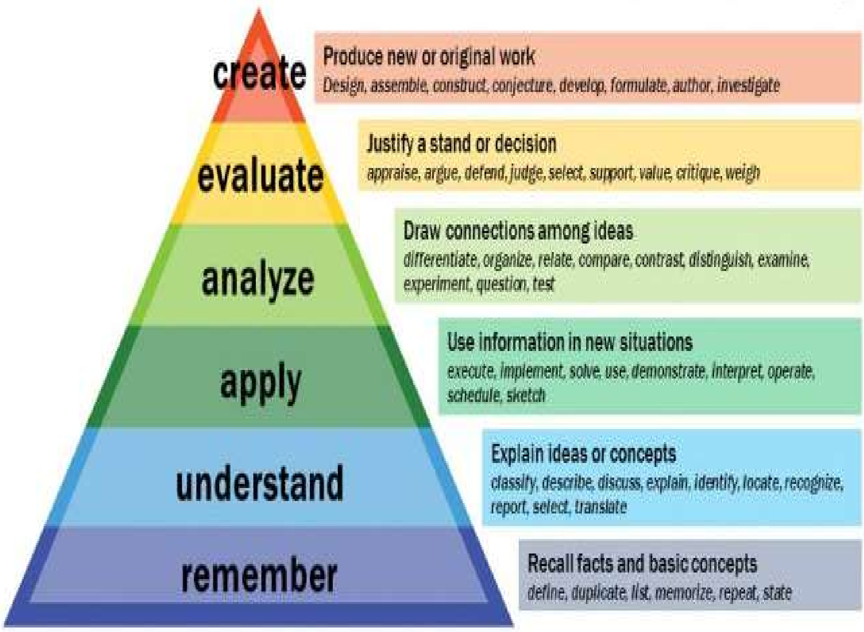

Figure 1.1: Bloom Taxonomy

developing a smart waste management system that is more efficient and cost-effective than existing traditional system.

1.6.1 Design, development and investigation

Designing a SWMS includes creating the architecture and specifications for the system. This involves designing the sensor network, data collection methods, user interfaces, and overall system structure. The Design also extends to aesthetics, ensuring that the system is user-friendly and visually appealing.

The development process involves building the actual system based on the design and assembled components. It includes the software development, wiring, and installation of sensors and data transmission infrastructure. This system combines a network of sensors, data analytics, and communication infrastructure to create an efficient and sustainable approach to waste management. The communication infrastructure of the smart waste management system is essential for real-time monitoring and control. The system typically employs IoT technology, allowing seamless data transmission between the sensors, control center, and waste collection teams. It involves identifying the most efficient collection routes and schedules for waste collection trucks, taking into account factors such as traffic, road closures, and the fill level of waste bins. Google Maps API is used to plan the most efficient routes for waste collection trucks. The API can take into account factors such as traffic, road closures, and real-time location data to optimize routes for waste collection trucks. Google map direction API is used to obtain directions between two or more locations, as well as the travel time, distance, and route coordinates. It can also provide different travel modes, such as driving, walking, or cycling. This API is a paid service, but Google provides a free tier that allows for a limited number of requests per day. Also, we have used Google Maps distance matrix API it is used to obtain travel distances and times between multiple origins and destinations. It can also provide real-time traffic information and different travel modes. This Application Programming Interface (API) is also a paid service, but Google provides a free tier that allows for a limited number of requests per day. This API can be used to convert addresses into geographic coordinates (latitude and longitude) and vice versa. It can also provide information about places and points of interest. This API is a paid service, but Google provides a free tier that allows for a limited number of requests per day.

Mobile apps and web interfaces often provide easy access to data, enabling authorities to manage the system efficiently. In our project, we used react native for mobile app development. React native uses a component-based architecture, which allows to building of user interfaces by combining reusable components. By tracking the fill levels of waste bins smart waste management systems can help to reduce the number of trips that waste collection trucks need to make. SWMS are applicable and helpful in a variety of settings. It helps to reduce costs, improve efficiency, and reduce the environmental impact of waste disposal. One of the challenges is the initial cost of implementation however, the long-term savings can be significant.

1.7 Sustainability developmental goals

Smart waste management systems contribute significantly to several United Nations Sustainability Development Goals (SDGs) due to their potential to improve resource efficiency, reduce environmental impact, and enhance the quality of life in urban areas. Here are the key SDGs that smart waste management systems align with.

1.7.1 Climate action

Unsustainable consumption patterns in high-income countries are largely responsible for the climate crisis but every additional person on our planet adds more emissions. This project reduces climate crises by properly collecting solid waste and then managing it.

1.7.2 Sustainable cities and communities

Making cities sustainable means creating career and business opportunities, safe and affordable housing, and building resilient societies and economies. It involves investment in public transport, creating green public spaces, and improving urban planning and management in participatory and inclusive ways. This project is a great step toward keeping public spaces clean and creating career opportunities.

1.7.3 Responsible consumption and production

Achieving economic growth and sustainable development requires that we urgently reduce our ecological footprint by changing the way we produce and consume goods and resources. The efficient management of our shared natural resources, and the way we dispose of toxic waste and pollutants, are important targets to achieve this goal. By reducing the amount of time and resources spent on waste collection and disposal, a SWMS can help save costs associated with waste management. Also, it promotes recycling, which is the best way to conserve natural resources.

1.7.4 Industry, innovation, and infrastructure

The development and implementation of smart waste management technologies and systems promote innovation in urban infrastructure. These systems involve the use of IoT devices, data analytics, and real-time monitoring, fostering technological advancement.

1.7.5 Good health and well-being

Cleaner urban environments resulting from smart waste management systems lead to improved public health by reducing the risk of disease transmission and air pollution.

1.8 Report overview

This report has introduced a system that allows a reader to explore the initial concepts of the system. The report consists of eight chapters.

Chapter 1 is about the project plan, and the design of the system including the system architecture, data flow, and user interface design. The chapter also reviews the design principles and patterns used in the project.

Chapter 2 is about the project plan, and provides an in-depth review of the current state of waste management in Pakistan and globally, including its challenges and opportunities. It will also highlight the importance of sustainable waste management practices and introduce the concept of SWMS.

Chapter 3 is about the project plan, including the project schedule, milestones, and budget. It will also highlight the roles and responsibilities of the project team and discuss the project management methodologies used in the project.

Chapter 4 is about the project plan, and project requirements, including functional and non-functional requirements, performance criteria, and quality standards. It will also discuss the requirements validation and verification methods used in the project.

Chapter 5 is about the project plan, and the design of the smart waste management system, including the system architecture, data flow, and user interface design. The chapter also reviews the design principles and patterns used in the project.

Chapter 6 is about the project plan, and system architecture of the SWMS including the hardware and software components, system integration, and data storage and processing. The chapter also reviews the security and privacy considerations of the system architecture.

Chapter 7 is about the project plan, and system architecture of the SWMS, including the hardware and software components, system integration, and data storage and processing. The chapter also reviews the security and privacy considerations of the system architecture.

Chapter 8 is about the project plan, our solution, and in the future what would be done in this project. It also includes what we have achieved in this project. How effectively do we complete our functional and non-functional requirements?

1.9 Summary

- In many cities, the management of solid waste has become a major challenge due to the growing population and the increasing amount of waste generated.
- System aims to optimize waste collection processes and minimize the impact on the environment.
- By monitoring waste levels in bins and containers, the system can optimize resource utilization and reduce the number of trucks needed for waste collection.
- Smart systems help reduce the environmental impact by minimizing emissions from collection vehicles due to optimized routes and reducing the number of vehicles on the road.
- The SWMS project will use a combination of hardware and software components, including sensor technology, IoT, data analytics, mobile applications, cloud computing, and Agile software development.
- SWMS find application in various sectors and urban environments where efficient and sustainable waste collection and disposal are essential.

Chapter 2

Background and Problem Statement

2.1 Introduction

Waste collection services, today, are exhausted and unable to bear the burden of rising cities. It is one of the biggest ongoing challenges, being faced by developing economies, where a large variety of goods ranging from cars to metal and hardware end up in inadequately managed and uncontrolled dumpsites, spreading diseases and increasing pollution [5]. However, most of these plans have been able to manage waste once it has already been created. The smart waste management system project is a response to the growing challenges facing waste management systems in many parts of the world, including Pakistan. The current waste management practices in the country are inadequate and inefficient, leading to a range of environmental and health issues. The lack of proper waste collection, transportation, and disposal systems has resulted in the accumulation of waste in public areas, including streets and open spaces, leading to pollution, disease, and aesthetic issues. The problem is exacerbated by the growing population and urbanization trends, which are leading to increased waste generation and higher demand for efficient waste management systems [6]. The current waste management infrastructure in the country is unable to keep up with the pace of urbanization and population growth, resulting in a significant gap between the demand and supply of waste management services.

2.2 Literature review

In [7] the researchers' proposed system is capable in the collection of waste effectively, the detection of fire in waste material, and forecasting of the future waste generation. The IoT-based device performs the controlling and monitoring of the electric bins.

In [8] The procedures we designed involves a creative initiative that will inspire people to dump in designated area or bins, and an innovative method by using the Decrease Time Algorithm (DTA) for monitoring garbage generation and collection of garbages.

The researchers have proposed many techniques to resolve the issues related to waste management. In [9] the Radio Frequency Identification (RFID) sensor was used to automate the waste-picking process.

In [10] an efficient method to measure the waste level of bins was introduced. This system uses a microcontroller, transmitter, receiver, RF (radio frequency) module, and IR (Infrared) sensor to collect the information on waste from the bins on time. In this system, sensors sense the level of waste in the bins and send alerts to the controller. The microcontroller encodes these alerts and forwards them to the main central processing.

In [9] the researcher considers and deals with population and urban growth by using different truck sizes according to waste type and IoT devices that ease communication among system entities, such as smart bins, waste source areas, waste collection trucks, and waste management centers.

In [11] a waste collection management solution was proposed which was based on a huge volume of data collected from waste bins which was then used by intelligent and optimized algorithms to make decisions.

In [12] a smart bin was proposed which contains two IR sensors an Arduino and a Raspberry Pi. Each IR sensor detects the level of waste in the bin. It contains two IR sensors, Arduino Uno and Raspberry Pi. Amongst the two ultrasonic one IR sensor will detect 50 percent of the garbage collected in the dustbin and the second IR sensor will detect 100 percent of the garbage collected in the dustbin.

The proposed system in [13] comprises various technological modules and sensors which are integrated. All these components and modules in combination make this proposed system achieve the desired objectives.

2.3 Problem statement

Waste management is a major challenge in many cities around the world. The traditional method of waste management is inefficient and can lead to environmental problems. The lack of proper waste collection, transportation, and disposal systems has resulted in the accumulation of waste in public areas, including streets and open spaces, leading to pollution, disease, and aesthetic issues.

The implementation of a SWMS that can address the challenges of waste management in urban areas. The system should be able to collect and analyze data on the level of waste in the bins and optimize waste collection routes, leading to significant cost savings and a reduction in the environmental impact of waste management. The system should also provide real-time feedback to users through a mobile application, enabling them to dispose of waste correctly and contribute to a cleaner environment. By addressing the challenges of waste management, this project aims to promote sustainable development and improve public health in urban areas.

2.4 Benefits of the project

Smart waste management systems offer a wide range of benefits to municipalities, waste management companies, businesses, and communities. These benefits encompass economic, environmental, social, and operational advantages. Here are the key benefits of implementing a SWMS.

2.4.1 Efficient waste collection

Optimized Routes: Smart systems use real-time data to create efficient waste collection routes, reducing travel distances and fuel consumption. Dynamic Scheduling: Collection schedules can be adjusted in real-time based on fill levels, reducing the likelihood of overflowing bins.

2.4.2 Cost savings

- Fewer collection trips, optimized routes, and predictive maintenance result in substantial cost savings for waste management companies and municipalities.
- Optimized routes and reduced vehicle idle time lead to significant fuel savings

2.4.3 Environmental benefits

- Fewer collection trips and optimized routes contribute to lower greenhouse gas emissions from waste collection vehicles.
- Fewer collection trips and optimized routes contribute to lower greenhouse gas emissions from waste collection vehicles.

2.4.4 Improved public health and hygiene

- Smart systems help prevent overflowing bins and litter, leading to cleaner and more hygienic public spaces.
- Proper waste management reduces the risk of disease transmission through waste-related contamination.
- Bins are emptied when needed, ensuring that they do not overflow and maintaining the aesthetic appeal of neighborhoods and public spaces.

2.4.5 Reduced environmental impact

Proper waste management prevents waste from contaminating water bodies and natural habitats. By reducing litter and pollution, smart systems contribute to the preservation of aquatic and terrestrial ecosystems.

2.4.6 Resource optimization

- Resources such as collection vehicles, personnel, and equipment are allocated more efficiently, reducing waste-related costs.
- Reduced pollution and waste-related health risks enhance public health and well-being.

2.5 Summary

- The problem is exacerbated by the growing population and urbanization trends, which are leading to increased waste generation and higher demand for efficient waste management systems.
- Waste collection services, today, are exhausted and unable to bear the burden of rising cities. It is one of the biggest ongoing challenges, being faced by developing economies.
- By leveraging sensor technology, data analytics, IoT, cloud computing, and mobile applications, the project seeks to revolutionize waste management practices in the country and create a more sustainable and livable environment.
- The researchers have proposed many techniques to resolve the issues related to waste management. In the RFID sensor was used to automate the waste-picking process.
- The lack of proper waste collection, transportation, and disposal systems has resulted in the accumulation of waste in public areas, including streets and open spaces, leading to pollution, disease, and aesthetic issues.
- Smart waste management systems contribute significantly to several United Nations SDGs due to their potential to improve resource efficiency, reduce environmental impact, and enhance the quality of life in urban areas.

- SWMS offers a wide range of benefits to municipalities, waste management companies, businesses, and communities. These benefits encompass economic, environmental, social, and operational advantages like efficient waste collection, cost savings, environmental benefits, resource optimization, improved public health and hygiene, etc.

