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An IoT and Web-Based System for Efficient Waste Collection and Monitoring

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Abstract

Traditional waste management systems are plagued by inefficiencies, high costs, and significant environmental impact. To tackle these challenges, this project proposes an IoT and web-based system for more effective waste collection and monitoring system. Utilizing Arduino IDE, C++, Python, ThingSpeak, Android Studio, PHP, MySQL, and cloud storage, the system integrates IoT sensors into waste bins for real-time data transmission and analysis, featuring modules for monitoring, reporting, visualization, notifications, user registration, staff management, and trash vehicle coordination. The parallel development methodology enabled smooth project progress and significant improvements in efficiency, coordination, and management. The system was tested with a test plan and User Acceptance Test (UAT), proving to be successfully developed and meeting user requirements. This comprehensive solution enables garbage organizations to use a variety of tools in the system to optimize waste collection. By deploying this comprehensive solution, businesses is able operate at full scale, contributing to smarter and more sustainable urban settings.

1. Introduction

In the modern era of rapid urbanization and industrialization, traditional waste management systems, reliant on manual monitoring and periodic collection, often lead to inefficiencies, increased costs, and environmental degradation. Studies, such as those by Al-Naggar, Abdulghani, and Al-Areefi [1], have highlighted severe health risks from improper waste management, emphasizing the need for technological integration to prevent diseases and pollution .This project introduces a smart waste management system leveraging IoT and web-based platforms to revolutionize waste collection, management, and monitoring, addressing challenges such as overflowing bins, missed collections, and high greenhouse gas emissions. The proposed system, employs Arduino IDE, C++, Python, Thing Speak, PHP, MySQL and cloud storage, integrating IoT sensors into waste bins for real-time data transmission and analysis. It features modules for monitoring, reporting, visualization, notifications, user registration, staff management, and trash vehicle coordination. Research indicates the effectiveness of smart waste management systems. For example, a study outlines the implementation of IoT technologies for waste management, highlighting their ability to optimize waste collection and reduce operational costs [2]. Another study discusses the use of intelligent waste management systems to enhance efficiency and environmental sustainability [3]. Expected outcomes include optimized waste collection, reduced environmental impact, lower operational costs, improved public health and safety, increased recycling rates, and enhanced data-driven decision-making, contributing to smarter and more sustainable urban environments.

2. Related Work

This chapter describes the related work of this project which is an IoT-based smart waste management system. In section we will discuss the ultrasonic sensor, explain the overview of Arduino and give the details of Thing Speak Python Programming Language as described below. Three existing systems that are related to this project are selected and explained based on the architecture, strength, and limitations. A comparison between the existing systems and proposed system based on the characteristics and features.

In the project we will be using the HC-SR04 ultrasonic sensor stands out as a versatile and widely adopted device in IoT. Employing ultrasonic echo-ranging, it accurately measures distances by emitting waves and calculating the time taken for them to bounce back. Popular in robotics, automation, and various electronic projects, the HC-SR04's simplicity, affordability, and reliability make it a favorite among hobbyists and professionals alike [4]. Its applications range from obstacle detection systems to real-time distance measurement, enabling devices to adapt behavior or trigger actions based on proximity to objects perfect for my project.

Besides that, the hardware and software components involved in this system include the NodeMCU Amica (Arduino), an open-source electronics framework. The NodeMCU Amica board, representing the hardware, reads input and converts it to output using the Arduino IDE software. Arduino, known for its user-friendly interface, supports various boards, and the NodeMCU Amica facilitates the execution of C or C++ code transferred via USB. Additionally, Thing Speak, an open-source IoT analytics tool, plays a pivotal role in collecting, displaying, and analyzing real-time cloud data streams. Compatible with devices like Arduino and NodeMCU, Thing Speak allows engineers to develop IoT applications with seamless connectivity, creating a comprehensive ecosystem for effective data monitoring and analysis [4]. Finally, the Python programming language, known for its versatility and extensive standard library, can be integrated into the system to enhance functionality, especially in scenarios requiring a graphical user interface and compatibility across different operating systems.

2.1 Reviewing Existing System

In the realm of waste management solutions, three distinct approaches have been presented, each leveraging IoT technology to address the challenges associated with solid waste in different contexts. Bernie Fabito's (2019) Perazuhan mobile app targets the improper waste management issues in Metro Manila, Philippines. Its user-friendly design, accessible through mobile devices, fosters community engagement by providing features such as waste pickup scheduling, earnings tracking, and educational modules on proper waste segregation. However, the limitation of smaller screens and potential storage constraints on certain devices poses challenges to user experience [4].

Soumyabrata Sahaan and Rituparna Chakib (2022) proposed an IoT-based smart waste management system with a focus on handling both regular and COVID-19-related waste. The architecture incorporates various hardware and software components, including servo motors, sensors, Node MCU, and communication modules like Wi-Fi and LoRaWAN. While the integrated approach aims to enhance waste management efficiency, challenges such as reliance on sensor technologies and the need for active community cooperation underscore the importance of addressing potential difficulties for effective implementation [5].

In M. Karthik and L. Sreevidya's (2021) work, an efficient waste management technique utilizing an IoT-based smart garbage system is presented. The system employs ultrasonic sensors, a PIC microcontroller, and an ESP8266 Wi-Fi module to monitor waste levels in smart bins. Real-time data transmission to a web server triggers notifications to bin collectors for timely waste collection. However, potential challenges include assumptions about immediate responsiveness of bin collectors, operational issues, and the risk of technical failures or power outages. Balancing the technical aspects with practical considerations is crucial for the reliability of such systems in dynamic urban environments [6].

Table 1: Comparison between existing systems and proposed system

System/Characteristic	Mobile Apps for Waste Reporting	IoT based smart waste management system in aspect of COVID-19	An efficient waste management technique with IoT based smart garbage system	Smart Waste Management: An IoT and Web-Based System for Efficient Waste Collection and Monitoring
Web-based platform	Not Supported	Supported	Supported	Supported
Mobile-Based platform	Supported	Not Supported	Not Supported	Supported
Waste Capacity Detection	Not Available	Available	Available	Available
DStaff Registration	Not Available	Not Available	Not Available	Available
Simple Data interface	Available	Available	Available	Available
Bin Data Monitoring	Not Available	Not Available	Available	Available
Bin Live Location	Not Available	Not Available	Available	Available
LED Capacity Indicator	Not Available	Not Available	Not Available	Available
Involve worker	Not Available	Available	Not Available	Available
GPS Tracker	Not Available	Not Available	Not Available	Available
Checking Process	Average	Fast	Fast	Fast
Monitoring system	Mobile-based	Web-based	Web-based	Web-based

3. Methodology

3.1 Parallel Development Methodology

Parallel development is used when a system project requires separate development efforts on related code bases (SolutionsIQ, 2017) [7]. Parallel development is chosen due to some reasons. Firstly, there is a segregation of work on different features. This system involves 7 main modules which are monitoring website, reporting system, visualization, notification, registration, staff management and managing vehicle for the system, these modules have different features so can be designed and implemented at the same moment. Secondly, the software used to develop the modules is the same. The software used to build waste measuring system and data receivers are Arduino IDE and Thing Speak. Due to the same software requirement for the modules, the development for the two modules can be conducted at the same time. Furthermore, the time required to develop this system can be reduced as the modules can be built parallelly. Figure 1 shows the software development life cycle of parallel development methodology.

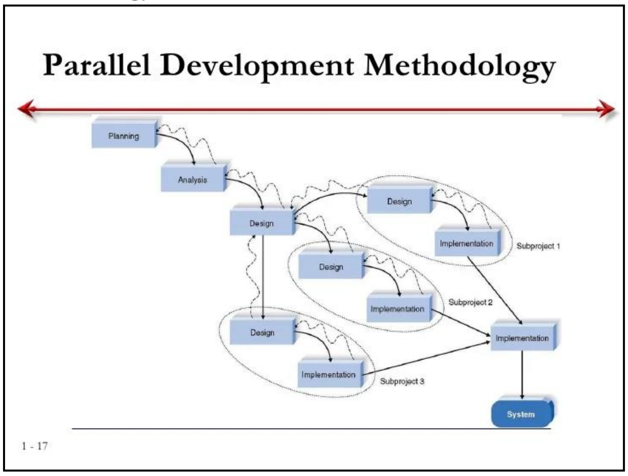

Figure 1: Software development life cycle of parallel development methodology [8]

In the planning phase of the parallel development methodology, a project proposal for an IoT and web-based waste management system was prepared, covering project background, problem statements, objectives, scope, expected results, and significance. A project schedule and Gantt chart were created for task management. In the analysis phase, information was gathered through literature review, observational analysis, and software and hardware analysis, leading to the identification of functional and non-functional requirements. The design phase involved creating the general system architecture, user interface design, wiring diagram, UML, and ERD based on the gathered data. During the implementation phase, the system was developed in three parts: the ultrasonic sensor system with Arduino, the database using MySQL, and the monitoring website with Python. Finally, in the testing phase, system tests, user acceptance tests, and accuracy tests were conducted to ensure the system met all requirements before deployment.

