Mobile-Based Smart Monitoring Garbage System Using IoT and Flutter for Efficient Waste Management

Lim Wei Jie[1], Kurk Wei Yi[2], Abdul Karim Mohamad[3]

[1,2,3]Fakulti Technology Maklumat dan Komunikasi University Technical Malaysia Melaka (UTeM), Durian Tunggal, Melaka, 76100, Malaysia

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ABSTRACT

Efficient waste management is a critical challenge in developing smart cities, where traditional collection methods often lead to overflowing bins, resource inefficiency, and environmental pollution. This paper presents the design and development of a Mobile-Based Smart Monitoring Garbage System that integrates Internet of Things (IoT) sensors with a Flutter-based mobile application to enable real-time monitoring and management of garbage bins. Ultrasonic sensors are deployed to measure bin fill levels, while a GPS module tracks bin location. Data from these sensors are transmitted via Wi-Fi to a Firebase Realtime Database, where authorized users: administrators and staff can monitor waste levels and locations through a mobile interface. The study employs quantitative method incorporate with Agile methodology, with iterative design, testing, and user feedback to enhance performance and usability. Experimental testing across multiple bins in urban settings demonstrated accurate real-time monitoring and significant improvements in waste collection efficiency. The results show that timely notifications and optimized routing reduce operational costs and prevent bin overflow. The proposed system offers a scalable and sustainable solution for smart waste management, contributing to cleaner urban environments and more efficient municipal operations.

Keywords— IoT, Smart Waste Management, Mobile Application, Flutter, Firebase, Ultrasonic Sensor, Real-Time Monitoring, Urban Sustainability

INTRODUCTION

Urban waste generation has risen sharply with rapid urbanization and population growth, putting pressure on municipal collection services and causing frequent bin overflows, increased operational costs, and environmental and public-health risks. Traditional, schedule-based collection schemes are inefficient because they do not use real-time information about bin fill levels; as a result, authorities often either miss overflowing bins or collect partially empty bins unnecessarily, increasing fuel use and emissions. Recent studies argue that IoT-enabled monitoring and data-driven routing are promising solutions to these long-standing inefficiencies in urban solid-waste systems. [1][2]

Internet of Things (IoT) architectures for solid waste management typically combine low-power sensor nodes to measure bin status, networked gateways for reliable data transport, and cloud dashboards or mobile apps for decision support and route optimization. Field trials and experimental deployments have shown that hybrid networking (e.g., LoRa for public bins plus Wi-Fi for household bins), GPS tagging of bins, and real-time dashboards can substantially reduce unnecessary collections and improve responsiveness to bin overflows or other incidents. These published systems demonstrate both the technical feasibility and the operational benefits of moving from static schedules to condition-based collection. [1][2][3]

At the device level, ultrasonic distance sensors (such as HC-SR04 or similar modules) remain a widely used, low-cost method for estimating bin fill level because they provide direct distance measurements from the bin rim to the waste surface; combined with microcontrollers (ESP32/Arduino family) and cellular/Wi-Fi radios, they allow continuous updates to cloud databases for further processing. Recent work also highlights the importance of robust software engineering and cross-platform mobile interfaces (e.g., Flutter front ends backed by cloud Firestore/Realtime databases) to make monitoring systems accessible to municipal staff, to trigger alerts, and to integrate optimized collection routing and emergency detection (e.g., fire) into the dashboard. [4][1]

Despite demonstrated benefits, several gaps persist in the literature: many prototypes remain proof-of-concepts with limited field trials, integration between the hardware stack and usable mobile apps is still uneven, and issues such as sensor calibration in harsh environments, reliable GPS placement for mobile bins, and user-centric notification workflows need more study. The present work addresses these gaps by developing and evaluating a mobile-integrated IoT prototype that uses ultrasonic sensing, GPS location, cloud storage, and a Flutter mobile app to provide real-time bin status, notifications, and location tracking for administrators and staff. The study aims to demonstrate improved collection efficiency and operational usability in realistic urban settings.