Chapter 3

Project Management

3.1 Introduction

The project management chapter for the Smart Waste Management System aims to provide a comprehensive understanding of the planning, execution, monitoring, and control of the project. It outlines the strategies and methodologies used to ensure that the project is completed within the agreed timeline, budget, and quality standards.

3.2 Project objectives

- Collection of various types of waste, including solid waste, recyclables, and organic waste.
- Implementation of technologies and systems to sort and categorize waste for proper disposal or recycling.
- Reduce fuel consumption, emissions, and operational costs by optimizing waste collection routes based on real-time data, traffic patterns, and fill levels of bins.
- Optimization of waste collection routes to minimize fuel consumption and reduce carbon emissions.
- Monitoring and control of waste management costs, including labor, equipment maintenance, and fuel expenses.
- Contribute to the overall sustainability of the community or city by reducing waste, conserving resources, and supporting environmental goals.
- Development of mobile applications for residents or waste collection personnel.

3.3 Approach

Considering the nature of the project, an Agile software development model is well-suited. Agile methodology is a flexible and iterative approach to project management and software development that emphasizes collaboration, customer feedback, and the ability to adapt to changing requirements. Fig 3.1 represents the Agile model.

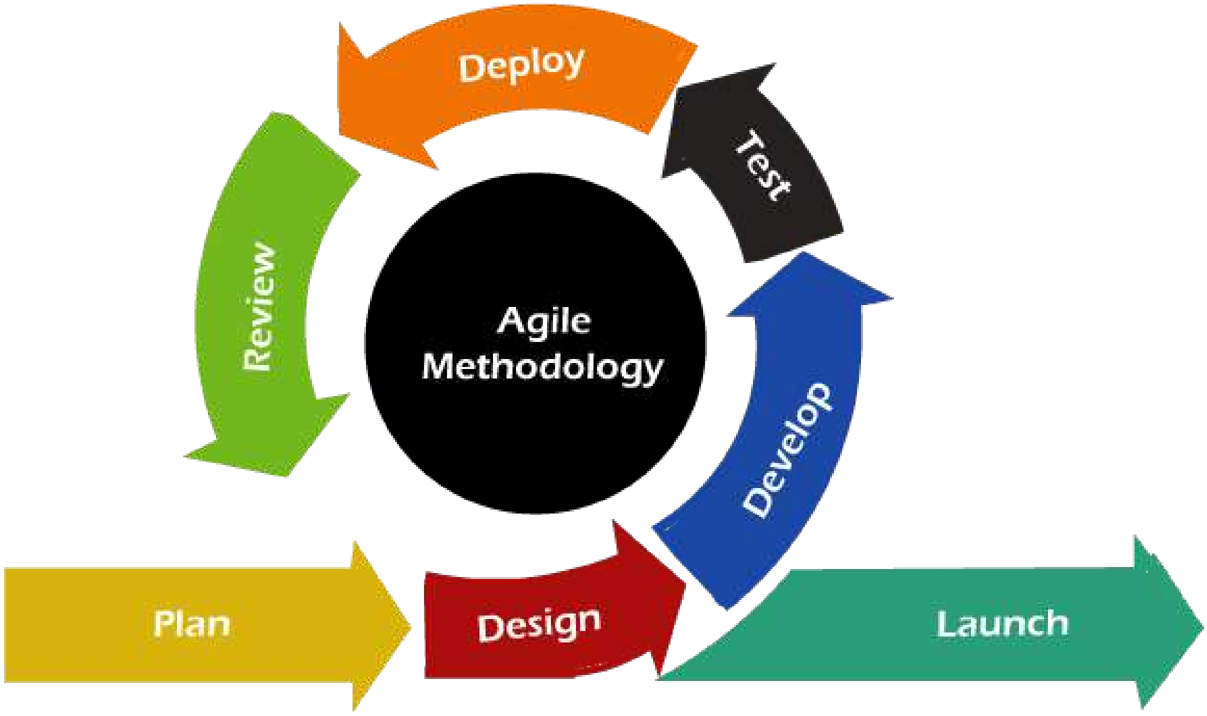

Figure 3.1: Agile model design.

3.3.1 Why agile?

The agile software development model enables the development team to prioritize and deliver the most critical features first, which is important for a project with a tight timeline and limited resources [14]. This approach ensures that the system's most important functions are available early on in the development cycle, allowing stakeholders to start using and benefiting from the system as soon as possible. Here are some key features of Agile methodology it is a strong choice for smart waste management systems.

Iterative development: Agile emphasizes iterative development with frequent reviews and adjustments. This approach is beneficial for smart waste management systems, where requirements may evolve, and it's important to adapt to changing environmental conditions, technology advancements, or user needs.

Flexibility: Agile allows for flexibility in responding to emerging issues or priorities. Waste management systems may need to adapt quickly to handle unexpected situations, such as increased waste generation during special events or emergencies.

Continuous improvement: Agile encourages a culture of continuous improvement. Smart waste management systems can benefit from ongoing enhancements, such as optimizing collection routes or introducing new recycling programs, to improve efficiency and sustainability.

Risk management: Agile approaches often include risk management strategies, making them suitable for addressing potential challenges and uncertainties that may arise during the implementation of a waste management system.

Collaboration: Agile promotes collaboration among cross-functional teams. In the context of waste management, this can facilitate coordination between technology developers, waste collection personnel, city planners, and environmental experts.

Adaptability to changing regulations: Waste management regulations may change over time. Agile methodologies can help organizations adapt to these changes by incorporating new compliance requirements into the system.

Complexity handling: Waste management systems can be complex, involving various components like sensors, data analytics, and user interfaces. Agile's ability to break down complex projects into manageable tasks can be advantageous.

3.4 Project gantt chart

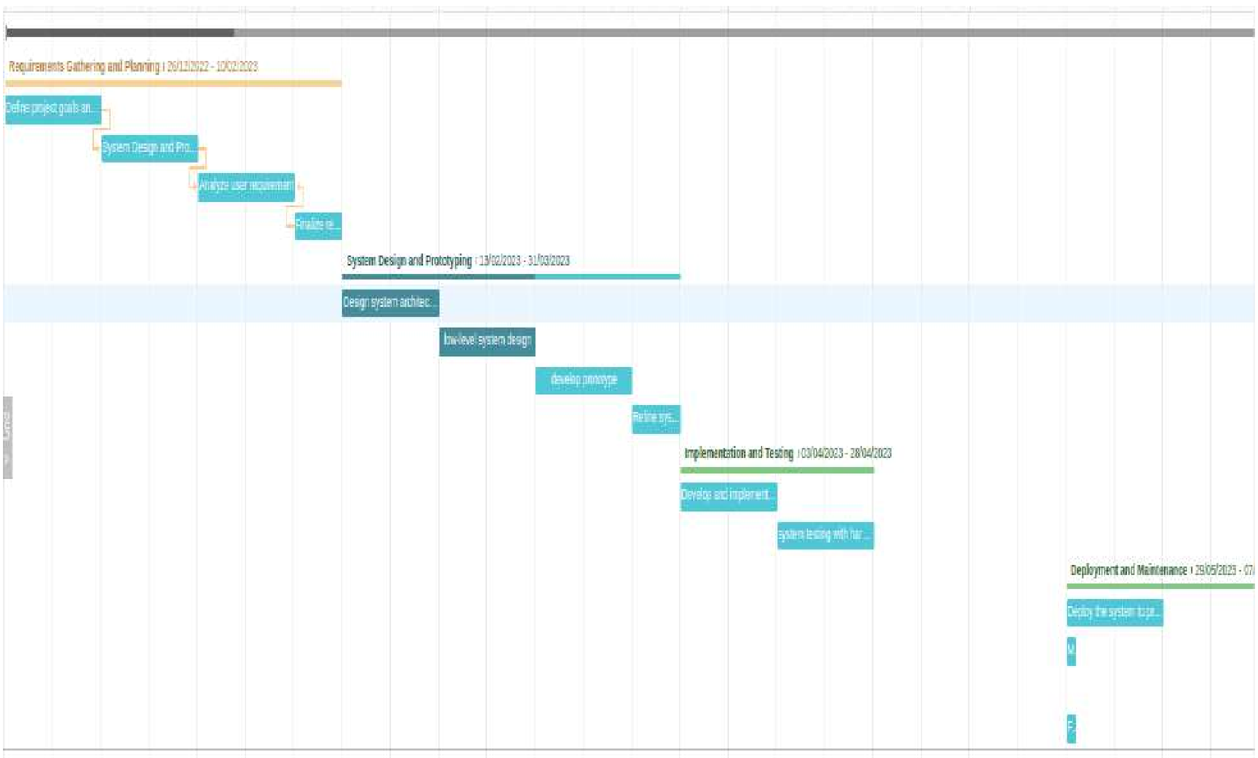

Figure 3.2: Project schedule plan

ID	TASK	START	END	DURATION
	Requirement gathering and planing	26/12/2022	10/02/2023	46
01	Analyze Requirements	26/12/2023	26/01/2023	30
02	Finalize requirements	25/01/2023	25/02/2023	16
	System design	11/02/2023	31/03/2023	50
03	Design and system architecture	11/02/2023	11/03/2023	30
04	Develop prototype	12/03/2023	31/03/2023	20
	Implementation and testing	01/04/2023	20/07/2023	110
05	Software development	01/04/2023	30/05/2023	60
06	Hardware development	02/06/2023	02/07/2023	30
07	Integrating hardware and software	04/07/2023	25/07/2023	20
	Testing	27/07/2023	20/08/2023	23
08	Website testing	07/07/2023	05/08/2023	8
09	Mobile application testing	07/08/2023	13/08/2023	7
10	Integration testing	20/08/2023	20/08/2023	8

Table 3.1: Project schedule plan

3.5 Initial project plan

The initial project plan for smart waste management involves various non-technical aspects that are crucial for the project's success. Here's a breakdown of the key components shown in table 3.1.

3.6 Problems and change to the plan

We face some problems one of the main challenges faced by the team during the project was the integration of hardware components with the software system. The team realized that the original plan did not account for the complexities involved in integrating the hardware with the software. As a result, the team had to re-evaluate the plan and make changes to ensure that the hardware and software components could work seamlessly together. The other Challenge was the lack of updated libraries for server and microcontroller connection.

3.7 List of complex engineering activities in final year project

Complex engineering attributes are the characteristics of engineering systems and products that make them difficult to design, develop, manufacture, and operate.

3.7.1 Depth of knowledge required

SWMS is a complex system that involves a variety of technologies, including smart waste bins, sensors, and a cloud-based platform. Additionally, SWMS need to be designed and operated in a way that is both efficient and effective. they need to understand how the smart waste bins work, how the data from the sensors is transmitted to the cloud-based platform, and how the data is analyzed to generate insights into waste generation and disposal patterns. They need to understand how the smart waste bins work, and how the data from the sensors is transmitted to the system. They need to be able to develop ways to use the data collected from the SWMS to optimize waste collection routes, and reduce fuel consumption. This knowledge is vital for creating an effective system that can optimize waste collection, reduce costs, and minimize environmental harm.

3.7.2 Range of conflicting requirements

Conflicting requirements include the need for efficient waste collection routes versus minimizing vehicle emissions. Balancing these conflicting requirements is essential. For example, conflicts can occur in different requirements: Cost vs effectiveness: A more effective SWMS will typically be more expensive to implement and operate. This is because more effective SWMS will typically involve more sensors and software. We use just one sensor at this initial level because it is providing the main functionality and is helpful for cost saving.

3.7.3 Extent of stakeholder involvement

Multiple stakeholders, such as waste collection agencies (Muslim Hand), municipalities, waste collector drivers, and the public, are involved. Collaborating with and addressing the needs of these stakeholders is a significant aspect of smart waste management system development. We developed the website including all the functionalities related to the admin (Companies) and mobile application for the waste collectors.

3.7.4 Interdependence

Various components of the system are interdependent. For example, the sensor network, and user interfaces must work together seamlessly. Changes in one component can have ripple effects on the entire system, making interdependence a crucial attribute to manage. The smart waste bins in a SWMS use software to collect data on the fill level. This data is then transmitted to the cloud-based platform using Wi-Fi. In this way our system website and mobile app both depend on hardware without hardware both can not give their functionalities. Also, mobile applications depend on websites for route generation.

3.8 Summary

- It outlines the strategies and methodologies used to ensure that the project is completed within the agreed timeline, budget, and quality standards.
- Complex engineering attributes are the characteristics of engineering systems and products that make them difficult to design, develop, manufacture, and operate.
- Agile methodology is a flexible and iterative approach to project management and software development that emphasizes collaboration, customer feedback, and the ability to adapt to changing requirements.
- Agile allows for flexibility in responding to emerging issues or priorities. Waste management systems may need to adapt quickly to handle unexpected situations, such as increased waste generation during special events or emergencies.
- Agile approaches often include risk management strategies, making them suitable for addressing potential challenges and uncertainties that may arise during the implementation of a waste management system.

Chapter 4

Analysis

4.1 Introduction

In this chapter, the team responsible for the project takes a deep dive into the requirements of the system, identifies the goals and objectives, and analyzes the current state of the system and its potential limitations. The primary objective of the analysis chapter is to ensure that the system is designed to meet the needs of the users and stakeholders, while also considering the limitations and challenges that may arise during the development process.

4.2 Use cases

Use cases refer to a specific scenario or application where the technology and capabilities of the system are employed to address a particular challenge or achieve a specific objective [15]. These use cases demonstrate how the SWMS can be practically applied to solve real-world problems and improve waste collection and disposal processes. Use cases often encompass a range of functionalities and benefits, from optimizing collection routes to reducing operational costs, enhancing public engagement, and promoting environmental sustainability.

4.2.1 Use-case for login

The table 4.1 outlines request garbage collection use case and their corresponding details for the smart waste management system, illustrating its versatile applications in optimizing waste collection and management processes.

4.2.2 Use-case for check bin status

The table 4.4 outlines the check bin status use case and their corresponding details for the smart waste management system, illustrating its versatile applications in optimizing waste collection and management processes.