4. System Analysis and Design

This section discusses about the general system architecture, unified modelling language which include use case diagram, sequence diagram, and activity diagram, wiring diagram, database design, user test acceptance testing form, and lastly user interface design for an IoT-based waste management system.

4.1 General System Architecture

The system architecture diagram of IoT-based waste management system is shown in figure 2. First , staff setup bins that are equipped with ultrasonic sensors that measure their fill level and send data to the Thing Speak cloud platform by NodeMCU amica. The system then uses this data to optimize waste collection routes, considering the location of bins, their fill level, and the availability of collection vehicles. Staff members can access the system to view bin status, manage their accounts, and track vehicle details. The system also generates reports that can be used to monitor the performance of the waste collection system. In addition, administrators can read reports, manage staff account information, control vehicle status, and perform other tasks to enable staff members to utilise the system. Staff can access feature to get notification about the optimum route to take for waste collecting increasing the efficiency of the whole system.

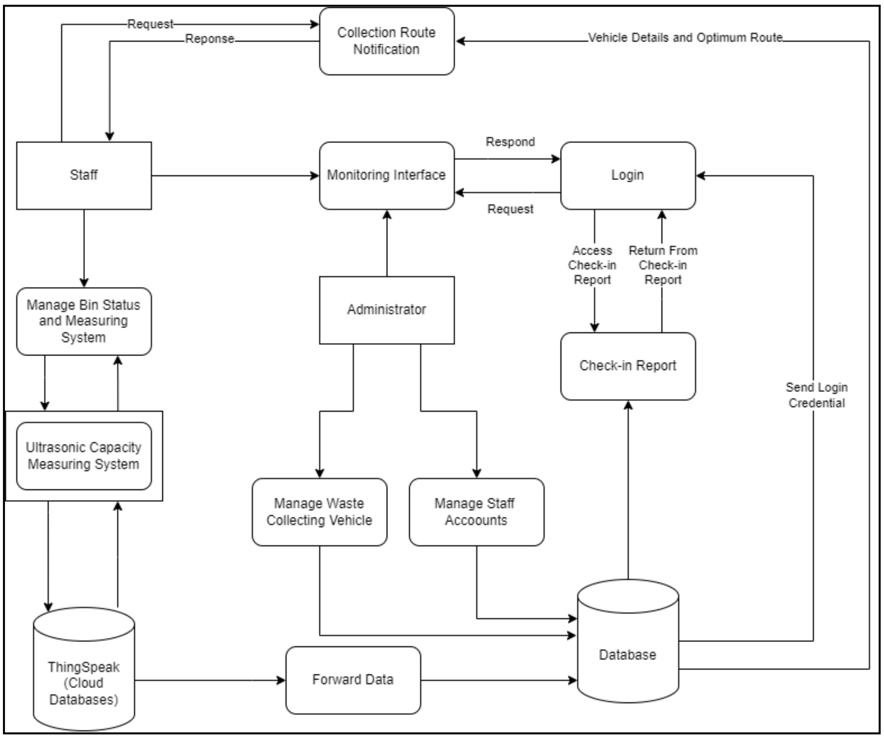

Figure 2: System architecture Diagram of IoT-based Waste Management System

4.2 Requirement Analysis

Requirement analysis is the process of systematically gathering, documenting, and evaluating user needs and system specifications to ensure a comprehensive understanding of project objectives and constraints. The functionalities of the modules are explained in Table 2.

Table 2: Functional Requirement of proposed system

No	Module	Functionality
1	Ultrasonic Waste Measuring System	This module deploys IoT sensors within waste bins to continuously monitor fill-level and status. The data collected by sensors is sent to a central database for real-time monitoring.
2	Notifying Trash Vehicle	An interface with waste collecting vehicles equipped with IoT devices to send route information and real time bin fill-level data. It optimizes collection routes and ensure bins are collected when they reach capacity.
3	Monitoring Website	A user-friendly web-based dashboard must be provided to visualize waste collection data through graphs, charts, and maps. The stakeholders should also gain insights into waste patterns for informed decision-making.
4	Staff Management	To empower waste collection staff with tools for route optimization, work allocation, and task tracking. Additionally, it enables staff members to report encountered issues during collection, ensuring swift resolution and smooth operational workflows.
5	Register	Allows administrators, or waste collection agencies, to register and manage staff accounts within the system. This module serves as a pivotal component for user management and access control.
6	Reporting	Plays a crucial role by allowing users to access both historical and real-time data related to waste collection activities. This includes the generation of detailed reports on fill levels, collection schedules, and trends, empowering stakeholders to optimize waste management operations.
7	Visualization	Provides a web-based dashboard that presents waste collection data through visually informative graphs, charts, and maps. This feature enables stakeholders' staff to gain valuable insights into waste patterns, aiding in informed decision-making for efficient waste collection strategies.

The Non-functional requirements of the modules are explained in Table 3.

Table 3: Non-functional Requirement of proposed system

No	Requirement	Functionality
1	Performance	The system must provide real-time monitoring with minimal latency. It should be handling a large volume of data efficiently.
2	Reliability	The system must be reliable, ensuring continuous monitoring and data collection. The project should also have backup mechanisms to handle system failures.
3	Scalability	A system should be scalable to accommodate a growing number of waste bins and users. The system must handle increase data without compromising performance.
4	Security	The system should implement robust security measures to protect user data and system integrity. An access control mechanism should be in place to manage user permissions.
5	Usability	The system user interface must be intuitive and easy to use so that stakeholders, including waste collection staff, should be able to navigate and use the system without extensive training.
6	Compatibility	Compatibility with different devices and browsers is also a must to support common operating systems and web browsers.
7	Maintainability	The system should be designed for ease of maintenance and updates. than that, documentation should be provided for system administrators and users.
8	Environmental Impact	The implementation of the system should contribute to a reduction in environmental impact through efficient waste management practices.

4.3 Unified Modelling Language

The standard language for system modelling is called Unified Modelling Language (UML). It is employed to visualize a system's behavior and structure. Use case diagrams, sequence diagrams, and activity diagrams are the three types of diagrams that are contained in UML [9].

4.4 User Case Diagram

A use case diagram was created to illustrate the primary features of the suggested system as they might be utilized by various actor kinds. There were two actors involved in this system which are administrator and staff. The functions of the system that can be used by the administrator are login, register, generate reports, manage account, delete account. Next, the administrator can login to the monitoring website to view the bin status. If the staff does not have an account for the monitoring system, then he is required to register an account for staff to access the monitoring system. Furthermore, the functions of the system can be performed by staff are login, monitor bin status and generate reports. Besides that, staff can also update the database of the system and carry out optimized routes for bin collection through the monitoring website. Figure 3 illustrates the use case diagram of the proposed system.

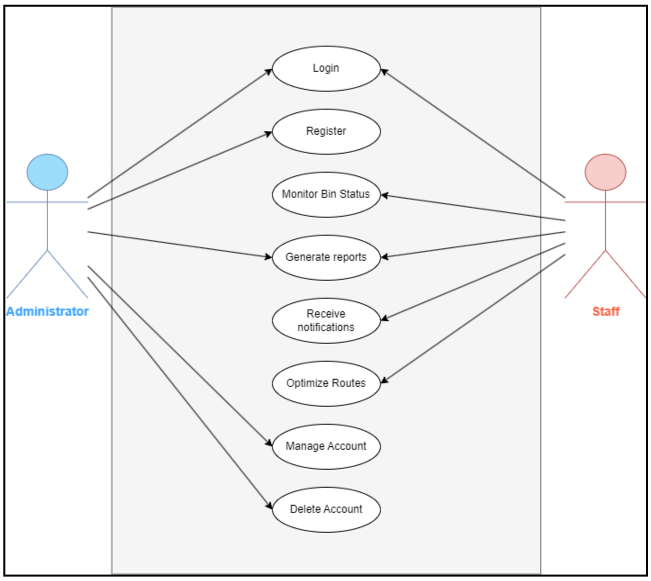

Figure 3: Use case diagram of IoT-based waste management system

4.5 Sequence Diagram

A sequence diagram is a visual representation that illustrates the interactions and order of messages between objects or components in a system over time. An illustration of the sequence diagram of waste management systems is included in the Appendix below.

4.6. Activity Diagram

The sequence of steps taken by the Internet of Things-based waste management system is depicted in the activity diagram. From the start, the bin must check its status if the waste measuring system is active or inactive. If the measuring system is not online the cycle will keep looping until the bin is online. Once the bin is online the waste bin needs to check for waste in the provided bin area by using ultrasonic waste measuring system. If the ultrasonic sensor detects 85cm distance this means bin is empty else bin is not empty. The ultrasonic scanning system will emit green light when the is empty and red light when then the bin reaches its maximum capacity. After that, the data is recorded to cloud storage. The next step is to retrieve data from the cloud to be used in the search for a nearby garbage collection vehicle. If no vehicle is found, the system will repeatedly query the database to see if one is. The technology will determine the best and most efficient route and notify staff members if there is a garbage collection vehicle in the vicinity. After that, employees will carry out their duties in the most efficient way possible to improve the effectiveness of the waste management system. The activity diagram is shown in the Appendix.