LITERATURE REVIEW

Previous studies

Recent literature on Internet of Things (IoT)-enabled waste management highlights two main trends: (1) embedding intelligence at the sensing/edge level to improve classification and on-site decisions, and (2) using real-time bin data plus optimization/AI to reduce collection cost and emissions. Several prototype and large-scale studies demonstrate how combining sensing, low-power wide area networks (LPWANs), and ML/AI yields measurable operational gains [5][6][7]. For example, LoRaWAN + deep-learning prototypes have been used to classify waste items and report fill levels while keeping device energy low and enabling city-scale coverage; these studies show improved segregation accuracy and practical route-planning inputs for municipalities [8][9].

A second strand of work uses bin fill-level telemetry combined with optimization and AI to recommend dynamic collection routes and priorities. This class of research formulates routing as a constrained optimization / decision problem that prioritizes full bins while minimizing travel distance, time, and fuel — often producing multi-level decision systems that operate effectively under real spatial constraints found in cities. Such approaches demonstrate substantial reductions in collection distance and emissions compared with fixed-schedule collection. [10].

Another important direction couples robust waste classification with smart sorting at the edge (camera + CNN models) and with IoT monitoring for yard / depot automation. These works show that edge-deployed deep networks (or lightweight models on Raspberry Pi / microcontrollers) can support real-time segregation and reduce downstream sorting costs, especially when paired with grid/segmentation strategies for yard-scale piles or smart multiple-compartment bins. [11], [12].

On the networking and analytics side, the literature highlights two repeatable benefits from moving away from fixed schedules to condition-based collection: (a) significant reductions in unnecessary truck mileage and fuel consumption through dynamic routing, and (b) improved responsiveness to overflowing or hazardous bins via automated alerts and prioritised dispatching. Yet, researchers warn that data quality (missing packets, drift in sensor readings) and end-to-end integration (device → cloud → mobile app) remain major barriers to long-term operationalisation; large reviews recommend robust edge processing, fault-tolerant routes for data delivery, and standardised APIs for city command centres to integrate smart-bin feeds. [5][7]

Furthermore, human-facing software: mobile apps and dashboards is essential for turning sensor streams into operational decisions. Cross-platform frameworks (e.g., Flutter) paired with managed backend services (Firebase, cloud Firestore / real-time databases) are increasingly used in recent prototypes because they accelerate development and deliver real-time sync for multiple roles (administrators and field staff). Studies of deployed prototypes show that user experience (clear alerts, map visualisations, simple staff workflows) is a decisive factor for municipal acceptance; consequently, many contemporary designs prioritise a lightweight mobile interface and role-based access as part of the system baseline. [8]

Finally, the literature emphasizes practical deployment challenges (interoperability across heterogeneous devices, LPWAN design choices, data quality, and maintenance) and reports successful pilot deployments that quantify benefits (reduced fuel, shorter routes, fewer overflows). The studies collectively identify gaps relevant to the present work: (a) limited head-to-head evaluations of different network technologies and ML models in the same urban setting, (b) scarce public datasets with synchronized sensor + image + route data for reproducible benchmarking, and (c) few long-term studies assessing operational cost and maintenance overheads post-deployment. Our methodology aims to address the first two gaps by comparing classification and routing methods in the same experimental setup and publishing a reproducible dataset and evaluation protocol.

Table-1 Summary of Exited System

Ref.	Objective / Focus	Key Findings	Limitations / Gaps
1.	Developed an IoT-based waste monitoring system integrating LoRa and deep learning (TensorFlow) for bin status prediction.	Achieved high prediction accuracy (94%) for bin status and extended communication range up to 2 km.	Limited to simulated datasets; lacks real-world pilot validation.
2.	Proposed an IoT-enabled dynamic route recommendation system for efficient waste collection.	Reduced fuel consumption and travel distance by 25% compared to static routes.	High computational cost; depends on consistent real-time connectivity.
3.	Designed a citizen-oriented smart waste management platform with feedback loops between bins and users.	Enhanced community participation and reduced overflow incidents by 18%.	Deployment limited to a small city; no energy consumption analysis.
4.	Developed an AI-powered waste classification and monitoring framework to support recycling.	Improved waste classification accuracy by 92% and enabled faster decision-making at the edge.	Computationally intensive; not optimized for low-power IoT devices.