4.2.3 Use-case for display map view

The table 4.3 outlines the map view use case and their corresponding details for the smart waste management system, illustrating its versatile applications in optimizing waste collection and management processes.

Table 4.1: Login use case

Use case properties	**Details**
Use Case 1	Login
ID	UC-02
Actor	User
Pre-condition	User must have a profile
Flow of Event	User must have a profile. User will Click on login Button. The website will allow the user to request garbage collection.
Secondary Scenarios	User can go for signup
Post Condition	App transfers control to the user main screen to proceed further actions

Table 4.2: Check bin Status

Use case properties	**Details**
Use Case	CheckBinStatus
ID	UC-04
Actor	User
Pre-condition	User must have a profile
Flow of Event	User will login. User will click on bin status button
Secondary Scenarios	None
Post Condition	User can request garbage collection or make Report

4.3 Non functional requirements

Firebase is used as a backend server. Firebase provides secure channels of data flow between app and the server. Firebase is providing full support for non-functional requirements:

- **Performance:** Firebase is a Real-time database. Changes in DB are reflected to all users within 2-3 seconds.

Table 4.3: Display map view

Use case properties	**Details**
Use Case	DisplayMapView
ID	UC-05
Actor	Admin, worker
Pre-condition	User must have a profile
Flow of Event	User will login. User will click on the bin management button. User will click on view on map.
Secondary Scenarios	You can plan routes
Post Condition	None

- **Reliability:** User data once transferred to Firebase or initiated from the app for transfer 100 percent reliably transferred to intended users. If a user loses his local data in an app reinstalling the app will provide the user with all the data.
- **Scalability:** The system can easily integrate new sensors and bins. Also, we have used cloud service Firebase which can easily scale up or down according to need.
- **Usability:** The system should be easy to use by both citizens and waste management professionals. This includes using clear and concise language, providing user guidance, and using accessible design.

4.4 Functional requirements

Table 4.4: Functional requirements

Requirement	Description
REQ-1	**Bin sensor data transmission:** Bin sensors or smart bins should accurately measure and transmit data on the fill level of waste containers.
REQ-2	**Waste monitoring**: The system should be capable of monitoring and collecting real-time data about waste generation, including fill levels of waste containers, types of waste, and location data.
REQ-3	**login:** Users must be able to sign in to the system using a valid username and password.
REQ-4	**Display map view**: The map display function must display a map of the desired area with waste bin locations.
REQ-5	**Manage waste collectors:** System must be able to manage waste collectors by adding collectors, removing collectors, assigning them to routes, tracking their progress, and providing feedback.
REQ-6	**Manage bins:** Users must be able to manage bins by creating, viewing, and updating them. This will help to ensure that bins are properly tracked and maintained.

Chapter 5

Product/System Design

5.1 Introduction

The smart waste management system's product design will leverage cutting-edge technologies such as IoT cloud computing, data analytics, and mobile applications to optimize waste collection, transportation, and processing as shown in Figure 5.1 [16]. The design will ensure seamless integration between the hardware and software components of the system, providing real-time data on waste generation, collection, and disposal. The user interface will be intuitive and user-friendly, enabling easy access to the system functionalities and feedback mechanisms.

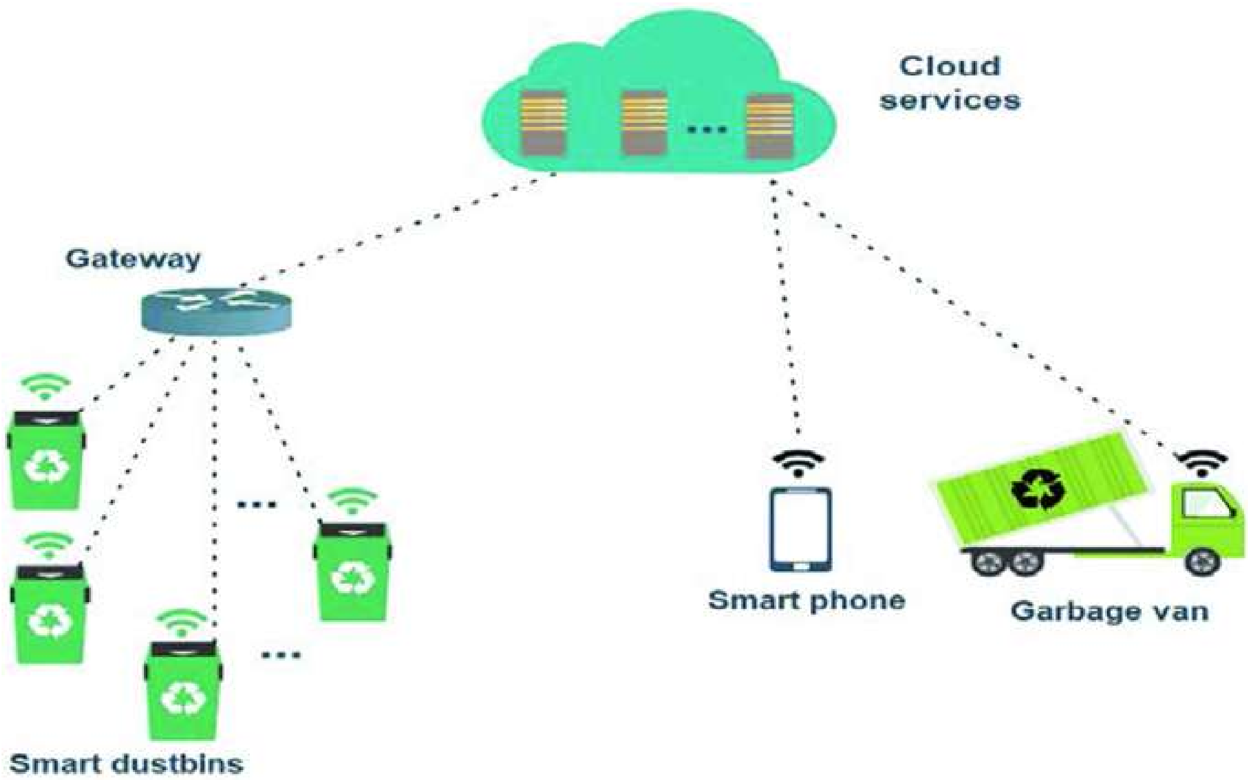

Figure 5.1: Application architecture diagram

5.2 Product features

The smart waste management system has the following features:

- The system will have sensors integrated into waste bins to monitor the waste level and notify the waste collection team when the bin is full.
- The system should have a cloud-based platform for storing and analyzing waste data in real-time, allowing for informed decision-making and optimization of waste management practices.

- The system will optimize the waste collection and transportation routes, reducing the travel time and fuel consumption while increasing the efficiency of waste management operations.
- The system will have a web application for users to report waste-related issues, provide feedback, and track the status of waste management operations.
- The system will have a user-friendly interface that is easy to use, allowing for seamless integration of the system with the waste management team's existing processes.

5.3 User interface

- Buttons
- Buttons
- Edit text
- Spinners
- Touchable icons
- Notification
- Pop-Up Verifications
- Slider
- Loading-Bar
- Image Views
- Placeholder
- Tab

5.4 Web interface

The website of smart waste management system is designed for administration it include following pages.

5.4.1 Bin management

The Bin Management page is a crucial component of our Smart Waste Management System, offering a comprehensive overview of the status and management of waste bins in your community as shown in Fig 5.2 This page provides essential tools and information for efficient waste collection and monitoring.

Bin status overview: Upon entering the Bin Management page, users are greeted with a visual representation of all waste bins within the designated area. Each bin is color-coded to indicate its current status: green for empty, yellow for partially full, and red for full. This at-a-glance view enables waste collectors to prioritize their routes effectively.

Bin details: Clicking on individual bins reveals detailed information, including the bin's location, capacity, and last collection date. This data helps waste collectors plan their routes and ensures that bins are serviced on schedule.

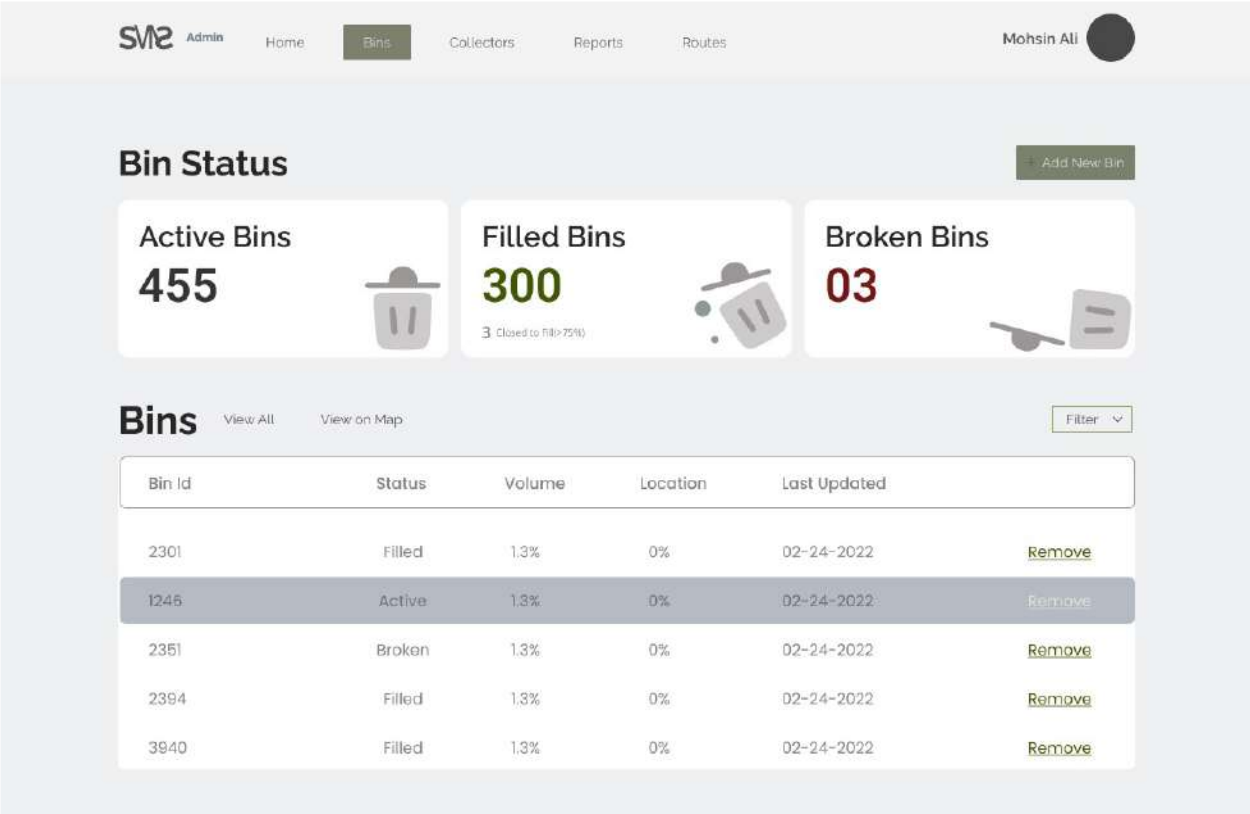

Figure 5.2: Bin management page

5.4.2 Collector management

The Collector Management page is a pivotal component of our SWMS, offering a comprehensive platform for managing waste collectors and optimizing their operations. It is shown in Fig 5.3 This page provides the tools and information necessary to ensure efficient waste collection and monitor the performance of waste collection personnel.

Collector profiles: Upon entering the Collector Management page, administrators can view profiles for each waste collector. These profiles include essential information such as the collector's name, employee ID, contact details, and work schedule. This centralized database streamlines the management of waste collection personnel.

Assignment and scheduling: Waste management administrators can assign specific routes and areas to individual collectors directly from this page. The scheduling feature allows for the efficient allocation of tasks and ensures that each collector's workload is balanced and optimized.

Work detail: The page provides real-time information about the work status of each collector, including their current location, ongoing tasks, and progress on assigned routes. This feature enhances transparency and enables supervisors to track collector efficiency.

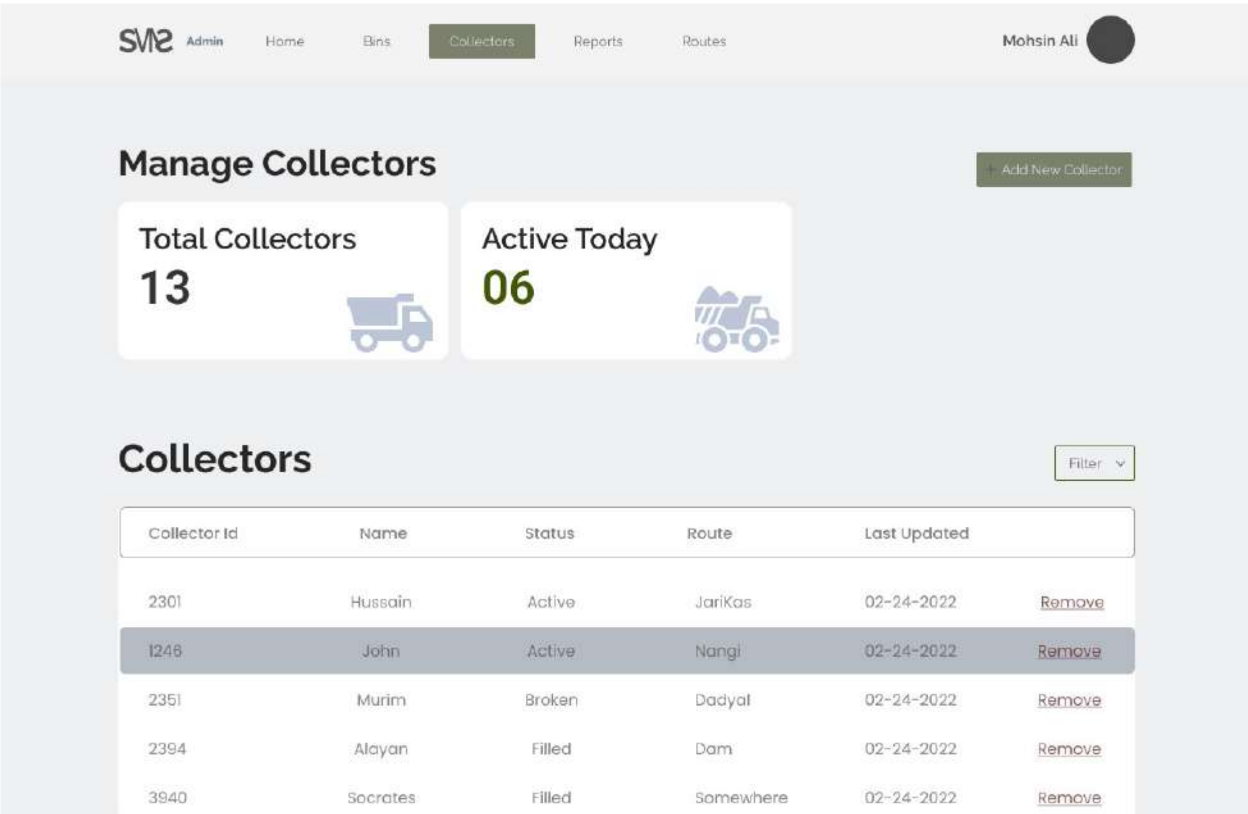

Figure 5.3: Collector management page

5.4.3 Routes management

The Routes Management page is a critical component of our SWMS, serving as the command center for planning, organizing, and optimizing waste collection routes as shown in Fig 5.4 This page provides a centralized platform for efficient route management and monitoring.