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4.7 Wiring Diagram

A wiring diagram on Arduino illustrates the connections between various electronic components, such as sensors, actuators, and the Arduino board itself, providing a visual guide for constructing and interfacing with the hardware. The wiring diagram of the IoT-based waste measuring system is displayed in figure 4 below.

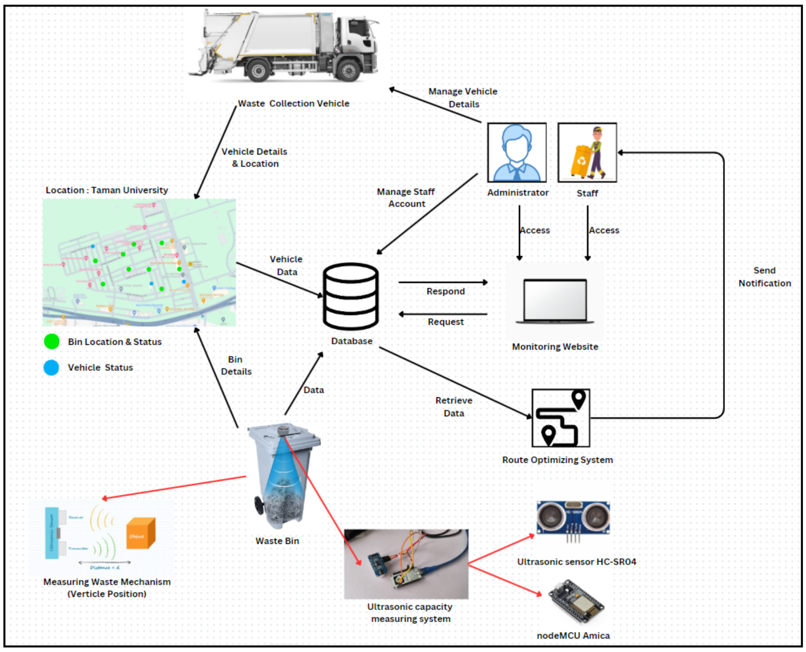

Figure 4: Wiring diagram of IoT-based waste management system

4.8 Database Design

Database design is the process of structuring and organizing data in a systematic and efficient manner to facilitate data storage, retrieval, and management in a way that meets the requirements of an organization or application [11]. There are two types of database designs in this IoT-based waste management system which are logical design (Entity Relationship Diagram) and physical design (Data Dictionary) which can be found in Appendix C.

4.9 Prototype

(a) (b)

Figure 5: (a) & (b) prototype of wastebin

Figure (a)and (b) show the main monitoring website user interface design for IoT-based waste management system. The rest of the user interfaces and waste capacity measuring system prototype are shown in Appendix C.

5.0 Results and Discussion

An IoT and Web-Based System for Efficient Waste Collection and Monitoring is implemented using Hypertext Markup Language (HTML), Cascading Style Sheets (CSS), Python, Android Studio, PHP and Cloud Storage for the web interface, and the Internet of Things (IoT) components are programmed using the Arduino IDE. The system employs MySQL as the database management system, which is widely used for data storage and management across various applications.

5.1 System Implementation

The figures depict an IoT-based waste collection system prototype integrated into a standard waste bin. The setup includes sensors and a microcontroller attached to the bin's exterior and interior, which monitor the fill level. This system facilitates efficient waste management by tracking and reporting the bin's status.

Figure 6: Wiring diagram of IoT-based waste management system

The login figures show the login interfaces for an IoT and web-based waste management system. The first image displays the "Admin Login" page, designed for administrative access, where users can enter their username and password. The second image shows the "Staff Login" page, intended for regular staff members to log in. Both interfaces provide a clean, user-friendly design and include options to switch between admin and staff login pages, ensuring that different levels of users can access appropriate system functionalities efficiently.

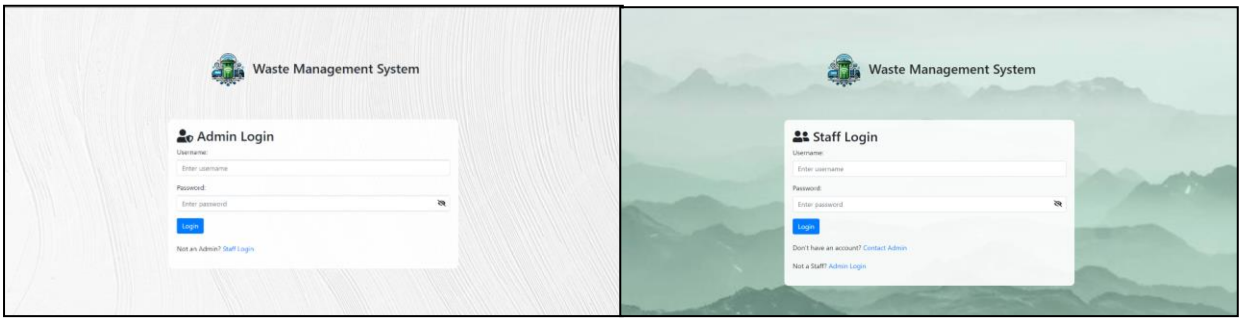

Figure 7: Admin & Staff Login Page

The figures showcase the admin and staff profile management pages within an IoT and web-based waste management system. The first image displays the admin profile page for "Ellison," detailing personal and professional information that can be edited by the admin themselves, including the addition of their experience and role details. The second image shows a similar profile setup for a staff member named "Alpha," indicating that only the admin has the capability to edit or update staff profiles, reinforcing a hierarchical structure in the system's access controls. This setup helps maintain data integrity and manageability by restricting editing rights to higher-level users.

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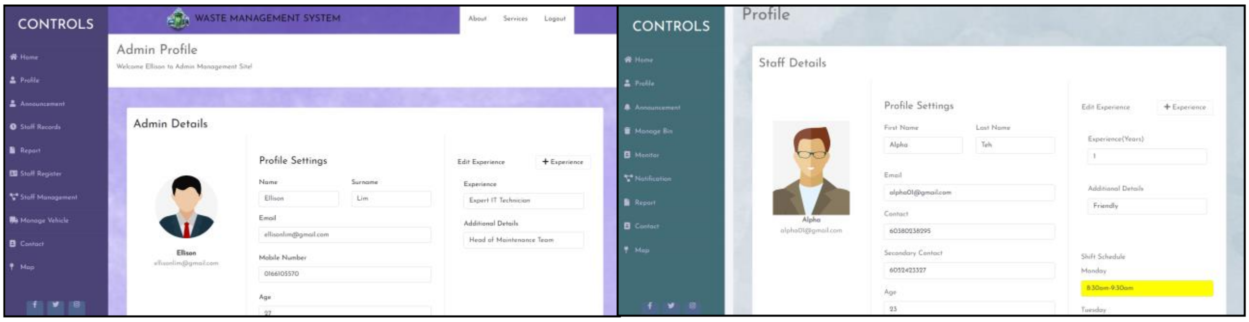

Figure 8: Admin & Staff Profile Page

These figures display the announcement management pages of an IoT and web-based waste management system. The admin interface allows the posting, editing, and deletion of announcements, ensuring that information stays current and controlled. Conversely, the staff interface only permits viewing of these announcements, preventing any unauthorized edits and maintaining centralized message integrity. This setup efficiently keeps staff updated on important notices and operational changes.

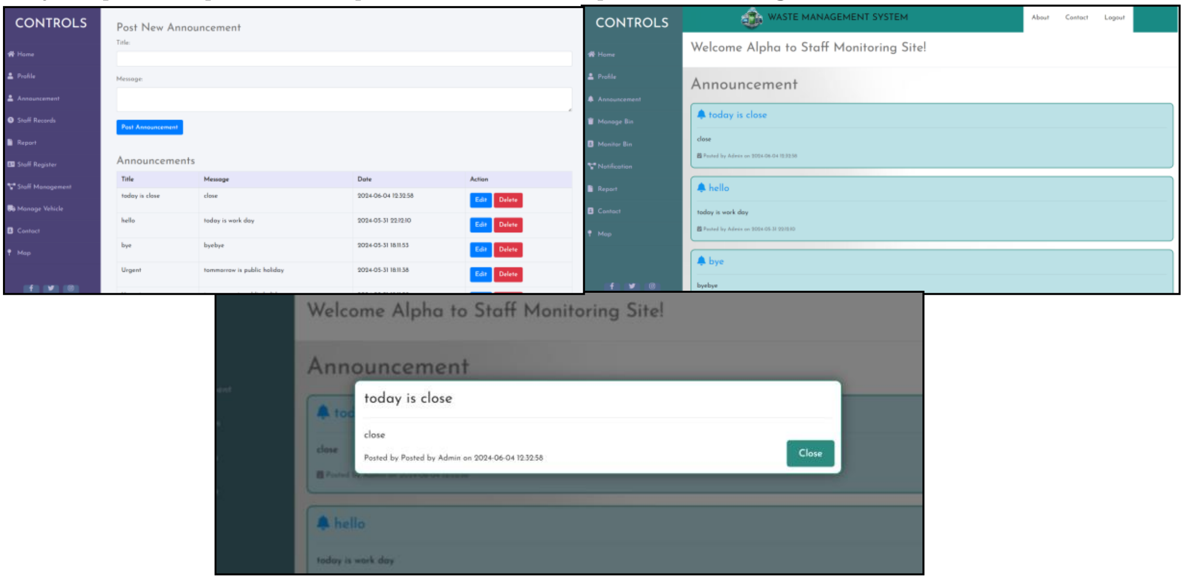

Figure 9: Admin & Staff Announcements Management

The figures showcase the "Punch In and Out" management pages within an IoT and web-based waste management system. The first image displays the admin interface for viewing and managing staff punch records. It lists each punch in and out activity, detailing the time records and duration of each shift for staff members, which allows for efficient tracking of work hours and attendance.