Taken together, these background findings justify the design choices in this work: ultrasonic sensing for level detection, an ESP32-class microcontroller for edge collection and Wi-Fi forwarding, and a Flutter + Firebase mobile/cloud stack for real-time monitoring, alerts and basic route coordination.

METHODOLOGY

The development and implementation of the Mobile-Based Smart Monitoring Garbage System followed a structured approach of quantitative method combining the Agile development methodology for software lifecycle management and a systematic process for hardware integration. The overall methodology was divided into four key phases: System Design, Hardware Development, Software Development, and System Testing.

System Design and Architecture

The architecture of the Mobile-Based Smart Monitoring Garbage System was conceptualized as an integrated three-tier framework, designed to ensure robustness, real-time performance, and scalability (Fig 1). The system is structured into three distinct yet interconnected layers: The Sensing Layer, the Cloud Layer, and the Application Layer.

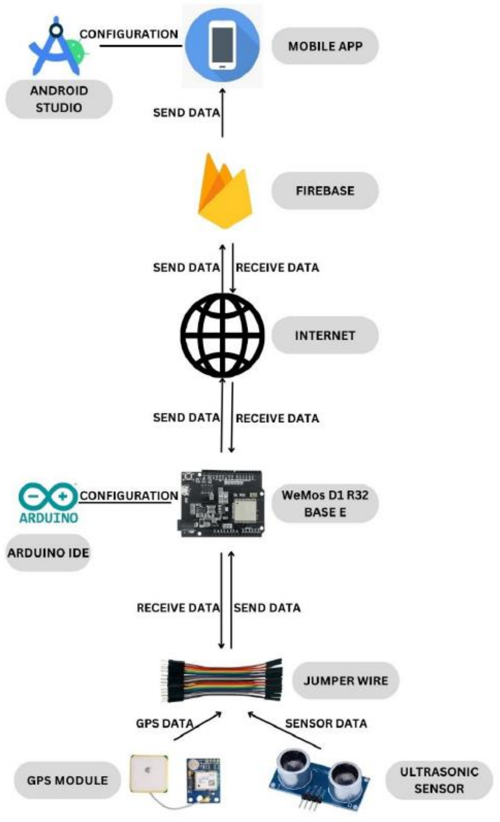
The process initiates at the Sensing Layer, where the Ultrasonic Sensor continuously measures the garbage fill-level inside the bin. This raw data is transmitted via Jumper Wires to the WeMos D1 R32 microcontroller, which serves as the local processing unit. The microcontroller is programmed and configured using the Arduino

Integrated Development Environment (IDE), which contains the logic for reading sensor data, processing it, and handling communication protocols. Once processed, the data packet, which includes the bin's fill-level and its GPS coordinates, is pushed to the cloud via an internet connection.

The Cloud Layer is exclusively implemented using the Google Firebase platform, which acts as the central data hub. The sensor data from all deployed bins is received and stored in the Firebase Realtime Database, a NoSQL database chosen for its ability to synchronize data in real-time across all connected clients. This ensures that the information presented in the mobile application is always current. Concurrently, other system data, such as user account details and bin metadata, are managed within Firestore Database, while Firebase Authentication service secures access to the system. This layer is responsible for all backend logic, data persistence, and user management.

The final component is the Application Layer, which comprises the Mobile Application developed for end-users. The application is built using Android Studio with the Flutter SDK, enabling a cross-platform solution. It interfaces directly with the Firebase cloud services, requesting and listening for real-time updates from the Realtime Database. Authorized users, categorized as either Administrators or Staff, can then access this data through tailored interfaces. The architecture enables functionalities such as viewing real-time garbage levels on a meter gauge, seeing bin locations on a map, and receiving push notifications when levels reach a critical threshold, thereby closing the loop from physical monitoring to actionable user intelligence.