Route overview: Upon entering the Routes Management page, administrators and route planners are presented with an overview of all waste collection routes within the system. Each route is represented visually, displaying key details such as the route name, assigned collector, start and end times, and the areas covered.

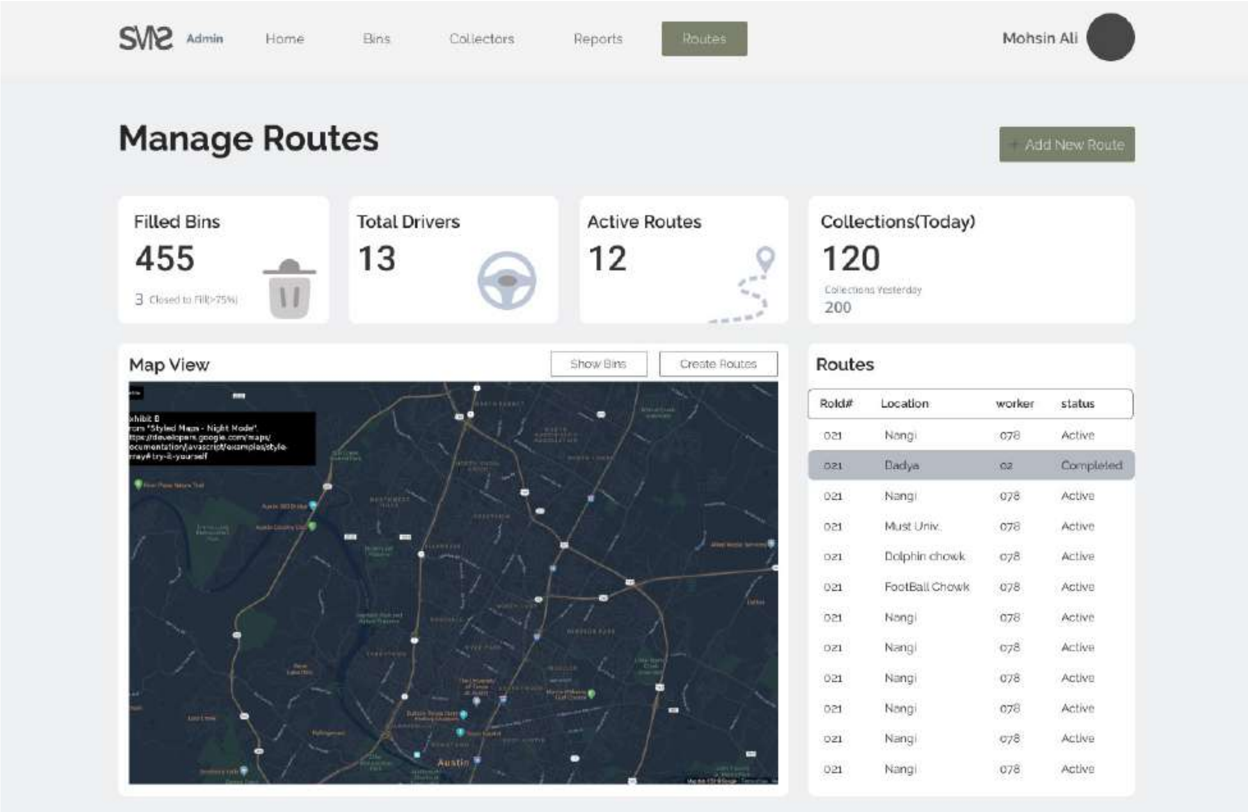

Figure 5.4: Routes management page

Route planning and creation: Route planners can create new routes, edit existing ones, or duplicate previously optimized routes directly from this page. The route planning feature allows for the selection of specific areas or zones for collection, taking into account factors such as bin fill levels and geographic proximity.

Alerts and notifications: The page includes a notification system to alert administrators and collectors to critical events or issues during route execution. These alerts help ensure that any deviations from the planned route are addressed promptly.

5.4.4 Add new bin

The "Add New Bin" page is a vital component of our Smart Waste Management System, facilitating the seamless integration of new waste bins into the system. This page streamlines the process of adding bins to the network, ensuring efficient and effective waste collection. It is shown in Fig 5.5

Bin information: Upon accessing the "Add New Bin" page, authorized users can input essential information about the new waste bin. This includes details such as the bin's location, and any unique identifiers.

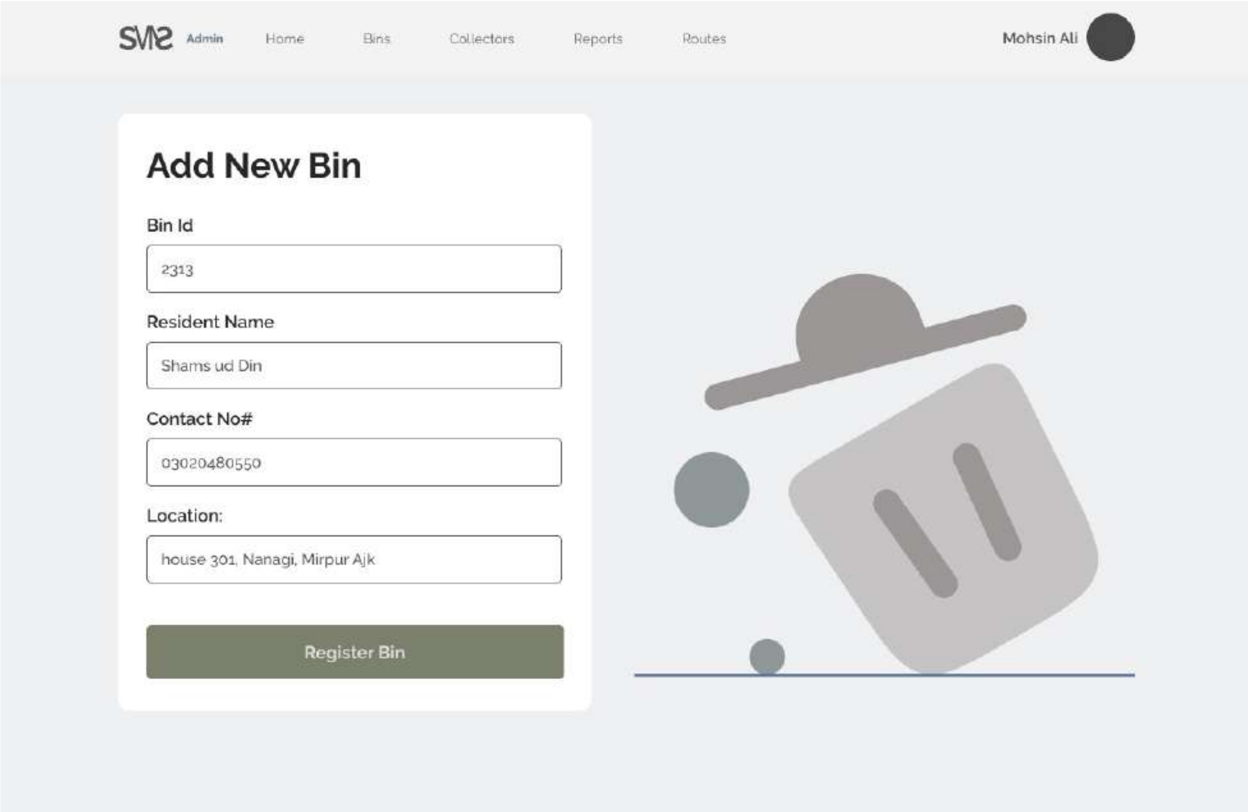

Figure 5.5: Add new bin page

5.4.5 Add new collector

The "Add New Collector" page is a pivotal feature of our SWMS, facilitating the seamless onboarding of new waste collectors into the system as shown in Fig 5.6 This page simplifies the process of adding and managing collector profiles, ensuring efficient workforce management.

Collector information: When accessing the "Add New Collector" page, authorized users can input essential information about the new waste collector. This typically includes the collector's full name, contact details, employee ID, and work schedule.

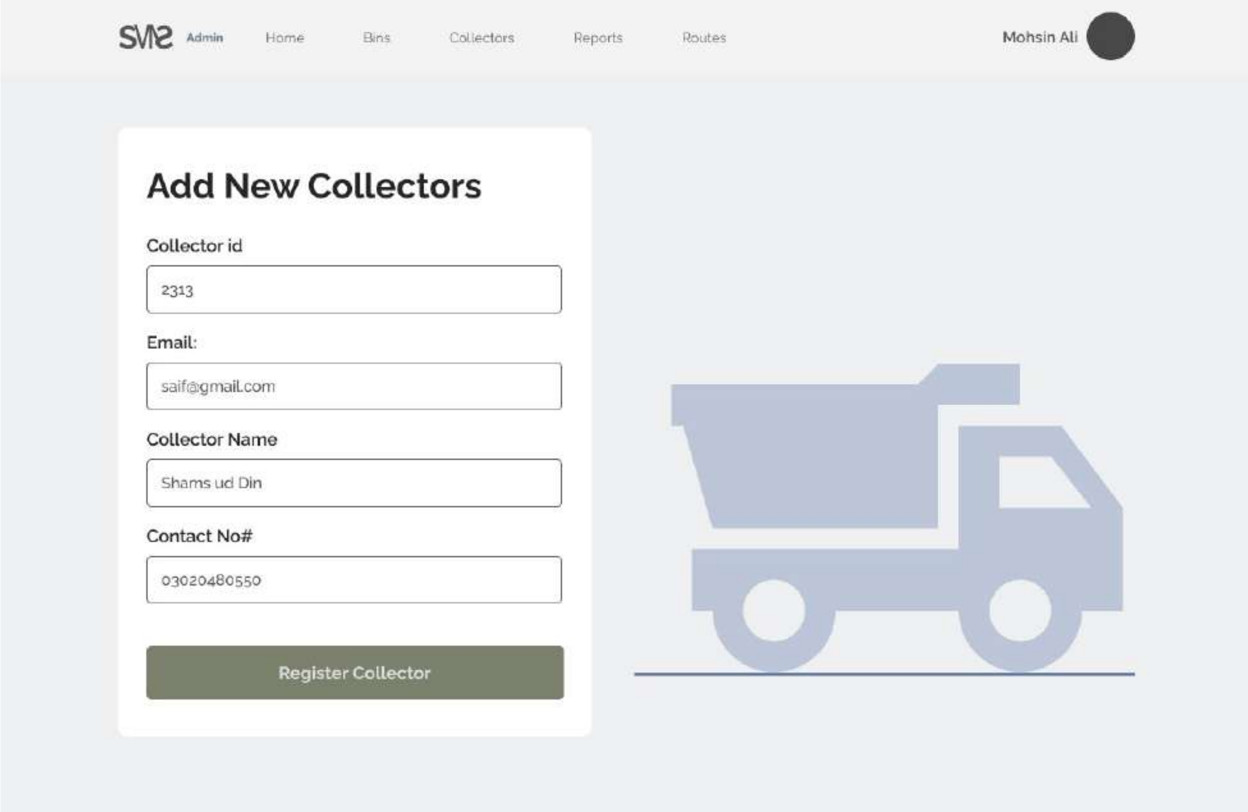

Figure 5.6: Add new collector page

5.5 Android application interface

Android app consists of the following pages:

5.5.1 Login page

The login page of the Smart Waste Management System is the starting point for users to access the platform securely. It offers features to enhance user experience, security, and accessibility while providing essential information and support options. It is shown in Fig 5.7

5.5.2 Home page

The home page of our Smart Waste Management System App serves as the central hub for efficient waste collection and management. It provides users with an overview of the app's key features and functionality as shown in Fig 5.8

Collector information: The home page prominently displays information about the assigned waste collector, including their name, unique identifier (employee ID), contact details, work shift timing,

Figure 5.7: Login page

and the specific area they are responsible for following tasks.

Figure 5.8: Home page

Generated routes: Users can access a list of routes generated for the collector on that particular day. Each route includes details such as start and end times, as well as the stops the collector will make during their route. This information helps users understand when waste collection will occur in their area.

Live tracking: The app offers real-time tracking functionality, allowing users to monitor the collector's progress as they follow their designated routes. This feature enhances transparency and ensures that waste collection is carried out efficiently.

5.6 Summary

- The design will ensure seamless integration between the hardware and software components of the system, providing real-time data on waste generation, collection, and disposal.
- User interfaces include the following UI elements Buttons, labels, edit text, spinners, etc.
- Reliability, maintainability, portability, and usability are the non-functional requirements of SWMS.