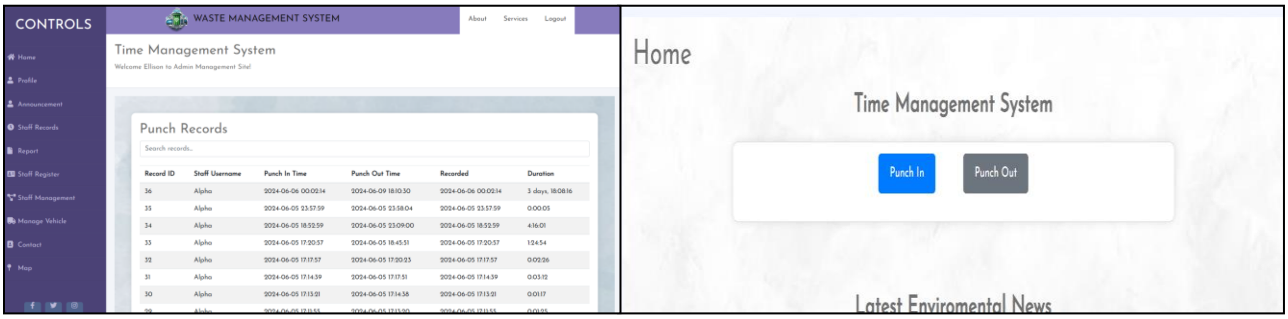

Figure 10: Admin & Staff Time Management System

The figures depict the report generation and management interface within an IoT and web-based waste management system. The first image shows a detailed table of various bins across different locations, listing each bin's ID, location, active time, coordinates, and fill status with color indicators—green for empty, yellow for not full, and red for full—to provide a clear, quick visual reference for which bins require attention. The second image offers a graphical representation of bin capacities in the form of a bar graph, making it easier for administrators and staff to visually assess and compare the fill levels of multiple bins. This setup aids in efficient waste management by allowing for the optimization of collection routes and schedules, thus helping reduce operational costs and ensuring timely waste collection based on real-time data.

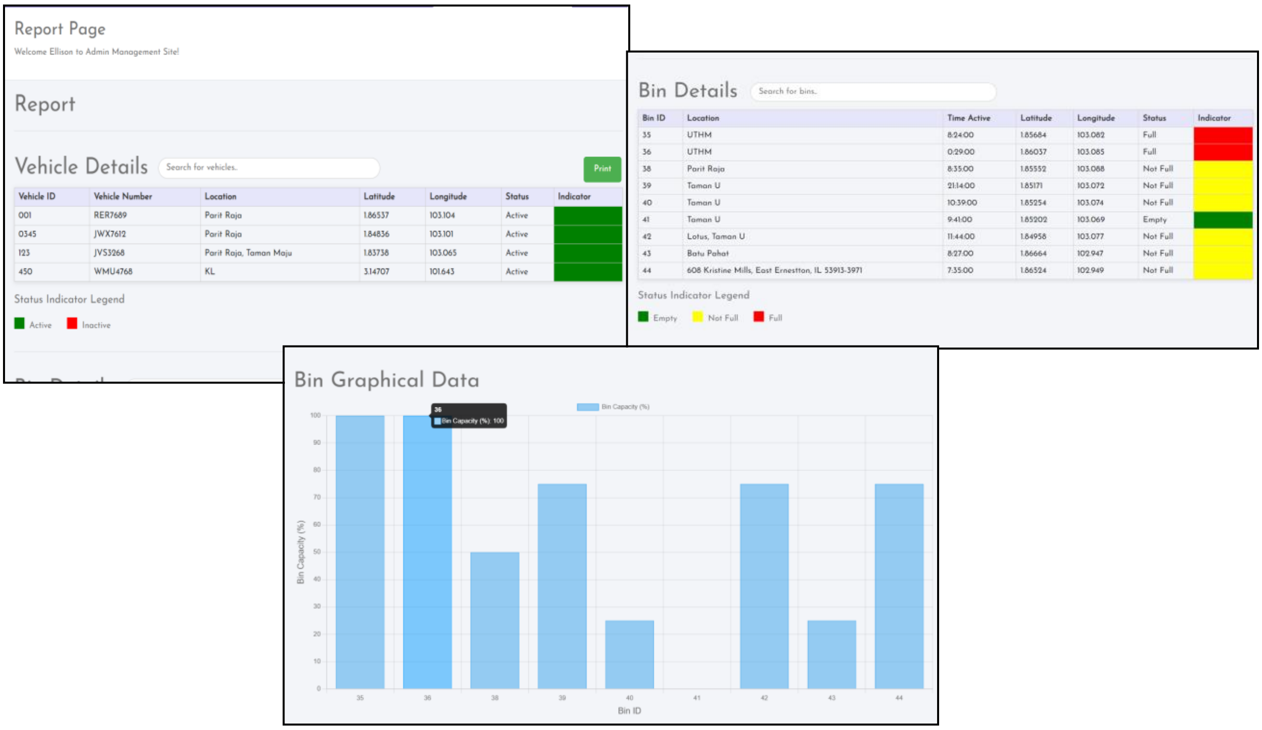

Figure 11: Admin & Staff Report Generation & Management

The below figures show the admin's side of the staff registration pages, which include detailed forms for inputting staff personal information, contact details, job specifics, and shift schedules, allowing the admin to enroll new staff members comprehensively into the system.

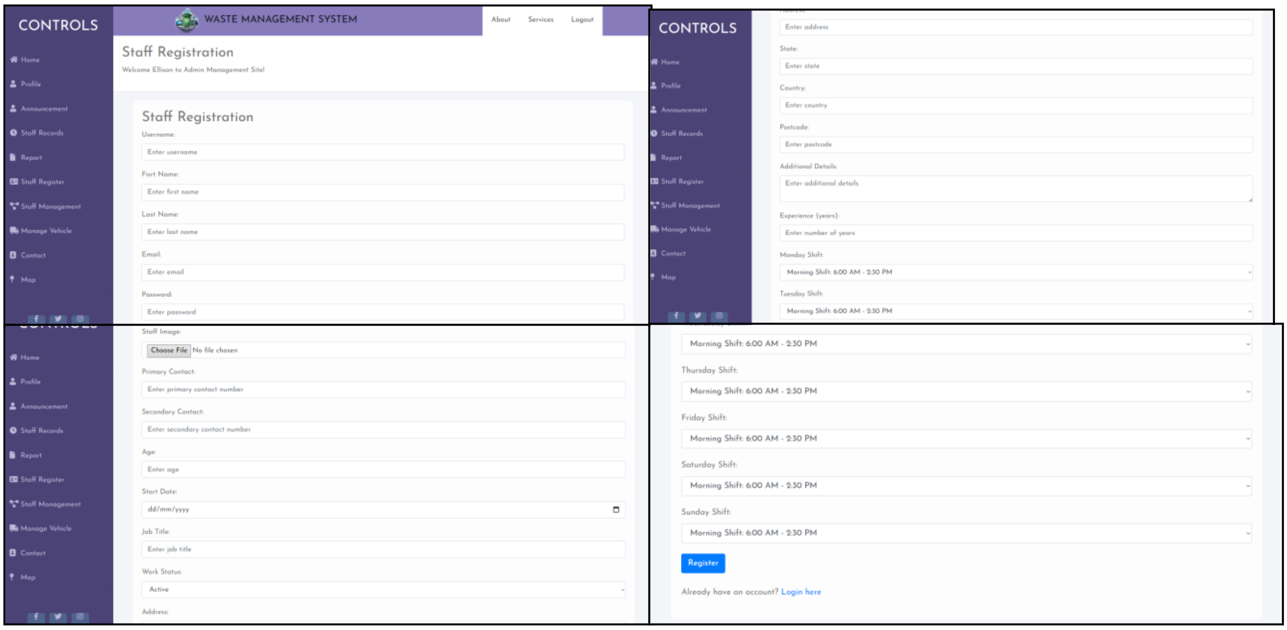

Figure 12: Admin's Side Staff Registration

Next, the figures show the admin's side of the staff management interface in an IoT and web-based waste management system, featuring a user-friendly table layout where administrators can view, edit, or delete staff records, along with a confirmation dialog box to ensure secure and intentional actions when removing staff entries.