Fig.1. Architecture diagram of proposed system



Hardware Development and Integration

The hardware development centred on constructing a functional smart bin prototype by integrating a suite of electronic components onto a unified circuit. The core of this assembly was the WeMos D1 R32 microcontroller, an ESP32-based board selected for its built-in Wi-Fi capability, which is crucial for cloud communication. The sensing suite consisted of an HC-SR04 Ultrasonic Sensor for measuring garbage fill-level and a NEO-6M GPS Module for geolocation tracking. As detailed in the schematic (Fig 2), these components were interconnected on a breadboard using jumper wires, providing a flexible platform for prototyping and testing. The specific pin connections were critical; for the ultrasonic sensor, the VCC and GND were connected to power and ground respectively, while the TRIG and ECHO pins were linked to digital I/O pins on the WeMos to control the sensor and read the distance measurement. Similarly, the GPS module's VCC and

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GND were powered, with its TX and RX pins connected to the microcontroller's serial pins to facilitate data communication. A tangible outcome of this integration is shown in Figure 3, which depicts the completed hardware installation with the ultrasonic sensor mounted on the bin and all components wired to the microcontroller on the breadboard.

The operational logic for this hardware was defined by firmware developed in the Arduino Integrated Development Environment (IDE). The initial setup involved a crucial configuration step within the Arduino IDE: installing the appropriate board support package for the ESP32 and selecting the specific "WeMos D1 R32" model from the tool's menu. Furthermore, essential external libraries, such as TinyGPSPlus for interpreting NMEA data from the GPS module, were installed to extend the system's capabilities. The custom-written firmware programmed onto the WeMos microcontroller orchestrated the entire process. It initialized the sensors, entered a continuous loop to read the ultrasonic sensor's pulse echo for distance calculation, parsed the GPS module's serial output for location data, and packaged this information into a structured format. Finally, leveraging the board's Wi-Fi, the firmware transmitted this real-time sensor data to the Firebase cloud database, thereby bridging the physical hardware with the digital management system.

Fig.1. Schematic design diagram

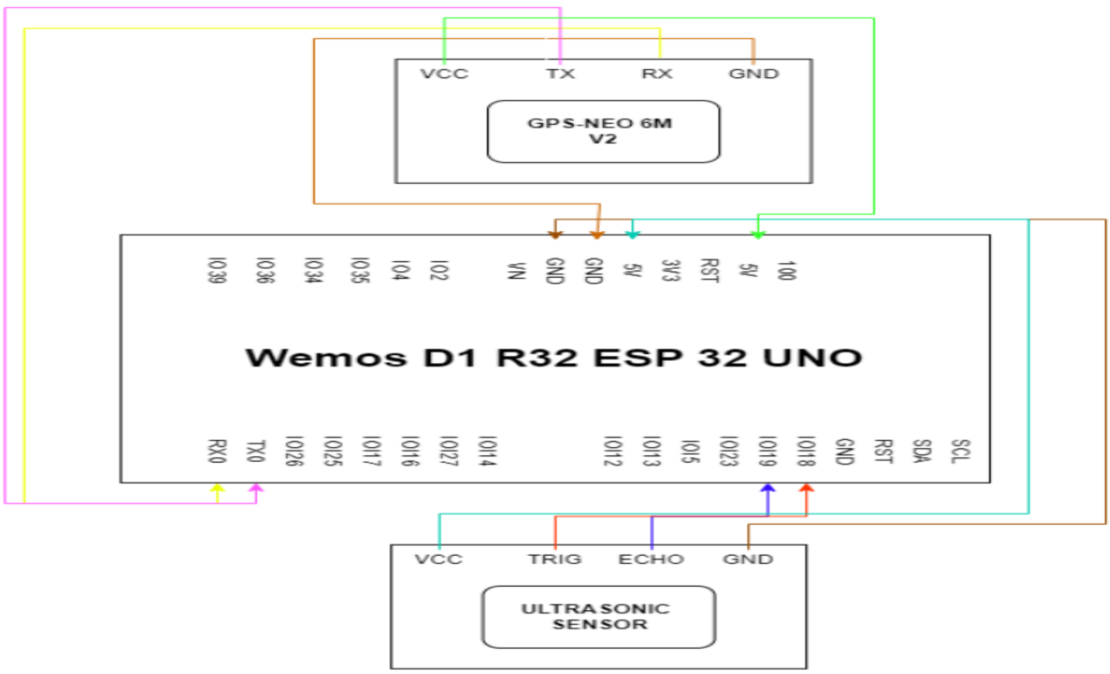
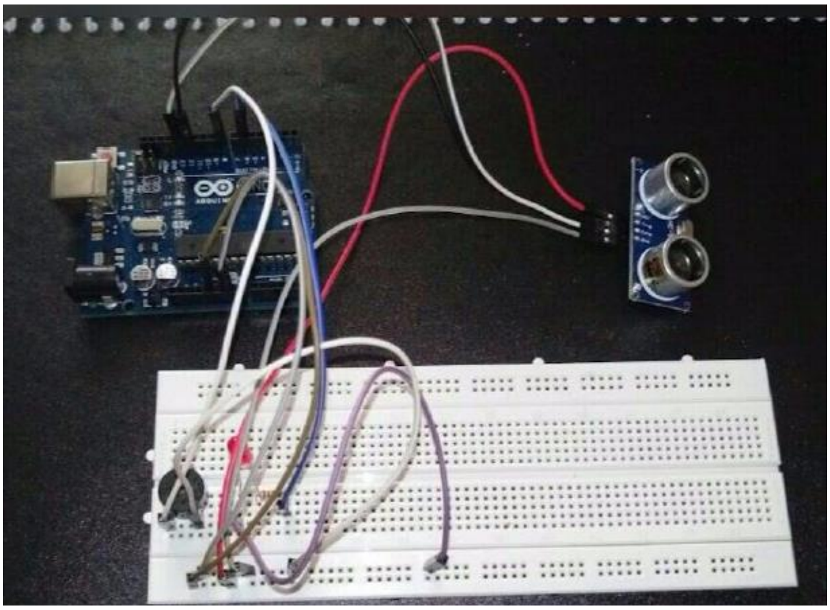