Chapter 6

Software Design

6.1 Introduction

Software Design involves transforming the system requirements into a detailed system design that meets those requirements while adhering to best practices for software development. This chapter will provide an overview of the software design process, including the tools and techniques used to create an effective design. The design phase is important because it is the phase in which the overall architecture of the system is defined and the different components are specified. The design phase also includes the development of use cases and class diagrams, which are used to understand the different ways in which the system will be used and the different components that make up the system.

In the design phase of our SWMS, we embark on the journey of transforming conceptual ideas into concrete technical plans. This pivotal phase encompasses the creation of a comprehensive system architecture that forms the backbone of our waste management solution [17]. Our design efforts extend to the development of Unified Modeling Language (UML) diagrams, which serve as invaluable tools for visualizing system components, interactions, and data flow. Here are some of the key steps involved in the design phase of a SWMS:

This may include smart waste bins, sensors, cloud-based software, and mobile apps. The developers will need to determine the functionality of each component and how they will interact with each other. The communication network will connect the different components of the system and allow them to exchange data. The developers will need to select a communication network that is reliable, secure, and cost-effective. Use cases describe the different ways in which the system will be used. Class diagrams show the different components of the system and how they interact with each other. Use cases and class diagrams can be used to validate the design of the system and to identify any potential problems.

6.2 Use case diagram

The use case diagram shows the different relationships between the actors and the use cases. For example, the user actor can perform the "Request waste collection services" use case. The waste collection worker actor can perform the "check bin status" use case and the "get map view" use case.

The use case diagram is a useful tool for understanding the different ways in which a SWMS can be used. It can also be used to identify the different requirements for the SWMS. For example, the

SWMS needs to be able to support the "Report an overflowing waste bin" use case, which means that it needs to be able to receive and store reports from residents about overflowing waste bins. Our system includes two actors admin and collectors admin interact with the website and collectors interact with the mobile application.

6.2.1 Use case diagram for admin

In a Use Case Diagram for an Admin as the primary actor in a Smart Waste Management System, you would typically have the following use cases:

Login: The admin needs to log in to the system with their credentials to access the system.

Manage Bins: The admin can manage the smart waste bins, including adding new bins, updating bin information, and removing bins from the system.

Monitor Waste Levels: The admin can monitor the waste levels in the bins in real-time. This use case may involve viewing graphical representations of waste levels. Manage Users: The admin can manage user accounts, including adding new users, updating user information, and deactivating user accounts.

Logout: The admin logs out of the system to secure their session.

These use cases represent the key interactions and functionalities that the admin would perform in the context of a Smart Waste Management System. The use case diagram would visually represent these relationships between the admin actor and the system's use cases. The use case diagram of SWMS for admin is shown in Fig 6.1.

6.2.2 Use case diagram for collectors

In a Use Case Diagram for a Collector who interacts with a mobile app for waste collection, you would typically have the following use cases:

Login: The collector needs to log in to the mobile app with their credentials to access their account and perform actions.

View Assigned Bins: The collector can view a list of waste bins assigned to them for collection. This use case may involve displaying bin details and locations.

View Collection Route: The mobile app can provide the collector with a route map to efficiently navigate to the assigned bins.

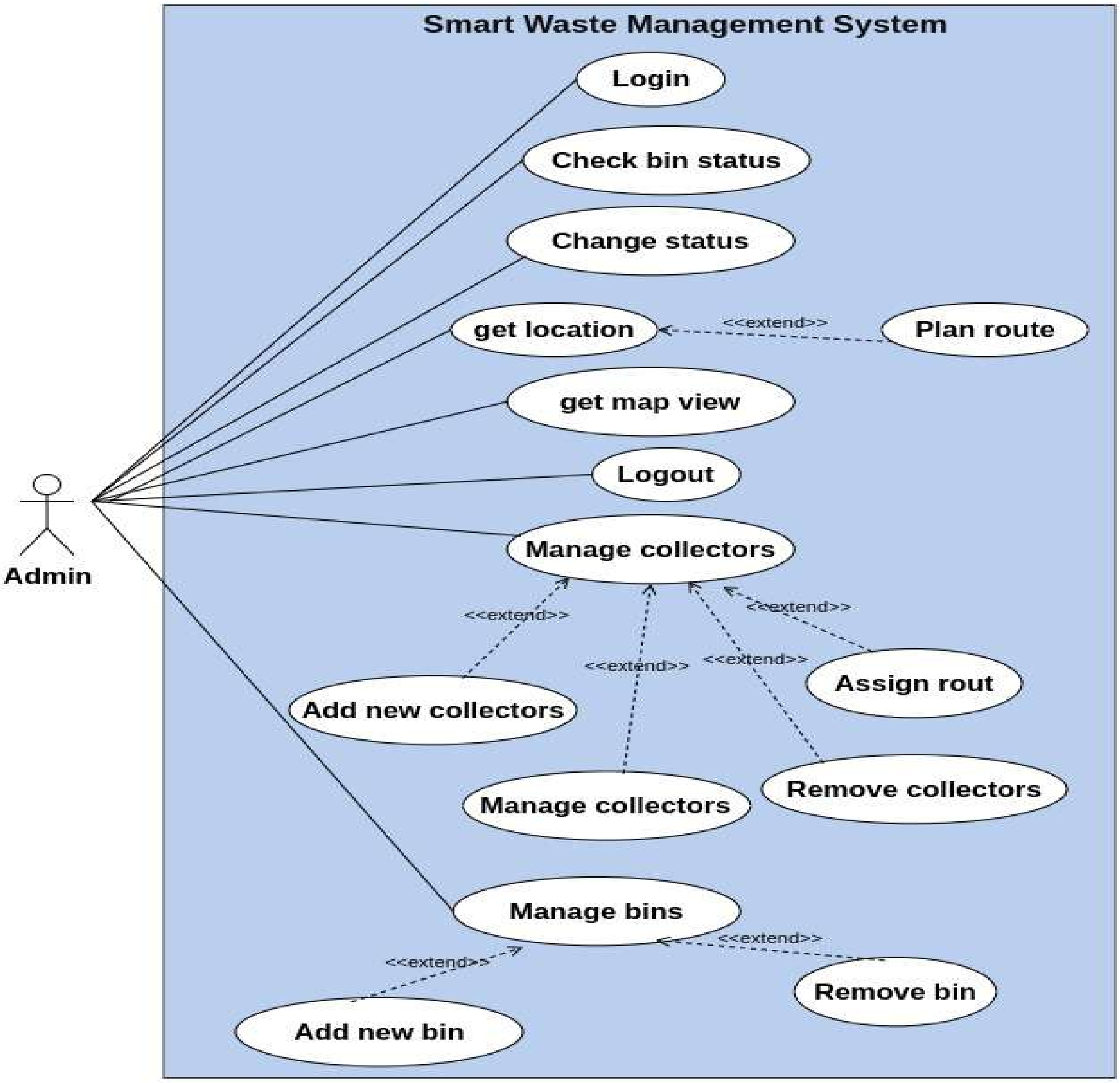

Figure 6.1: Use case diagram

View Bin Details: Collectors can access detailed information about each bin, including its capacity and collection schedule.

Receive Notifications: The mobile app can push notifications to the collector's device regarding route changes, new assignments, or important updates.

Logout: The collector logs out of the mobile app to secure their session. These use cases represent the key interactions and functionalities that a waste collector would perform through a mobile app for waste collection. The use case diagram would visually represent these relationships between the collector actor and the mobile app's use cases. The use case diagram of SWMS for admin is shown in Fig 6.2.

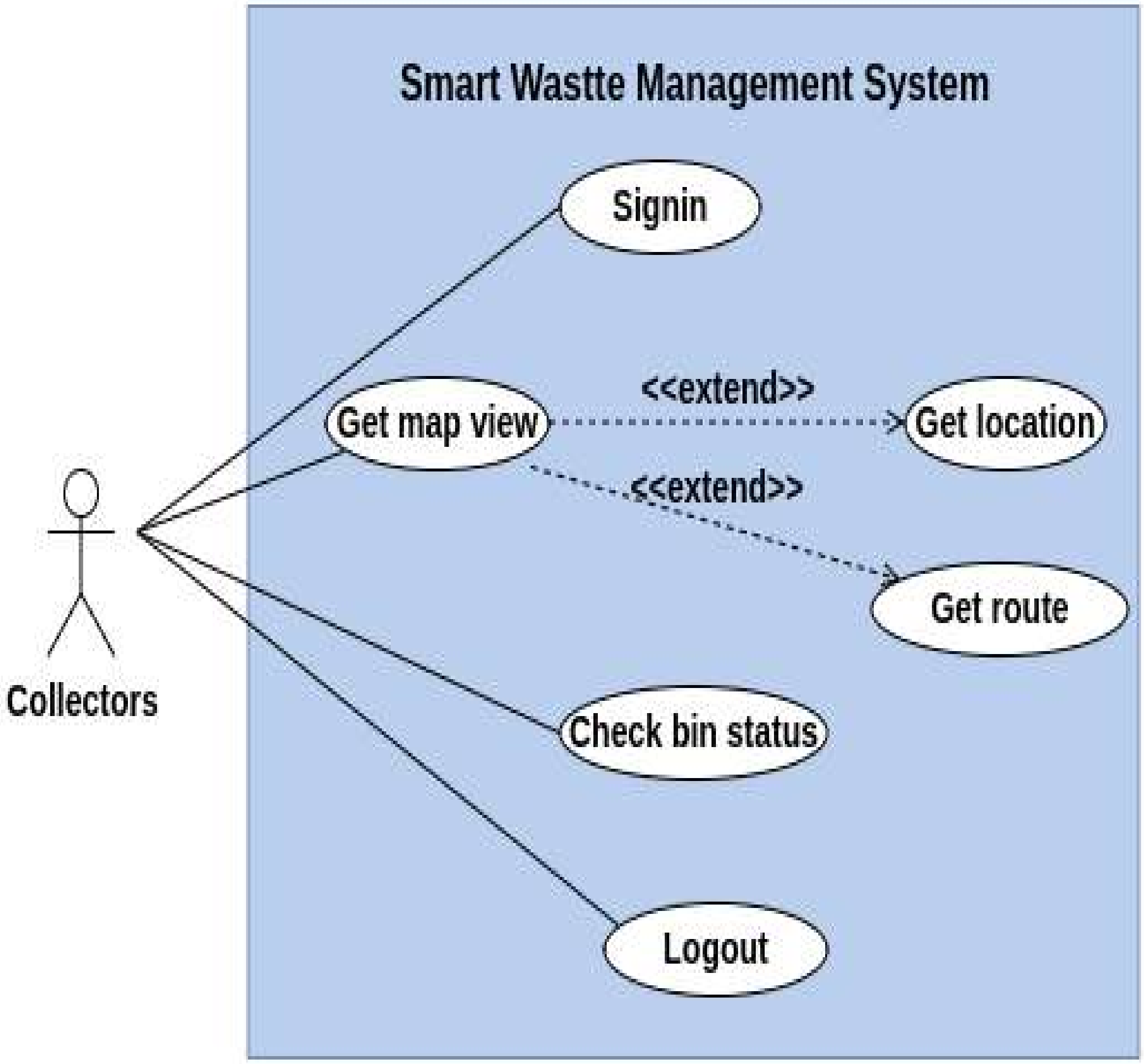

Figure 6.2: Use case diagram

6.3 Sequence diagram

In the realm of our SWMS, the sequence diagram serves as a vital visual tool, offering a dynamic portrayal of how various system components and actors interact over time to achieve specific tasks and functionalities. As we delve into this sequence diagram, we gain a deeper understanding of the intricacies behind the scenes, where the coordination of sensor data, user requests, and system processes seamlessly unfolds. The sequence Diagram for SWMS is shown in Fig 6.3.

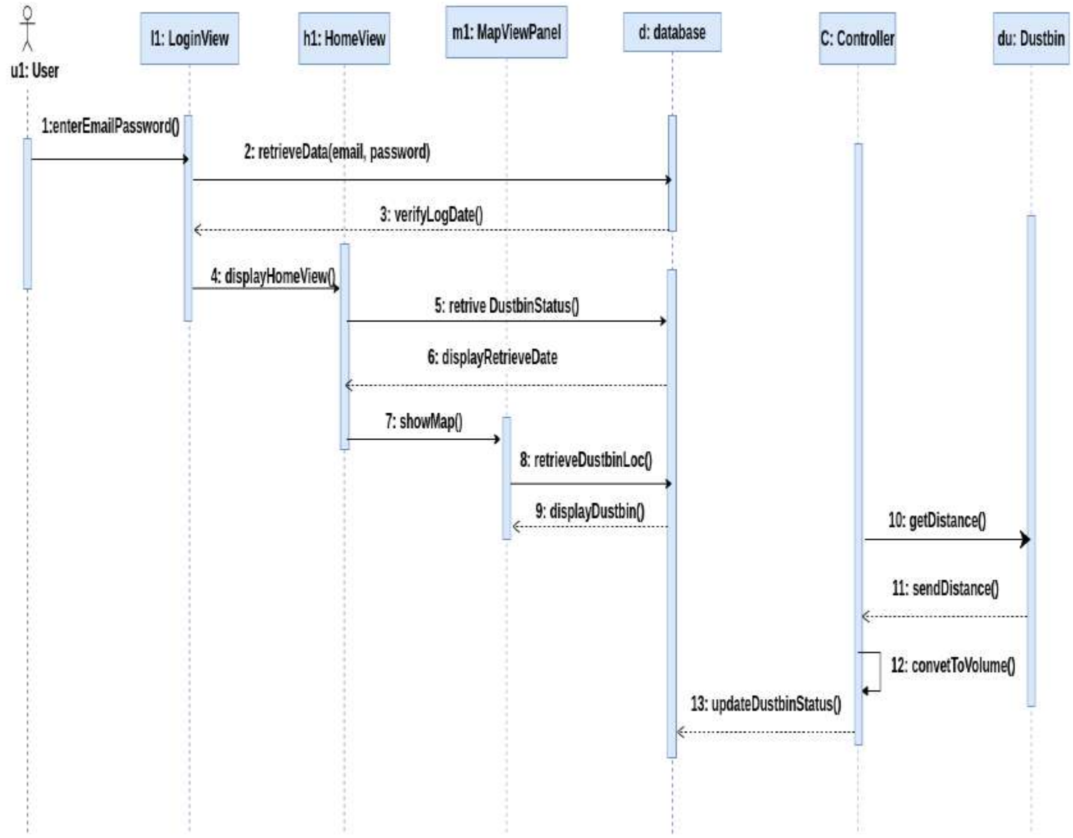

Figure 6.3: sequence diagram

6.4 Activity diagram

In SWMS, the activity diagram plays a pivotal role in visually representing the dynamic flow of activities and processes that underpin the efficient management of waste. This diagram provides a comprehensive view of the system's operations, illustrating how different tasks and actions interact to achieve the overall goal of optimizing waste collection and enhancing sustainability. It is explained in 6.4.