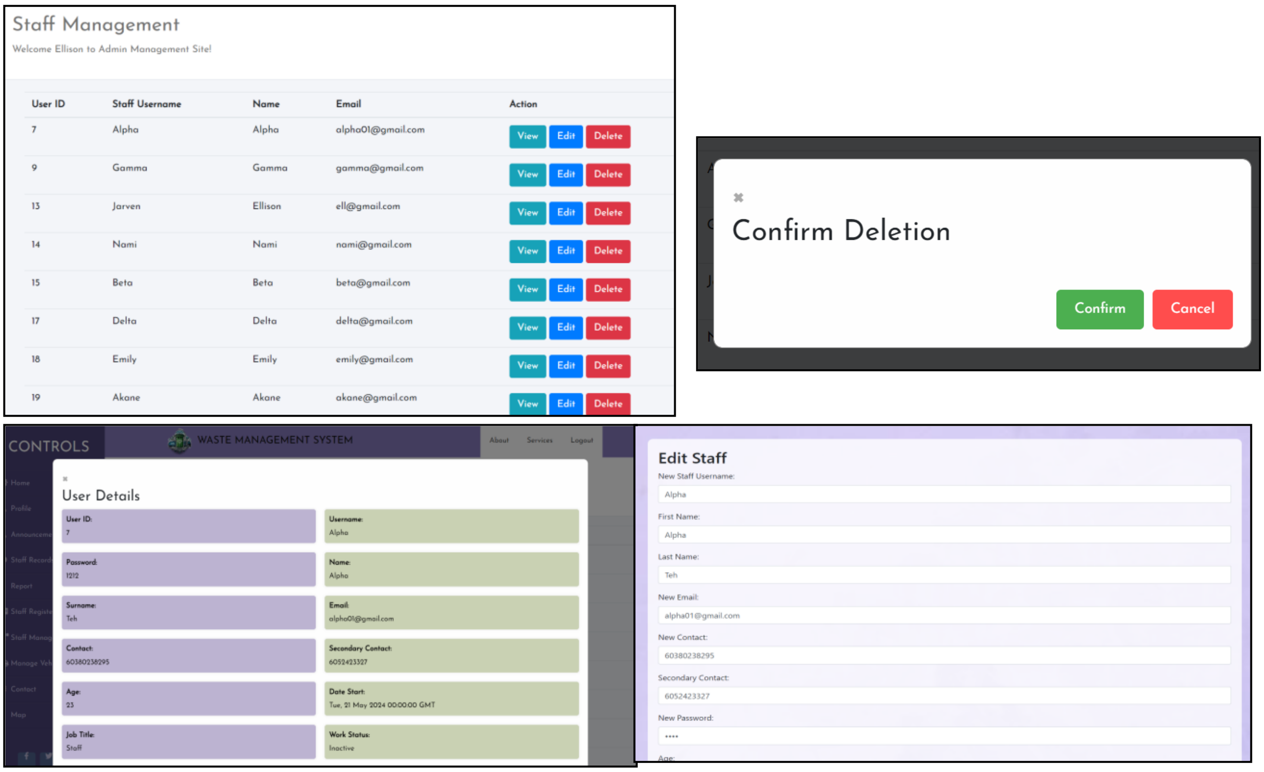

Figure 13: Staff Account Management

In the four figures listed below illustrate the admin's side of vehicle management within an IoT and web-based waste management system, where the admin can register vehicles by entering essential telemetry keys and details, and manage them by viewing, editing, or deleting vehicle records, ensuring efficient tracking and coordination of the waste collection fleet.

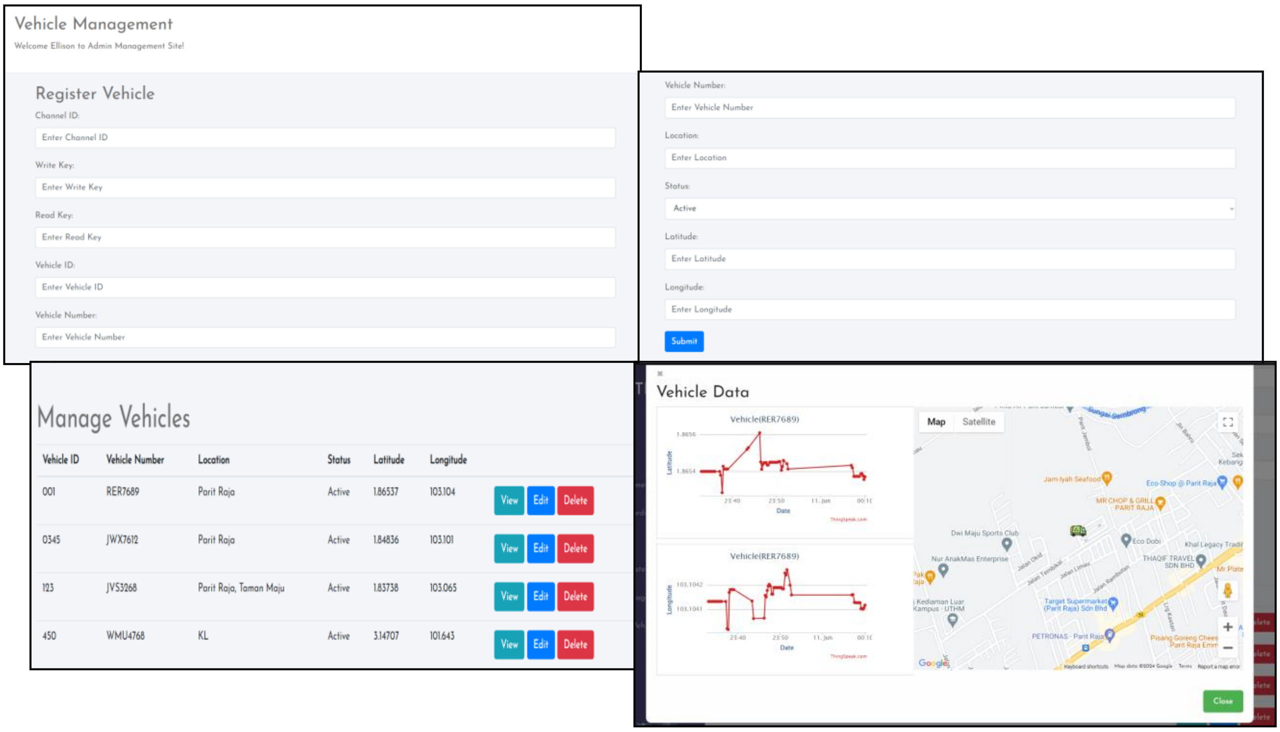

Figure 14: Waste Vehicle Management

The three figures display the admin and staff side of the IoT and web-based waste management system's map interfaces, with one showing the location of waste bins and the other tracking waste collection vehicles, enabling precise management and coordination of waste collection activities in real-time.