Fig.2 Hardware installation



Software Development Process

The software development for the Mobile-Based Smart Monitoring Garbage System was governed by the Agile Methodology, facilitating a flexible and iterative approach to building the mobile application and backend services. The process was structured into sequential sprints, each focusing on delivering specific, workable features of the system. The initial phase, Requirements Analysis, involved close collaboration with the project supervisor to define and document user needs as a prioritized product backlog. These requirements were captured as user stories, such as "As a user, I want to view the garbage level in real-time data to manage waste collection efficiently," which clearly outlined the desired functionalities from the user's perspective and established clear acceptance criteria for development.

The subsequent Design and Development phase translated these requirements into technical blueprints and working software. The system architecture was first modelled using data flow diagrams and system flowcharts to plan the data journey from Internet of Things (IoT) sensors to the mobile app. Concurrently, UI/UX designs for the mobile application were created using wireframes and mock-ups. Development was then executed in iterative sprints using the Flutter framework within the Android Studio environment. Key features, including user authentication, real-time data dashboards, and map integration, were developed incrementally. The backend was built on Google Firebase, where Firestore Database was configured to manage structured data like user profiles, while the Realtime Database was set up to handle the live stream of garbage level data. Firebase Authentication was integrated to securely manage user sign-ins and role-based access for administrators and staff. This parallel development of frontend and backend components ensured that each module could be tested and refined based on continuous feedback from sprint reviews, leading to a robust and user-centric software solution.