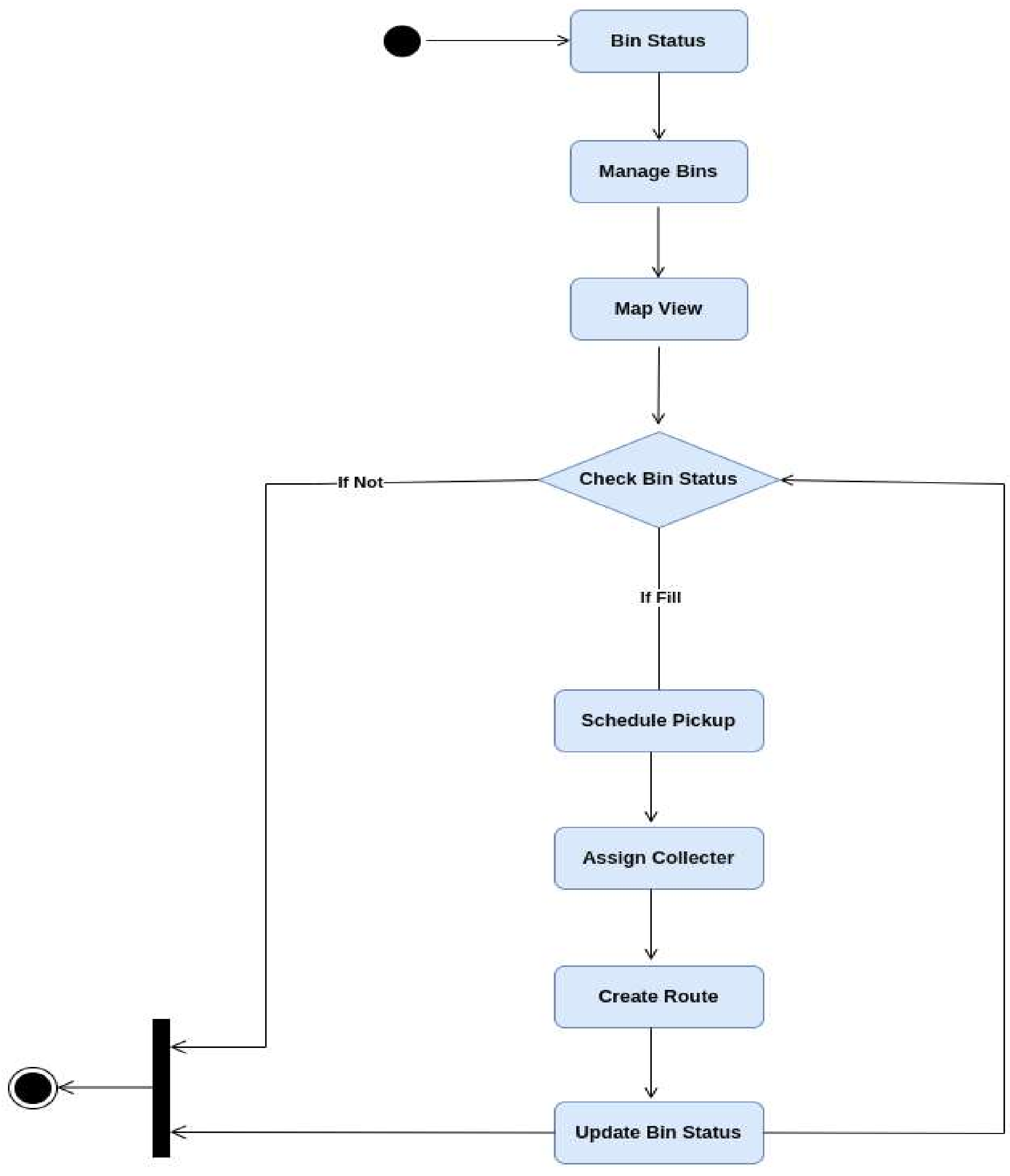

Figure 6.4: Activity diagram

6.5 Class diagram

The class diagram is used to identify the different types of data that need to be stored in the SWMS. For example, the class diagram shows that the WasteBin class has attributes such as fill level, waste type, and location. This means that the SWMS needs to store this information for each smart waste bin. It also be used to identify the different operations that the SWMS needs to support. For example, the class diagram shows that the Smart Waste Bin class has a emptyBin() method. This means that the SWMS needs to be able to support the operation of reporting overflowing waste bins. It is also used to identify the different security requirements for the SWMS. For example, the class diagram shows that the Database class has a verifyEmail() method. This means that the SWMS needs to be able to authenticate and authorize city officials before allowing them to view the performance of the system.

The class diagram for SWMS is shown in Fig 6.5.

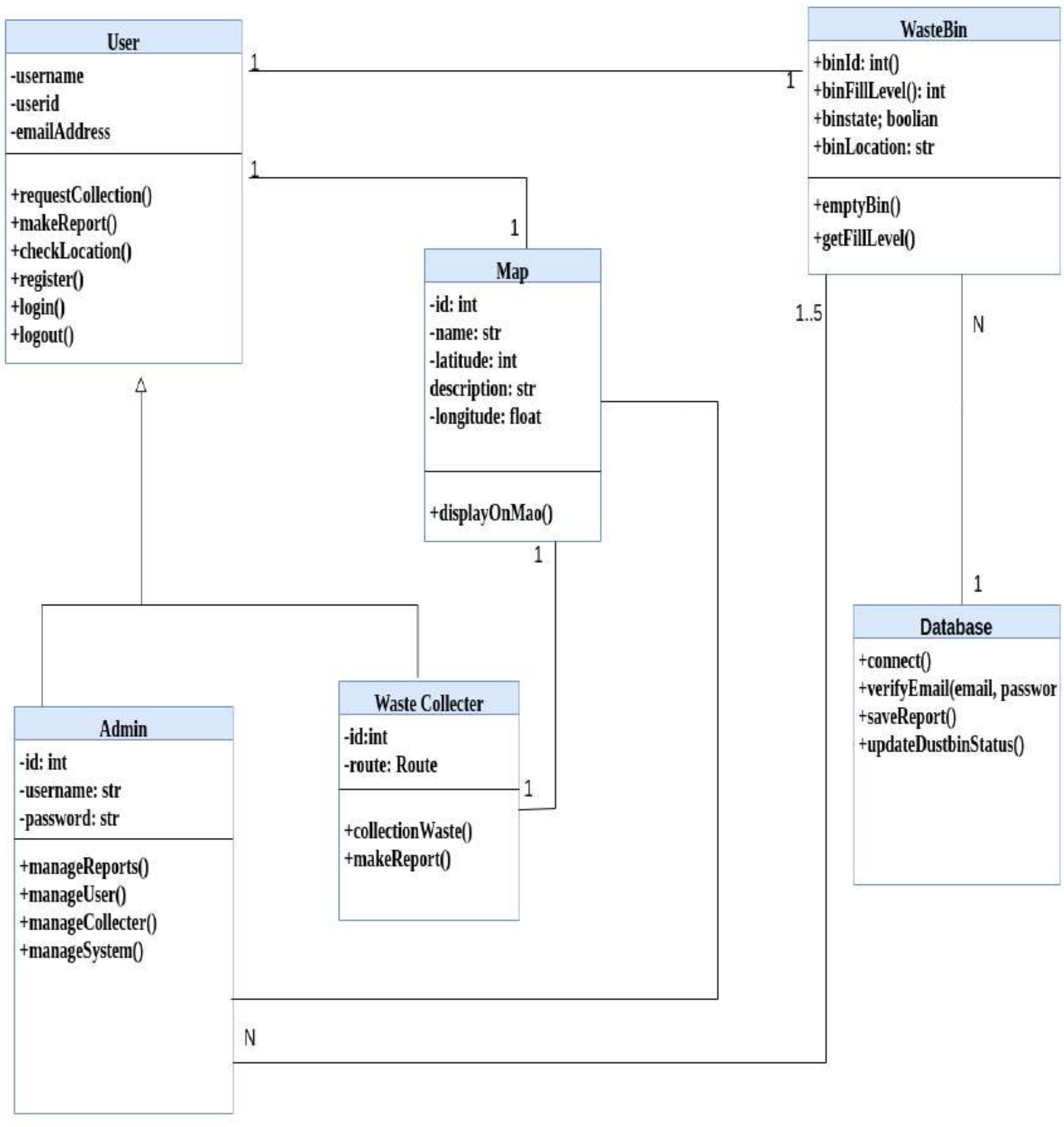

Figure 6.5: Class diagram

Chapter 7

Implementation

7.1 Introduction

Smart Waste Management System is implemented in React Native (RN) for Android phone for website JavaScript (React js) is used. For hardware, we have Installed the necessary infrastructure to support our SWMS. This involves setting up sensor networks, communication systems (e.g., Wi-Fi), and data storage solutions. The following Development environment is used while developing SWMS:

- Firebase
- React Native
- MS Word for documentation
- Visual Paradigm for system design and diagrams
- Visual Studio Code

7.1.1 Languages

User/Application End languages:

- JavaScript (react js)
- HTML
- CSS

7.2 Hardware component

Details of all hardware components used in the smart waste management system are below:

7.2.1 Ultrasonic sensor

An ultrasonic sensor is a device that uses sound waves to detect the presence, distance, and other characteristics of objects or obstacles in its vicinity as shown in Figure 7.1. It works on the principle of echolocation, similar to how bats and dolphins navigate using sound waves [18]. Ultrasonic sensors are commonly used in various applications. It includes the following components:

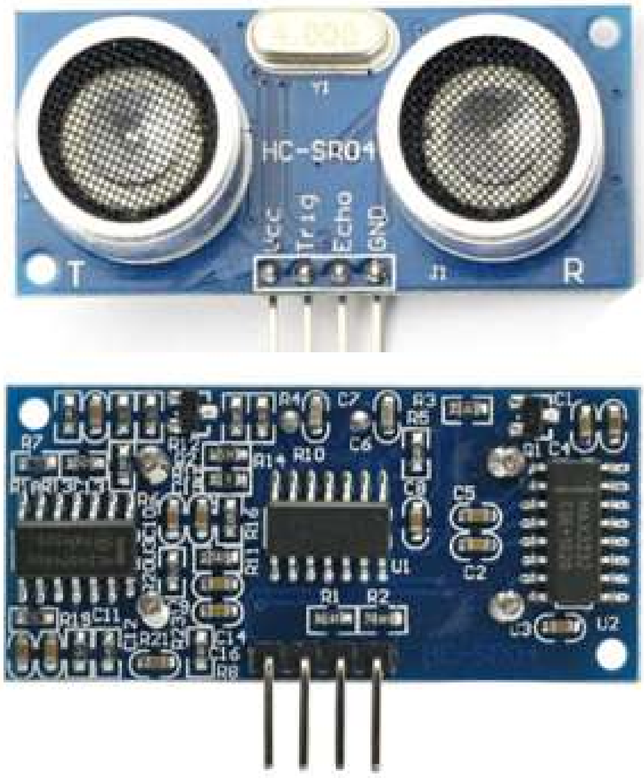

Figure 7.1: Ultrsonic diagram

- Transmitter
- Sound Waves Travel
- Object Detection
- Receiver

7.2.2 GPS module (Neo -6M)

GPS module is a device that receives signals from a network of satellites to determine its precise location on Earth. It is commonly used in various applications, including navigation systems, vehicle tracking, asset tracking, outdoor sports, and location-based services in smartphones[19]. It is shown in Figure 7.2. Here's how it works:

Satellite constellation: The GPS system consists of a constellation of at least 24 satellites orbiting the Earth. These satellites are spread out in different orbital planes to provide global coverage.

Figure 7.2: GPS module

Satellite signals: Each GPS satellite broadcasts signals continuously. These signals contain information about the satellite's identity and its precise location in orbit, as well as a very precise timestamp.

GPS receiver (Module): GPS module on your device is a specialized receiver that is capable of picking up signals from multiple GPS satellites. It contains:

- **Antenna**: The antenna is responsible for capturing the signals from the satellites. It needs a clear line of sight to the sky for optimal reception.
- **RF (Radio Frequency) Front-end:** This part of the module processes the signals received by the antenna.
- **Signal processor:** The signal processor decodes the information from the satellites' signals, including the satellite's position and the time the signal was transmitted.

7.2.3 ESP32 microcontroller

The Electronic stability control (ESP) 32 started a small revolution by bringing Wi-Fi to a small and cheap package that also had enough processing power and enough pins to get small things

Figure 7.3: ESP 32

done. Now get ready to take your bite-sized Wi-Fi capabilities to the next level with the ESP 32 development board. It is shown in Fig 7.3 It is a popular microcontroller and system-on-chip (SoC) that is widely used in the field of embedded systems, IoT, and other applications[20].

Dual-core processor: The ESP32 features a dual-core Tensilica Xtensa LX6 processor, which allows it to handle multiple tasks simultaneously. This is especially useful for applications that require real-time processing or multitasking.

Wireless connectivity: One of the standout features of the ESP32 is its built-in Wi-Fi and Bluetooth capabilities. It supports both 2.4 GHz Wi-Fi (802.11b/g/n) and Bluetooth Classic (Bluetooth 4.2) as well as Bluetooth Low Energy (BLE).