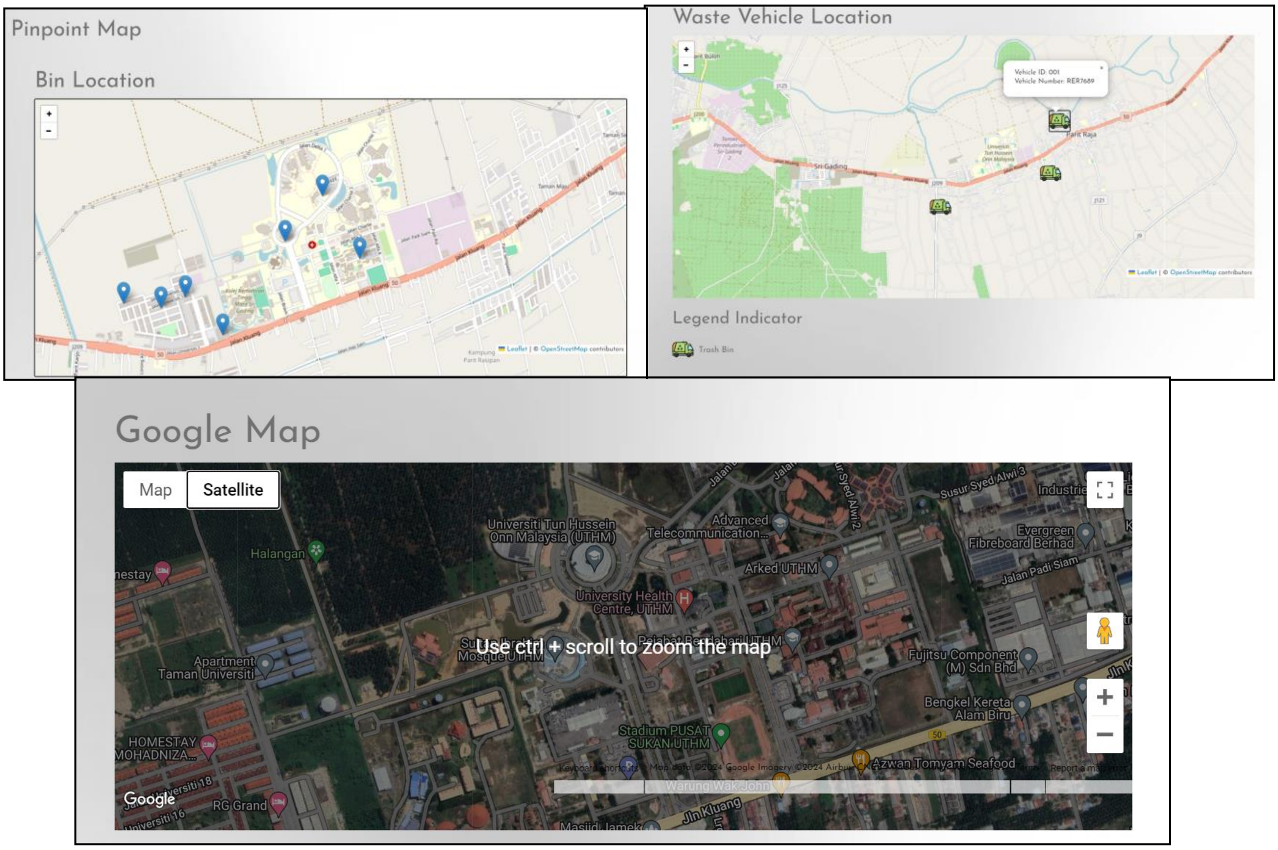

Figure 15: Bin & Vehicle Map Location

The figure shows the staff side of an IoT and web-based waste management system's bin monitoring system, which displays detailed bin data like location, status, and capacity percentage. Graphical data visualization is also included to help staff effectively monitor and manage bin statuses across various locations. The bin will show live data of the capacity of the bin every 5 mins .

Bin Data

Bin ID	Channel ID	Read Key	Location	Latitude	Longitude	Time Active	Distance Inch	Distance Cm	Bin Capacity(%)	Status	Indicator
35	2395179	9DDZ6N3P95TOGRMY	UTHM	1.85684	103.082	8:24:00	None	None	100	Full	
36	2511130	5BEPF2KQDUY5E7L3	UTHM	1.86037	103.085	0:29:00	None	None	100	Full	
38	2511132	PA3D7MVY8OB62ZP0	Parit Raja	1.85552	103.088	8:35:00	14.00	6.00	50	Not Full	
39	2517836	BG1ZTC3LQX8NW8IR	Taman U	1.85171	103.072	21:14:00	2.36	6.00	75	Not Full	
40	2517838	WVVXCYHG3LJ3MAIB	Taman U	1.85254	103.074	10:39:00	5.60	13.50	25	Not Full	
41	2517840	7HI9WQY86HACO67E	Taman U	1.85202	103.069	9:41:00	9.37	23.80	0	Empty	
42	2517841	284PT1A1EJB5MAKK	Lotus, Taman U	1.84958	103.077	11:44:00	5.82	14.80	75	Not Full	
43	2518190	IOA6IVS5X1XBF22Q	Batu Pahat	1.86664	102.947	8:27:00	1.05	2.68	25	Not Full	
44	2518192	W5337GXUPAV6N3U0	608 Kristine Mills, East Ernestton, IL 53913-3971	1.86524	102.949	7:35:00	5.30	13.47	75	Not Full	

Figure 16: Bin Live Monitoring Interface

The figure shows the staff side of the route notification system within a waste management platform. This platform provides real-time vehicle locations and routes on a map, along with detailed vehicle data such as arrival times, distances to collection points, and the specific vehicle responsible for each pickup.

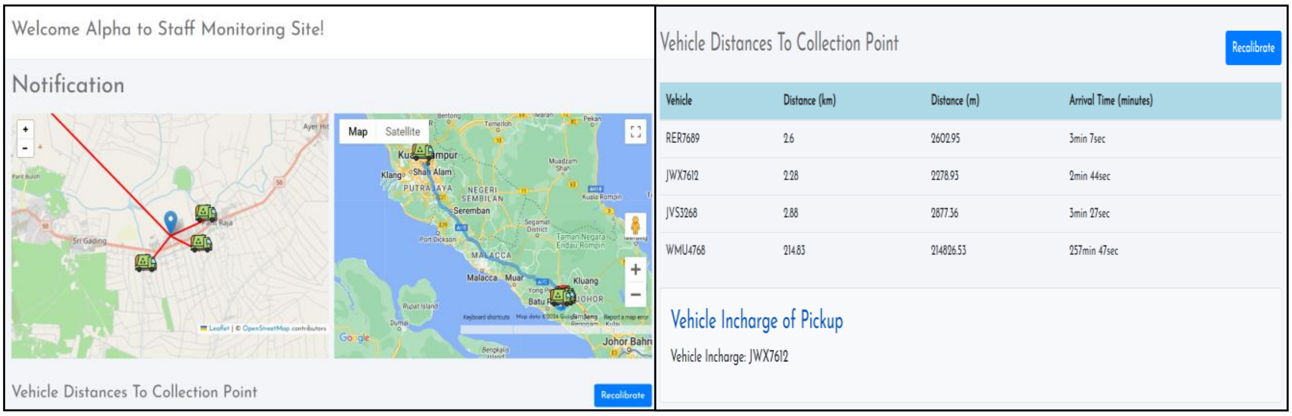

Figure 17: Vehicle Routing Interface

The mobile application depicted in the figure below is designed for an IoT and web-based waste management system, aimed at enhancing the efficiency of waste collection. The app includes a GPS navigation interface for guiding collection vehicles, a splash screen featuring the app's branding as "SMART Waste Management," and a notification screen alerting users to specific actions needed, such as attending to a designated vehicle. This system improves waste management by providing real-time directions, timely notifications, and vehicle tracking, ensuring efficient and prompt waste collection.

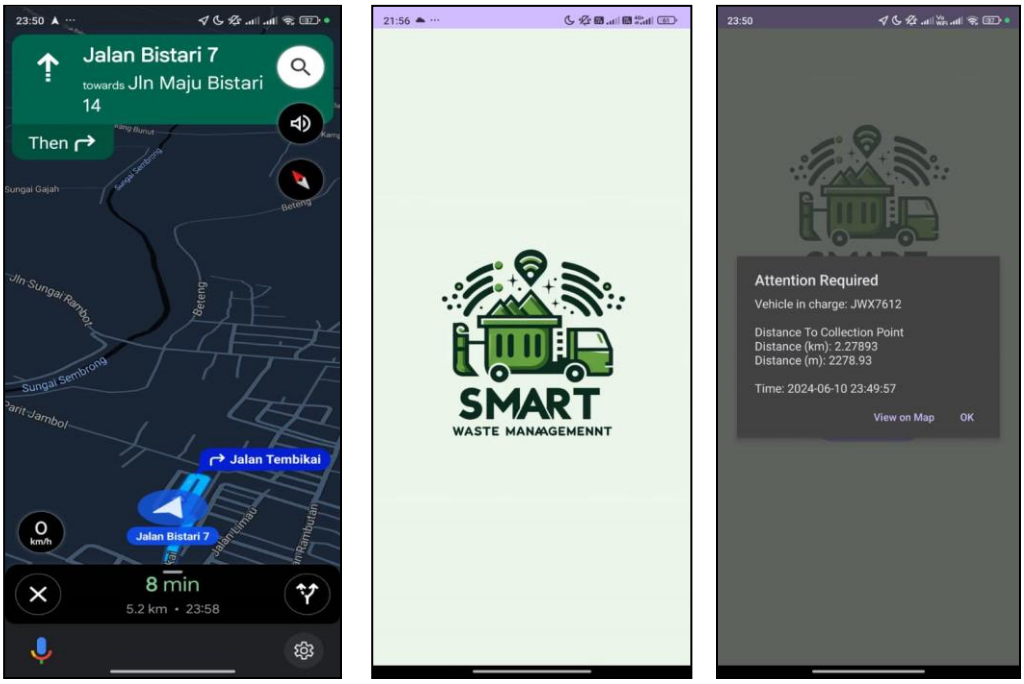

Figure 18: Mobile Based Application for Notification

5.2 System Testing

Before release, the proposed system must undergo rigorous testing to ensure it meets all specified requirements and is free of defects. This process is essential for guaranteeing system performance. To evaluate the system, a comprehensive test plan and user acceptance testing were employed.

5.2.1 Test Plan

A test plan outlines the system testing strategy, goals, timeline, deliverables, estimates, and resources. It gives instructions for the test activities and describes the testing process. Tables 4 through 9 provide exam strategies tailored to individual modules.