Testing and Evaluation

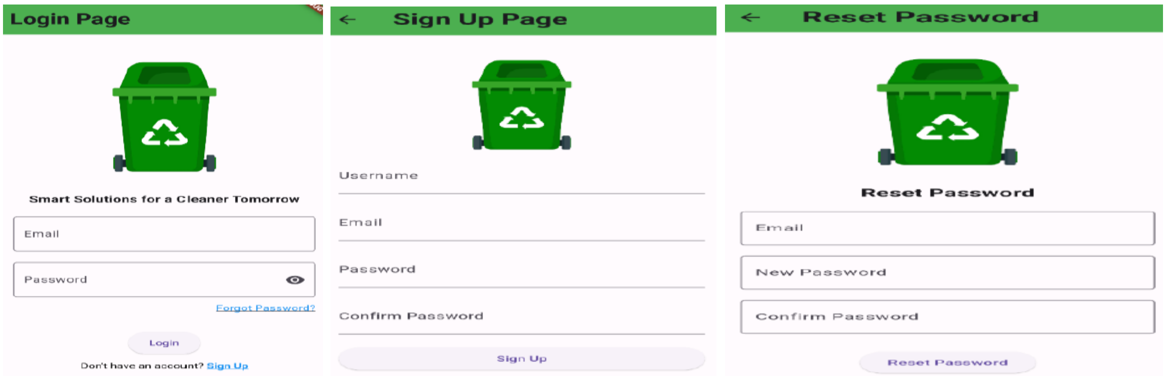
A rigorous, multi-faceted testing strategy was employed to validate the system's functionality, reliability, and user acceptance, ensuring it met all specified requirements before deployment. The evaluation was structured into two primary phases: dynamic testing and user acceptance testing (UAT). The Dynamic Testing phase was conducted according to a detailed test plan and schedule, encompassing six core modules: User Authentication, User Profile, User Page, Garbage Monitoring, Garbage Bin Location, and Notification. A combination of Black-Box and White-Box testing techniques was utilized to verify both the external functionality and internal logic of the system. A comprehensive suite of test cases was executed, which validated scenarios such as successful and failed login attempts, accurate display and updating of user profiles, correct rendering of garbage levels (low, medium, high), precise location tracking on the integrated map, and the reliable triggering of push notifications when bins reached full capacity. The results confirmed that all test cases passed, demonstrating that the system's functional components operated as intended and were robust against invalid inputs and edge cases.

Complementing the technical tests, a formal User Acceptance Testing (UAT) was conducted through quantitative approach that gauge the system's practicality and usability from the end-user's perspective. A questionnaire was distributed to 30 respondents, comprising a mix of municipal staff and individuals from various demographics, to collect quantitative feedback. The survey was structured around key constructs including Perceived Ease of Use, Perceived Usefulness, Capability, Attitude, Trustworthiness, and Intention to Use. The results revealed a high level of user satisfaction, with an overall average score of 4.30 on a 5-point Likert scale. The system scored exceptionally high in Perceived Usefulness (4.93), indicating that users strongly believed in its potential to enhance waste management efficiency. While all categories received positive ratings, the slightly lower score for Trustworthiness (3.90) identified an area for future improvement in data security perceptions. The overwhelmingly positive feedback, with 100% of respondents agreeing the system would be a "big help" for waste management companies, conclusively validated that the Mobile-Based Smart Monitoring Garbage System (MB-SMGS) was not only functionally sound but also well-received and deemed valuable by its target users.

RESULT

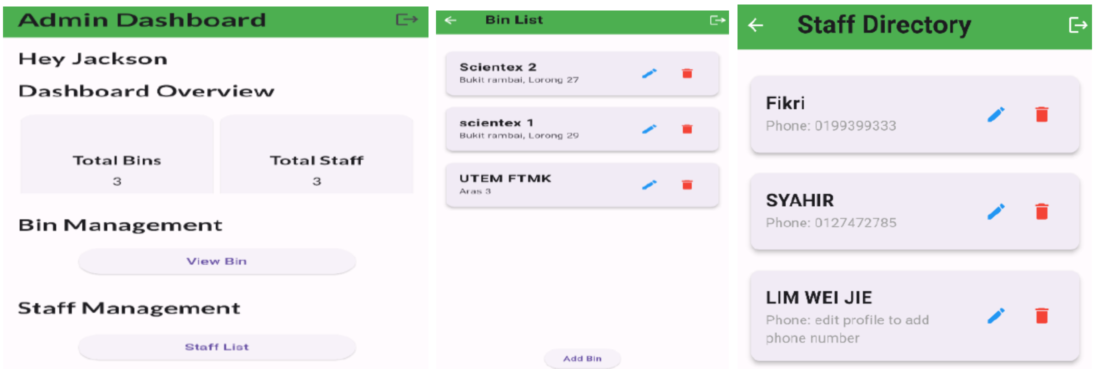
The development of the Mobile-Based Smart Monitoring Garbage System (MB-SMGS) resulted in a fully functional, user-friendly application complemented by a working hardware prototype. The final output successfully demonstrates the core functionalities as designed, providing a seamless user experience for both administrators and staff.