Memory: The ESP 32 typically comes with varying amounts of Flash memory (for program storage) and RAM (for data storage and program execution). The available memory configurations can vary between different ESP32 modules.

GPIO pins: The ESP32 has a significant number General Purpose Input/output (GPIO) pins, which can be used to interface with various sensors, displays, and other peripherals.

7.2.4 Breadboard and jumper wires

Breadboards are one of the most fundamental pieces when learning how to build circuits. In this tutorial, you will learn a little bit about what breadboards are, why they are called breadboards, and how to use them. [**undated-sl**]

Layout: A typical breadboard consists of a rectangular plastic base with numerous small holes

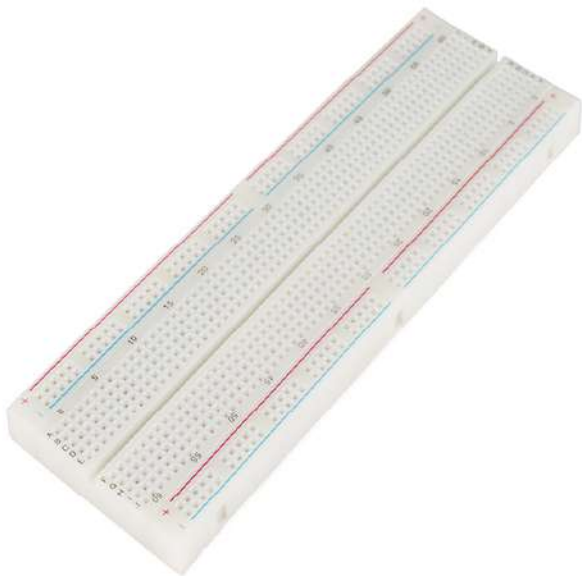

Figure 7.4: Breadboard

arranged in a grid pattern. These holes are used to insert and connect components.

Terminal strips: The holes are organized into rows and columns, with each row containing multiple holes connected internally. The rows are often labeled with numbers, while the columns are labeled with letters. The rows are typically used for connecting components and wires, while the columns are used for power distribution.

Power rails: Many breadboards have two vertical rows of holes on the sides, separated by a gap. These are called power rails. One rail is often labeled as "+," representing the positive voltage, and the other is labeled as "-", representing the ground (or 0V) reference. These rails allow you to easily distribute power to your circuit components. It is shown in Figure 7.4 [**noauthor_2015-zn**].

7.3 Codiing

For waste collection personnel who are constantly on the move, we've developed a dedicated Android application using the RN framework. This cross-platform app offers real-time access to assigned routes, bin locations, and navigation assistance. Collectors can easily update bin statuses, whether they are full, partially full, or empty, ensuring that the system's data remains accurate and up-to-date.

The hardware backbone of our system relies on Arduino-based sensors and microcontrollers strategically placed within waste bins. Ultrasonic sensors accurately measure fill levels, temperature sensors monitor environmental conditions, and GPS modules provide precise bin location data. These sensors are connected to Arduino microcontrollers, which efficiently process the data and transmit it to the central system using Wi-Fi or cellular connectivity.

7.4 Hardware implementation

In our smart waste management system, we have several IoT devices, including an Ultrasonic sensor, GPS module, ESP32 microcontroller, breadboard, jumper wires, and a battery. These devices work together to collect data and communicate with each other. Here's an explanation of how these devices communicate with each other as shown in Fig 7.5.

7.4.1 Ultrasonic sensor

The ultrasonic sensor is used to measure the fill level of the smart bin. It works by emitting high-frequency sound waves and measuring the time it takes for the sound waves to bounce back after hitting the bin's contents. This time measurement is used to calculate the bin's fill level[21]. The ultrasonic sensor communicates with the ESP32 microcontroller using GPIO pins. It sends distance data to the ESP32, which interprets it as fill-level data.

7.4.2 GPS module

The GPS module, in this context, might not be directly related to measuring the bin's fill level but can still be used to track the bin's location. It communicates with the ESP32 through UART or SPI as before, providing geographical coordinates that can be associated with the bin's position.

7.4.3 ESP32 Microcontroller

The ESP32 microcontroller acts as the central processing unit for the smart bin. It interacts with both the ultrasonic sensor and GPS module as follows:

Ultrasonic Sensor Interaction: The ESP32 reads distance data from the ultrasonic sensor, which

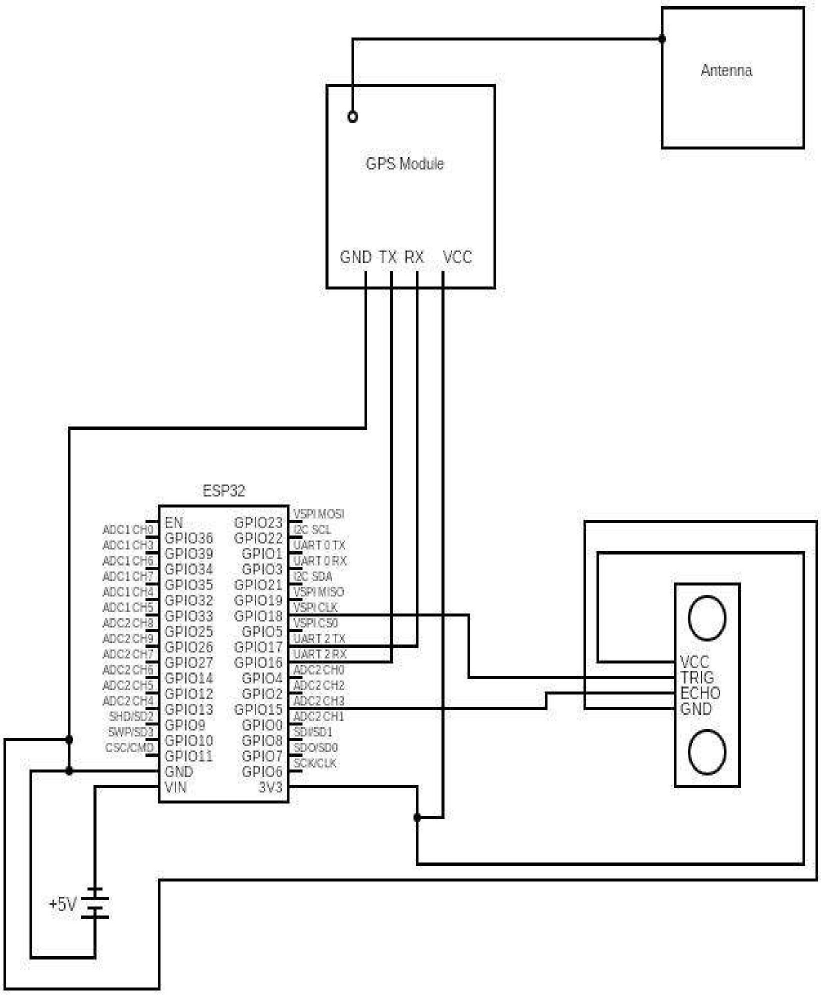

Figure 7.5: Circut diagram

corresponds to the fill level of the bin. It processes this data locally to determine when the bin is nearing full capacity. When a threshold is reached, it prepares to send a fill-level update to the central system.

GPS module interaction: The ESP32 receives location data from the GPS module, which can be used to track the bin's position. This information can be sent to the central system to provide location data alongside the fill level.

7.4.4 Breadboard and Jumper wires

The breadboard and jumper wires are used to create the necessary electrical connections between the ultrasonic sensor, GPS module, ESP32 microcontroller, and the power source (battery). They ensure that power, ground, and data signals are appropriately connected among these components.

7.4.5 Battery

The battery serves as the power source for the entire system. It supplies power to the ESP32, ultrasonic sensor, GPS module, and other components on the breadboard. The ESP32 manages power consumption and can implement power-saving strategies to prolong battery life.

7.4.6 Communication and data handling

The ESP32 is responsible for handling data from both the ultrasonic sensor and GPS module. It performs tasks such as: Processing fill level data from the ultrasonic sensor and determining when to trigger data transmission. Collecting location data from the GPS module to track the bin's movements and associate it with fill-level data. Sending bin fill level and location data to a central server or cloud-based platform using its built-in Wi-Fi or other wireless communication options (e.g., cellular connectivity if available). Communication between different components is shown in7.6.

7.5 Software implementation

Smart waste management systems rely on a variety of software applications to collect data from sensors, track waste collection vehicles, optimize waste collection routes, and generate reports. Software implementation of SWMS includes the following key points:

7.5.1 Web application

At the core of our system is a robust web application developed using web technologies such as HTML5, CSS, and JavaScript (React JS). This web-based interface serves as the nerve center for waste management administrators. It offers a feature-rich dashboard that provides insights into waste bin statuses, and collection routes. It is specially developed for the admin of SWMS.

The web application will provide an interface for stakeholders to interact with the system. The web application will be used by customers to request waste collection services, report issues, and receive notifications. The application will also display real-time information about the fill level of nearby waste bins and suggest the nearest available waste collection vehicle.

Some possible technical details for the smart waste management system website using React framework and Firebase are the following:

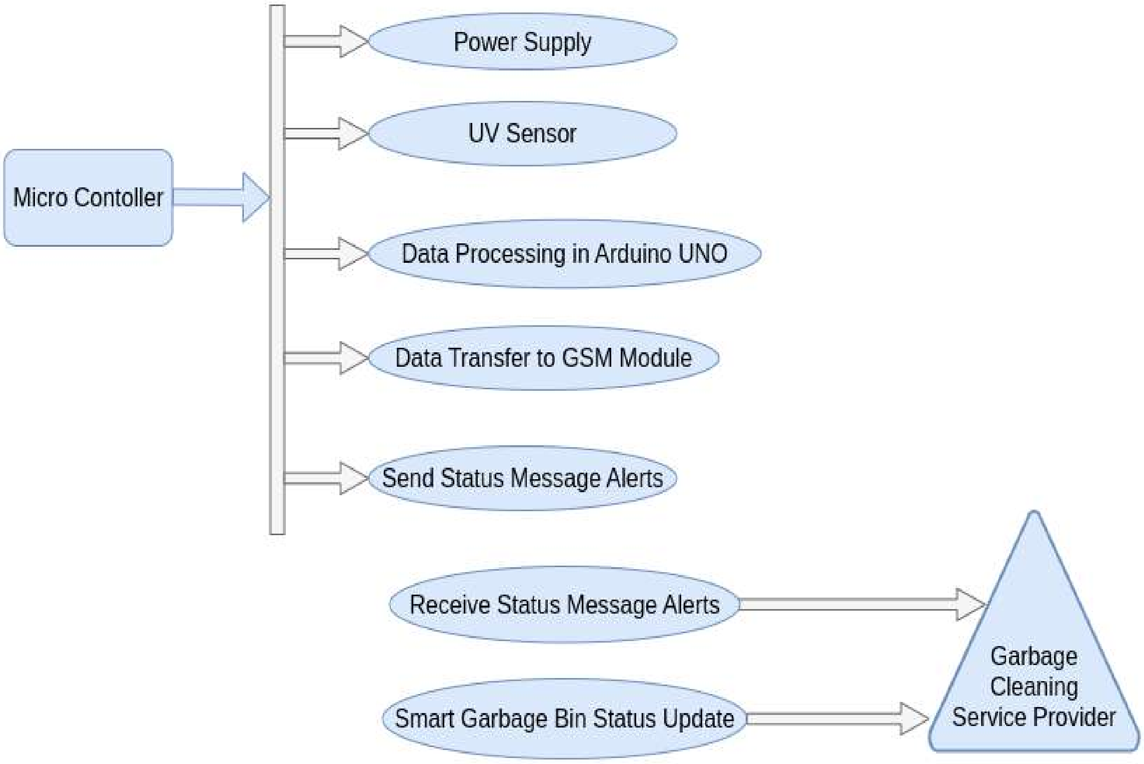

Figure 7.6: Hardware components communication

Architecture: The web application will be designed using a client-server architecture, with the client being the web browser and the server being the Firebase cloud infrastructure. The server-side code will be implemented using Firebase functions, while the client-side code can be implemented using React framework.

User interface: The web application's user interface will be designed using the React framework along with popular UI libraries like Material-UI or Ant Design. The UI should provide stakeholders with real-time access to the data generated by the system, such as the fill level of waste bins, the location of waste bins, and the routes of waste collection trucks.

Data storage: Firebase provides a NoSQL cloud database that will be used to store and retrieve data generated by the smart waste management system. The data will be structured in the form of collections and documents, and can be accessed by the web application through Firebase API.

Authentication and authorization: Firebase provide authentication and authorization services out-of-the-box, which will be used to secure the web application. The authentication can be implemented using various methods, such as email and password, social media logins, and phone number verification. Authorization will be implemented using Role Base Access Control (RBAC) or custom claims.

Real-time data Synchronization: Firebase provides a real-time database synchronization feature that enables the web application to receive real-time updates as soon as data changes in the database. This feature will be used to provide stakeholders with real-time insights into the system's status.

7.5.2 Android application

For waste collection personnel who are constantly on the move, we've developed a dedicated Android application using the RN framework. This cross-platform app offers real-time access to assigned routes, bin locations, and navigation assistance. Collectors can easily update bin statuses, whether they are full, partially full, or empty, ensuring that the system's data remains accurate and up-to-date. The most important function of this app is route planning which is described below:

Route planning is a critical component of the SWMS. It involves identifying the most efficient collection routes and schedules for waste collection trucks, taking into account factors such as traffic, road closures, and the fill level of waste bins. Google Maps API will be used for this purpose. Google Maps API will be used to plan the most efficient routes for waste collection trucks. The API can take into account factors such as traffic, road closures, and real-time location data to optimize routes for waste collection trucks[22]. It can optimize waste collection routes and schedules, reduce costs, and improve overall waste management efficiency as shown in Fig 7.7.