Table 4: Waste Measuring Module

Test	Expected Result	Actual Result
Bin measures capacity using ultrasonic sensors.	System detects and records the waste capacity in the bin.	Pass
Data is successfully sent to the database.	Database receives and stores the sensor data accurately.	Pass
Handle invalid or null sensor data.	System handles invalid or null values without crashing.	Pass
Edge case: Maximum sensor readings.	System correctly processes maximum capacity readings.	Pass
Edge case: Minimum sensor readings.	System correctly processes minimum capacity readings.	Pass

Table 5: Monitoring Website Module

Test	Expected Result	Actual Result
Administrator and staff login with user ID and password.	Successful login and access to the monitoring website.	Pass
Access to check-in reports for administrators and staff.	System displays accurate check-in reports.	Pass
Management of staff accounts by administrators.	Administrators can create, update, and delete staff accounts.	Pass
Update of bin status and details by staff.	Staff can update bin status and details accurately.	Pass
Receipt of notifications by staff.	Staff receive relevant notifications promptly.	Pass
Usability and accessibility of the UI.	Interface is user-friendly and compliant with accessibility standards.	Pass

Table 6: Waste Collecting Vehicle Route Module

Test	Expected Result	Actual Result
Notification sent for waste collection route request.	System retrieves data from the cloud database and sends notification.	Pass
Identification of nearby waste collection vehicles.	System detects and lists vehicles in the vicinity.	Pass
Best possible path provided to employees	System calculates and suggests the optimal route for waste collection.	Pass
Notification of the best and most efficient route.	System sends detailed route specifics to the relevant staff.	Pass
Determination of bin location and status.	System accurately determines and displays bin location and status.	Pass
Performance under various loads.	System maintains functionality and performance under different load conditions.	Pass
Security of data access and notifications.	System ensures only authorized access and secure notification delivery.	Pass

Table 7: Reporting Module

Test	Expected Result	Actual Result
Generation of historical data reports	System generates accurate and comprehensive historical data reports.	Pass
Generation of real-time data reports	System generates up-to-date real-time data reports.	Pass
Customizable report options	Users can customize and filter report options as needed.	Pass
Performance under heavy data loads	Reports generate quickly and accurately even with large datasets.	Pass
Secure access to reports	Only authorized users can access the reporting module.	Pass

Table 8: Visualization Module

Test	Expected Result	Actual Result
Display of waste collection data	Data is visualized accurately in graphs, charts, and maps.	Pass
Interactive data visualization	Users can interact with visualizations (e.g., zoom, filter).	Pass
Real-time data updates	Visualizations update in real-time with new data.	Pass
User-friendly dashboard interface	Dashboard is easy to navigate and understand.	Pass
Data accuracy and integrity	Data displayed in visualizations is accurate and up-to-date.	Pass

Table 9: Notification Module

Test	Expected Result	Actual Result
Sending alerts for bin overflows.	System sends timely alerts when bins are full.	Pass
Notification of collection schedule deviations	System sends alerts for any deviations from the scheduled collection.	Pass
Alerts for system malfunctions	System sends alerts for any detected malfunctions.	Pass
Customizable alert conditions	Admin can set and modify conditions for different types of alerts.	Pass
Secure and reliable notification delivery	Notifications are delivered securely and reliably.	Pass

Table 10: Registration Module

Test	Expected Result	Actual Result
User registration process	Admin can register for user successfully with all required details.	Pass
Management of user profiles	Admin can update user profiles and manage their accounts.	Pass
Validation of registration details	System validates registration details for correctness and completeness.	Pass
Handling of duplicate registrations.	System detects and prevents duplicate registrations.	Pass

Table 11: Staff Management Module

Test	Expected Result	Actual Result
Route optimization for waste collection	System suggests optimized routes for waste collection.	Pass
Work allocation to staff	System allocates tasks efficiently to staff members.	Pass
Task tracking and reporting	Staff can track and report the status of their tasks.	Pass

Issue reporting by staff	Staff can report any issues encountered during collection.	Pass
Secure access and management	Only authorized staff can access and manage their tasks.	Pass

Table 12: Notify Trash Vehicle Module

Test	**Expected Result**	**Actual Result**
Sending route information to vehicles	Vehicles receive accurate and timely route information.	Pass
Real-time bin fill-level data to vehicles	Vehicles receive real-time updates on bin fill levels.	Pass
Optimization of collection routes	System optimizes routes based on real-time data.	Pass
Reliable communication with vehicles	System maintains reliable communication with waste collection vehicles.	Pass
Security of data transmission	Data transmitted to vehicles is secure and unaltered.	Pass

Table 13: Time Tracking Module

Test	**Expected Result**	**Actual Result**
Recording of employee work hours	Employees can accurately record their work hours.	Pass
Accuracy of time tracking	System accurately calculates and records work hours.	Pass
Integration with payroll processing	Time tracking data integrates seamlessly with patrol processing	Pass
Monitoring of work schedules	System allows for monitoring and management of employee work schedules.	Pass
Secure storage of time tracking data	Time tracking data is stored securely and is accessible only to authorized personnel.	Pass

Table 14: Announcement Module

Test	**Expected Result**	**Actual Result**
Creation of announcements	Administrators can create new announcements successfully.	Pass
Editing of existing announcements	Administrators can edit announcements as needed.	Pass
Delete of announcements	Administrators can delete announcements when they are no longer needed.	Pass
Accessibility of announcements	Announcements are easily accessible to all staff members.	Pass

Table 15: Routing Module

Test	**Expected Result**	**Actual Result**
Identification of closest vehicle	System accurately identifies the closest vehicle for a specific location.	Pass
Optimization of resource allocation	System optimizes resource allocation for waste collection.	Pass
Efficient route suggestions	System suggests the most efficient routes for waste collection.	Pass
Real-time updates and adjustments	System provides real-time updates and adjusts routes as needed.	Pass
Secure and reliable routing information	Routing information is secure and delivered reliably to the relevant personnel.	Pass

To make sure the technology lives up to user expectations in real-world operating contexts, User Acceptance Testing, or UAT, is carried out in the latter stages of designing the Internet of Things and Web-Based System for Efficient Waste Collection and Monitoring. During this testing phase, the focus is on usability, user requirements, and waste management-specific demands. With the help of fifteen carefully chosen users, and one selected user will only test the administrative panel in this effort. User satisfaction will be rated on a scale from 1 (not satisfied) to 5 (very satisfied) once data from these individuals has been gathered and analyzed.

Table 16: Result of user acceptance testing for admin user

No.	**Acceptance Requirement**	**Actual Result**				
		1	**2**	**3**	**4**	**5**
User Interface						
I.	Easy to use and understand				√	
II.	Navigation					√
III.	Interface design (e.g., color, background, font)					√
System Function						
IV.	Login function				√	
V.	Account management function					√
VI.	Bin status and detail update					√
VII.	Route optimization for waste collection				√	
VIII.	Notification management					√
IX.	Data visualization function					√
X.	Report generation function					√
XI.	Admin panel effectiveness for overseeing user accounts and permissions				√	
XII.	Administrator dashboard functionality for vehicle management					√

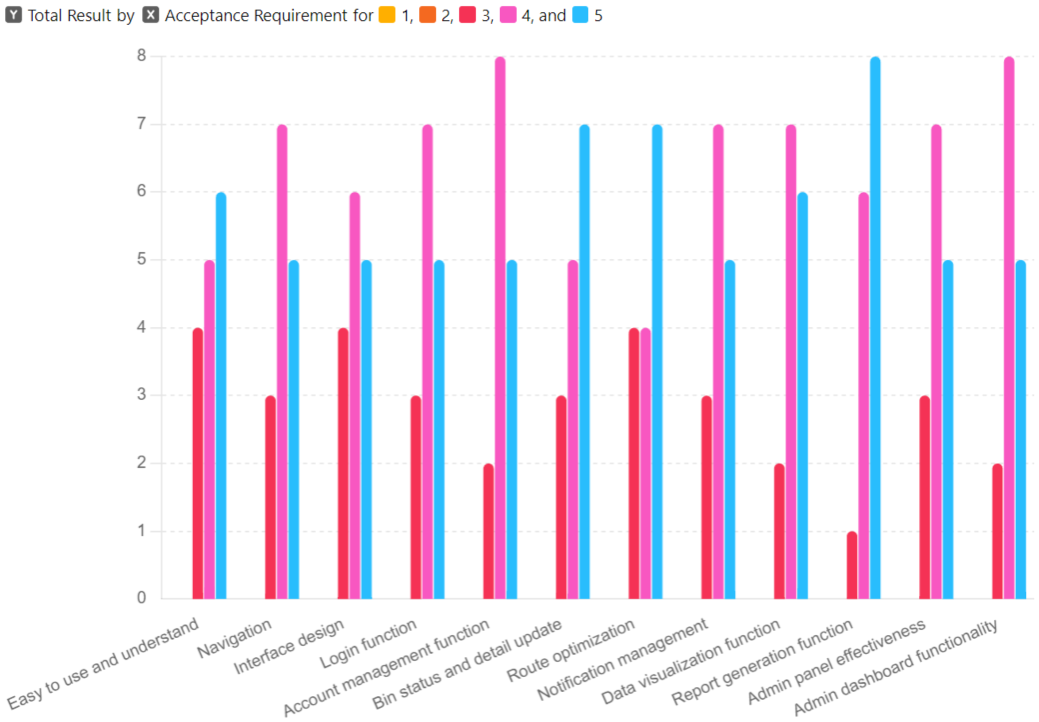

Figure 19: Result of user acceptance testing for admin user

Conclusion

In conclusion, the proposed IoT and Web-Based System for Efficient Waste Collection and Monitoring presents a comprehensive solution to the pressing challenges of traditional waste management systems. The project is driven by the urgent need to address inefficiencies, high operating costs, environmental degradation, and the lack of real-time data in waste management practices. Through the integration of IoT technologies, ultrasonic sensors, Arduino, Thing Speak, Android Studio, PHP, and a web-based platform, the system aims to revolutionize waste collection, monitoring, and management. The methodology employed, including parallel development, detailed requirement analysis, and thorough testing, ensures the robustness and effectiveness of the proposed system. The project's expected results encompass improved waste collection operations, reduced environmental impact, lowered operational costs, enhanced public health and safety, and increased overall efficiency in waste management.