We have used the following APIs in route planning with Google Maps:

Google Maps directions API: This API can be used to obtain directions between two or more locations, as well as the travel time, distance, and route coordinates. It can also provide different travel modes, such as driving, walking, or cycling. This API is a paid service, but Google provides a free tier that allows for a limited number of requests per day.

Google maps distance matrix API: This API can be used to obtain travel distances and times between multiple origins and destinations. It can also provide real-time traffic information and different travel modes. This API is also a paid service, but Google provides a free tier that allows for limited number of requests per day.

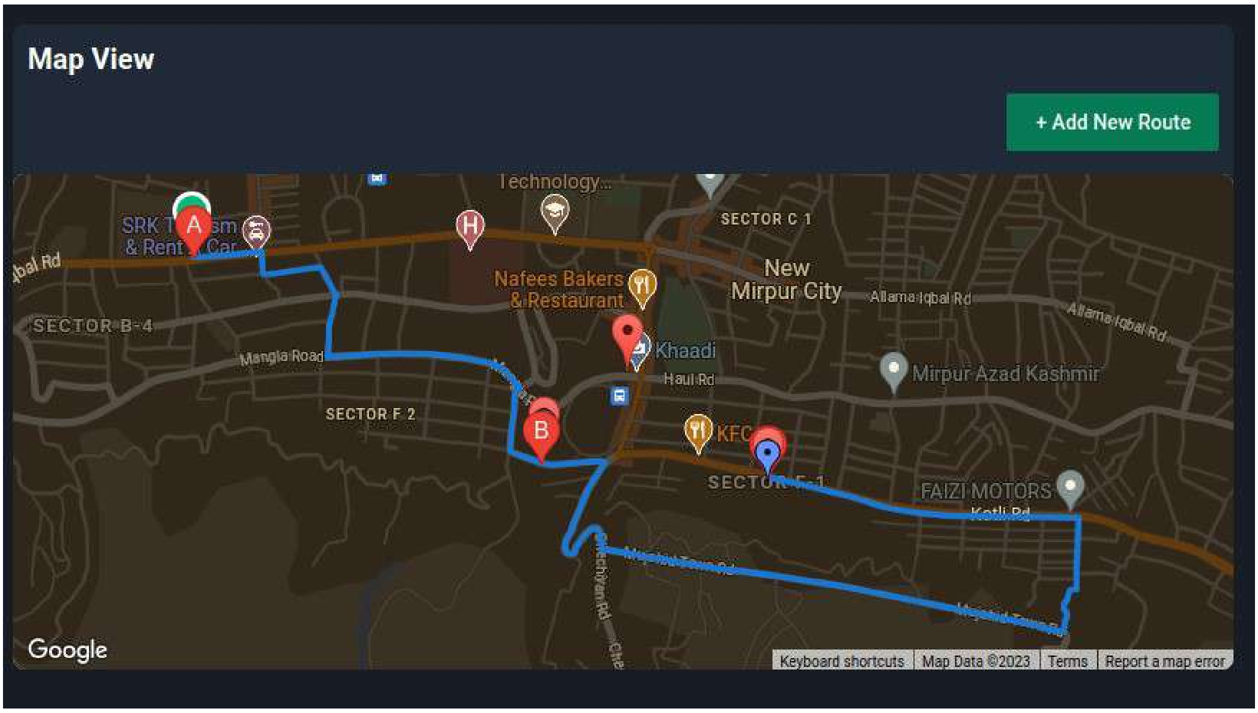

Figure 7.7: Roue generation

Google Maps geocoding API: This API can be used to convert addresses into geographic coordinates (latitude and longitude) and vice versa. It can also provide information about places and points of interest. This API is a paid service, but Google provides a free tier that allows for a limited number of requests per day.

Verifying a smart waste management system involves ensuring that the system functions as intended, meets performance, and delivers the expected benefits. Here are a general steps of the verification process for a smart waste management system:

7.5.3 White-box testing

White-box testing focuses on the internal structure and logic of the system's components. It is used to verify that the code and algorithms work correctly, and it's typically performed by developers and testers who have access to the system's source code[23].

Code review: Examine the source code of the system to identify potential vulnerabilities, coding errors, and logic flaws.

Unit testing: Test individual functions and modules within the system to verify that they perform as expected. For unit testing, we have used the React JEST library.

Integration testing: Verify that different components of the system work together seamlessly. This includes testing how sensors, communication modules, and data processing components interact.

7.5.4 Black box testing

Black-box testing of a smart waste management system focuses on evaluating the system's functionality, user experience, and overall behavior without looking into its internal code or structure. This type of testing is conducted from an external perspective to ensure that the system works as intended and meets user requirements.

Waste bin monitoring: Verify that the system accurately detects the fill levels of waste bins and triggers alerts or notifications when bins are full.

Data collection and reporting: Test if data from waste bins is collected and reported correctly to the central management system.

User registration and authentication: Ensure that user registration and login functionalities work smoothly.

User interface testing: Assess the usability and functionality of the web portal where administrators and users interact with the system.

Mobile app: Test the mobile app's user interface, navigation, and features, if applicable

7.6 Test cases

The smart waste management system's testing phase includes a comprehensive set of test cases to ensure its functionality, reliability, and efficiency. First, we verify the system's sensor accuracy by conducting tests to confirm that waste bins accurately detect their fill levels and transmit data to the central monitoring platform. We also assess the system's responsiveness by simulating real-time alerts for waste collection teams based on fill-level thresholds.

Verify login functionality: The login functionality is a critical component of any software application, including a smart waste management system. Testing this functionality is essential to ensure that user authentication is secure and seamless. A typical test case for login functionality would involve verifying that users can successfully log in using valid credentials, such as a username and password as shown in table 7.1.

Verity wrong credentials response test case: In the wrong credentials test case, the focus is on verifying how the system handles invalid login attempts. Testers intentionally input incorrect

Table 7.1: Login test case

Test Case No	SWMS-TC-01
Purpose of the Test	To verify registered user can get access to the system.
Input	Login credentials(Username, Password).
Expected output	User should be login successfully.
Pass/Fail	Pass

usernames and passwords to assess whether the system correctly identifies and responds to such errors as shown in the table 7.2.

Table 7.2: Wrong credentials response test case

Test Case No	SWMS-TC-02
Purpose of the Test	To verify the user is not available in the system database.
Input	Invalid login credentials(Username, Password).
Expected output	Alert that shows: "Authentication failed! Please check your username and password and try again."
Pass/Fail	Pass

Fill level monitoring accuracy test: This test case involves placing a series of waste bins at predetermined fill levels, ranging from empty to full. The system's sensors are then activated to measure the fill levels, and the recorded data is compared with the known fill levels of the bins. It is shown in table 7.3.

New collectors addition test: The test case begins by initiating the addition of a new collector profile within the system's administrative interface. The system should validate essential information, such as the collector's name, contact details, and assigned collection routes, to guarantee the accuracy and completeness of data entry. It is shown in table 7.4

Verify route generation functionalities: Test cases include evaluating how well the system minimizes travel distances between bins, prioritizes high-fill bins, and adapts to dynamic changes in fill levels. Additionally, route generation tests consider various factors, such as traffic conditions and time constraints, to ensure that waste collection teams can follow the generated routes efficiently.

Table 7.3: Fill level monitoring test case

Test Case No	**SWMS-TC-03**
The purpose of the Test	To verify that the system accurately detects and reports the fill level of the smart bin.
Input	Select a specific waste bin from the list of monitored bins for testing.
Expected output	The "Fill Level" section should be accessible to the user. The system should show the accurate fill level information for the selected bin.
Pass/Fail	Pass

Table 7.4: Add new collector functionality test case

Test Case No	**SWMS-TC-04**
Purpose of the Test	To verify that the system successfully added a new collector
Input	Select a specific waste bin from the list of monitored bins for testing.
Expected output	Enter the information like name, email, address, default password, etc. Click on the “Add” button.
Pass/Fail	Pass

7.7 Validation

Validation of a smart waste management system involves assessing whether the system meets the intended user needs and requirements, operates effectively in real-world scenarios, and provides value to stakeholders. Here are the key steps and considerations for the validation of a smart waste management system.

Table 7.5: Rout generation test case

Test Case No	**SWMS-TC-05**
Purpose of the Test	To verify that the system is generating an optimized waste collection route
Input	The "Fill Level" section should be accessible to the user. The system should show the accurate fill level information for the selected bin.
Expected output	The system should generate a clear and detailed route plan for each vehicle, including estimated arrival times.
Pass/Fail	Pass

7.7.1 User requirements

Initial user requirements are well-documented and clearly defined. Our system is achieving all the user requirements.

7.7.2 Usability and user experience testing

Smart Waste Management System user interface (e.g., web portal, mobile app) is very easy to use. Users can easily perform essential tasks, such as monitoring bins, viewing reports, and managing routes.

7.8 Summary

- Smart Waste Management System is implemented in RN React Native for Android phones for website JavaScript (React js) is used. For hardware, we have Installed the necessary infrastructure to support our smart waste management system.
- In our smart waste management system, we have several IoT devices, including an Ultrasonic sensor, GPS module, ESP32 microcontroller, breadboard, jumper wires, and a battery.
- The coding or implementation phase of a smart waste management system is a critical step in turning the system's design and specifications into a functional software solution. At the

core of our system is a robust web application developed using web technologies such as HTML5, CSS, and JavaScript (React JS).

- The web application will provide an interface for stakeholders to interact with the system. The web application will be used by customers to request waste collection services, report issues, and receive notifications.
- Verifying a smart waste management system involves ensuring that the system functions as intended, meets performance, and delivers the expected benefits.
- Validation of a smart waste management system involves assessing whether the system meets the intended user needs and requirements, operates effectively in real-world scenarios, and provides value to stakeholders.

Chapter 8

Discussion and Conclusion

8.1 Solution review

We addressed the problem effectively. Our proposed solution is highly effective in improving the efficiency, sustainability, and cost-effectiveness of waste collection. Here is solution review is described against objectives.

8.1.1 Minimizing operational costs

The IoT-based approach can help optimize waste collection routes and schedules, reducing operational costs associated with fuel and labor. Real-time monitoring of waste bins can prevent unnecessary collections and ensure that bins are only emptied when needed, leading to cost savings.

8.1.2 Minimizing environmental impact

By optimizing waste collection, the project can contribute to reducing fuel consumption and emissions, thus minimizing its environmental footprint. Promoting recycling and waste reduction through data-driven insights can further enhance its positive environmental impact.

8.1.3 Streamlining waste collection

Real-time data from IoT sensors enables the efficient routing of collection trucks to areas with bins that are nearing capacity, streamlining the waste collection process. The system's ability to detect overflows and anomalies allows for quick responses to address issues in the waste collection process.

Overall, your project appears to align well with its stated goals of minimizing operational costs, reducing environmental effects, and streamlining waste collection processes through IoT technology.

8.2 Key skills

Key skills learned are improved in this project's design and development are stated below: **Problem-solving and critical thinking:** Smart waste management systems are complex and often involve new technologies. Skills in problem-solving and critical thinking are essential for identifying and addressing the challenges that may arise during implementation.

Project management skills: Smart waste management system implementation is a complex project that requires careful planning and execution. Project management skills are essential for ensuring that the project is completed on time and within budget.

IoT Development: We have gained hands-on experience in designing, building, and implementing an IoT system, including sensor integration, data transmission, and device management.

Programming: We likely have improved your programming skills, particularly in languages such as Python, C/C++, or JavaScript for IoT development.

Sensor Integration: Knowledge of how to select and integrate various sensors (e.g., ultrasonic, RFID, GPS) into IoT devices to collect relevant data.

Data Analysis: Skills in processing, analyzing and visualizing data collected from IoT devices, which may involve using tools like Python libraries, databases, and data visualization platforms.

Cloud Services: Proficiency in utilizing cloud platforms(Firebase) for data storage, processing, and remote device management.

Mobile App Development: Our project involved a user interface or a mobile app for monitoring waste bins. This increases our mobile app development skills.

Communication: Enhanced communication skills, as you likely had to explain your project to non-technical stakeholders or team members.

Documentation: Proficiency in documenting your project, including technical documentation, user manuals, and reports.

Testing and Quality Assurance: Skills in testing the system for reliability, security, and performance, as well as implementing quality assurance measures.

These skills can be valuable in a wide range of industries, including IoT development, environmental management, and technology-related fields. They can also be leveraged for further education or future IoT projects.

8.3 Future work

In the future SWMS could be more effective by developing and integrating energy-harvesting sensors that can power themselves using solar, reducing the need for battery replacements. Research and implement eco-friendly waste disposal methods, such as advanced recycling techniques and waste-to-energy conversion, to minimize environmental impact. AI-powered waste sorting robots can help to improve the accuracy and efficiency of waste sorting. This can lead to increased recycling rates and a reduction in the amount of waste that goes to landfills. Future work in SWMS includes:

- Develop more advanced and cost-effective sensors for waste containers to improve accuracy in monitoring waste levels and types.
- Utilize machine learning and artificial intelligence to analyze data collected from sensors for predictive maintenance, route optimization, and anomaly detection.

These future directions will contribute to more efficient, sustainable, and environmentally friendly waste management solutions in the IoT era.

8.4 Conclusion

The Smart Waste Management System represents a significant leap forward in addressing the growing challenges associated with waste disposal in our modern cities. Through the seamless integration of advanced technologies such as IoT sensors, this system has demonstrated its ability to not only streamline waste collection processes but also to optimize resource allocation and minimize the ecological footprint of waste management operations. This project's success is underscored by its capacity to dynamically adapt to changing conditions, enabling waste collection trucks to prioritize areas with higher waste accumulation, thus reducing both operational costs and emissions. Moreover, the real-time monitoring and data-driven insights offered by the system empower waste management authorities to make informed decisions, allowing for more precise planning and resource allocation. This, in turn, not only reduces the strain on public budgets but also significantly contributes to the overall sustainability and cleanliness of urban areas.

In conclusion, the Smart Waste Management System is not just a project; it represents a vision for a more sustainable and intelligent urban future, where waste is managed with precision, resource utilization is optimized, and our cities become exemplars of responsible environmental stewardship.

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