Despite its promising potential, the system has certain limitations. The reliance on continuous internet connectivity and the potential for sensor malfunctions could affect system reliability. Additionally, the initial costs for setting up IoT infrastructure and the need for regular maintenance might pose challenges. Future work should focus on enhancing system robustness through redundant communication pathways and more resilient hardware components. Expanding the system's capabilities to include predictive analytics for waste generation and integrating advanced AI algorithms for further optimization of collection routes could also be beneficial. Finally, pilot projects and user feedback will be crucial for iterative improvements, ensuring the system evolves to meet the dynamic needs of urban waste management.

The comparison with existing systems and the detailed analysis of related work provide valuable insights into the strengths and limitations of the proposed system. As urban environments continue to evolve towards smarter solutions, the Smart Waste Management project stands as a significant contribution to fostering more connected, intelligent, and sustainable cities .

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

This journal requires that all authors take public responsibility for the content of the work submitted for review. The contributions of all authors must be described in the following manner:

The authors confirm contribution to the paper as follows: **study conception and design:** Ellison Lim Jian Hung, Nayef Abdulwahab Mohammed Alduais; **data collection:** Ellison Lim Jian Hung; **analysis and interpretation of results:** Ellison Lim Jian Hung, Nayef Abdulwahab Mohammed Alduais; **draft manuscript preparation:** Ellison Lim Jian Hung, Nayef Abdulwahab Mohammed Alduais. All authors reviewed the results and approved the final version of the manuscript.

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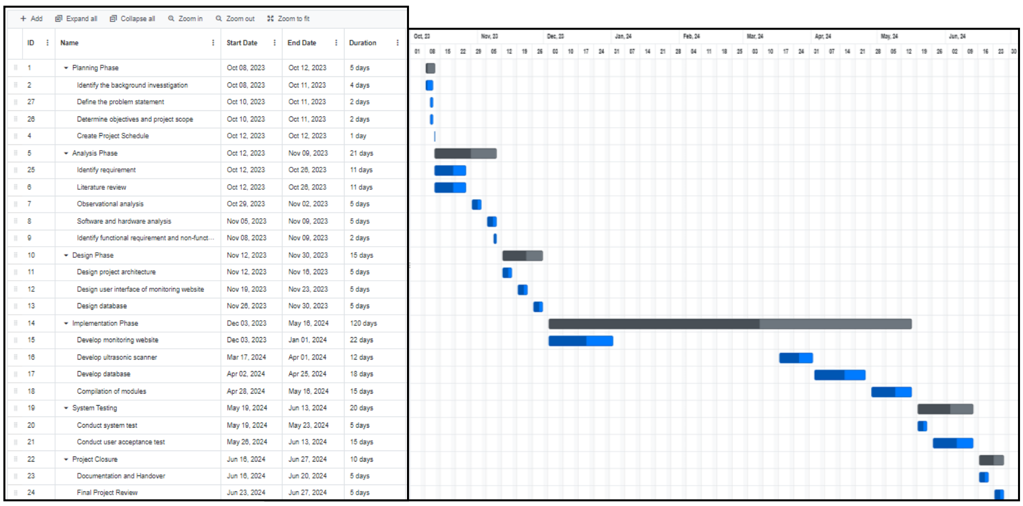
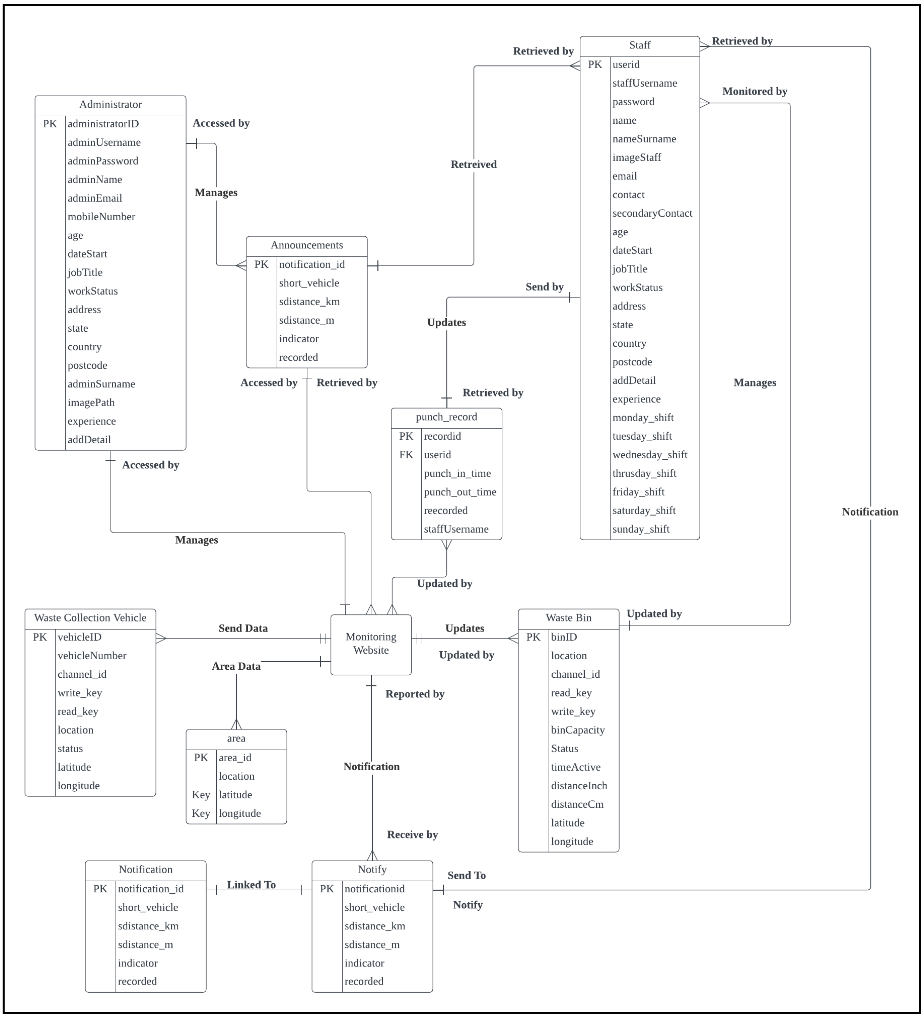
Appendix A Gantt chart



ID	Name	Start Date	End Date	Duration
1	Planning Phase	Oct 08, 2023	Oct 12, 2023	5 days
2	Identify the background invesstigation	Oct 08, 2023	Oct 11, 2023	4 days
27	Define the problem statement	Oct 10, 2023	Oct 11, 2023	2 days
26	Determine objectives and project scope	Oct 10, 2023	Oct 11, 2023	2 days
4	Create Project Schedule	Oct 12, 2023	Oct 12, 2023	1 day
5	Analysis Phase	Oct 12, 2023	Nov 09, 2023	21 days
25	Identify requirement	Oct 12, 2023	Oct 26, 2023	11 days
6	Literature review	Oct 12, 2023	Oct 26, 2023	11 days
7	Observational analysis	Oct 29, 2023	Nov 02, 2023	5 days
8	Software and hardware analysis	Nov 05, 2023	Nov 09, 2023	5 days
9	Identify functional requirement and non-funct…	Nov 08, 2023	Nov 09, 2023	2 days
10	Design Phase	Nov 12, 2023	Nov 30, 2023	15 days
11	Design project architecture	Nov 12, 2023	Nov 16, 2023	5 days
12	Design user interface of monitoring website	Nov 19, 2023	Nov 23, 2023	5 days
13	Design database	Nov 26, 2023	Nov 30, 2023	5 days
14	Implementation Phase	Dec 03, 2023	May 16, 2024	120 days
15	Develop monitoring website	Dec 03, 2023	Jan 01, 2024	22 days
16	Develop ultrasonic scanner	Mar 17, 2024	Apr 01, 2024	12 days
17	Develop database	Apr 02, 2024	Apr 25, 2024	18 days
18	Compilation of modules	Apr 28, 2024	May 16, 2024	15 days
19	System Testing	May 19, 2024	Jun 13, 2024	20 days
20	Conduct system test	May 19, 2024	May 23, 2024	5 days
21	Conduct user acceptance test	May 26, 2024	Jun 13, 2024	15 days
22	Project Closure	Jun 16, 2024	Jun 27, 2024	10 days
23	Documentation and Handover	Jun 16, 2024	Jun 20, 2024	5 days
24	Final Project Review	Jun 23, 2024	Jun 27, 2024	5 days

Appendix B Entity Relationship Diagram (ERD)



Sequence Diagram