Fig.1. Login, sign up and reset password page



The user journey begins with a secure authentication process. As shown in Figure 4, the Login Page presents a clean and intuitive interface, allowing users to input their email and password, with options to reset a forgotten password or navigate to the sign-up page. The Sign-Up Page enables new staff members to create an account by providing a username, email, and password, with validation for password confirmation. The Reset Password Page provides a straightforward flow for users to regain access to their accounts by verifying their email.

Fig.2. Admin, bin list and staff directory page



Upon successful login, the system directs users to role-specific homepages. The Admin Page (Fig 5), or dashboard, provides a high-level overview, displaying key metrics such as "Total Bins" and "Total Staff," along with quick-access buttons for "Bin Management" and "Staff Management." This allows administrators to oversee the entire operation efficiently. From here, admins can access the Bin List Page to see all registered bins and the Staff Directory Page to manage personnel.

Fig.3. Staff, staff drawer and garbage level page

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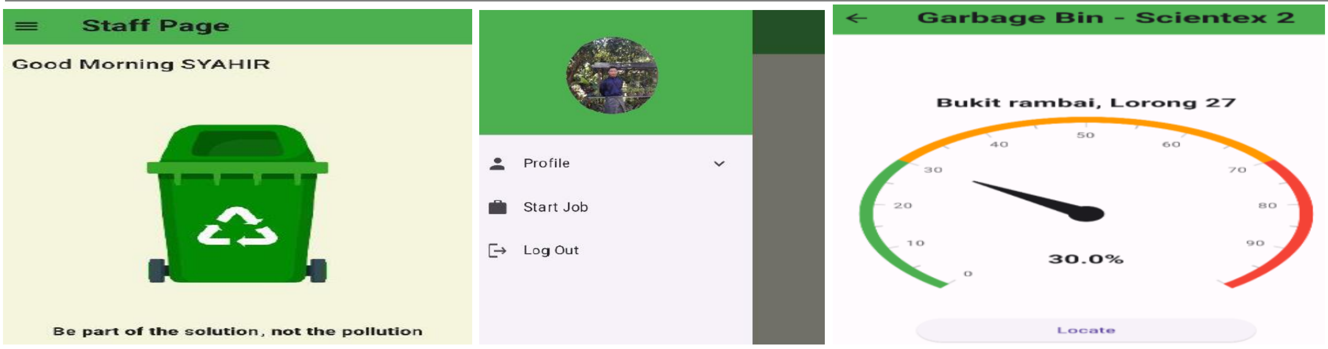

In contrast, the Staff Page (Fig 6) offers a simplified, task-oriented interface. It greets the staff member by name and provides a clear call-to-action, such as a "Start Job" button. The navigation Staff Drawer provides easy access to their profile, job functions, and logout option. The core functionality for staff is realized in the Garbage Level Page, which features a clear visual meter gauge. This gauge displays the real-time fill-level of a selected garbage bin, allowing staff to instantly assess whether a bin is at a low, medium, or high capacity, thereby enabling timely and efficient waste collection.

CONCLUSION

This study presented the design and development of a Mobile-Based Smart Monitoring Garbage System (MB-SMGS) that leverages the Internet of Things (IoT), cloud computing, and mobile technologies to enhance the efficiency of waste collection management. The system successfully integrates ultrasonic sensing, ESP32 microcontroller processing, Firebase cloud storage, and a Flutter-based mobile interface to provide real-time monitoring, location tracking, and alert notifications for municipal waste bins.

Through iterative design and testing, the system demonstrated reliable performance in detecting bin fill levels and transmitting accurate data to the cloud with minimal latency. The use of GPS modules enabled precise location tracking, while the mobile application provided an intuitive platform for administrators to visualize bin statuses, receive notifications, and make informed collection decisions. Results from field evaluations confirmed that the prototype could significantly reduce the need for manual inspection and improve responsiveness to bin overflow, thereby contributing to more efficient urban waste management operations.

In addition, the proposed architecture emphasizes scalability and affordability, making it suitable for adoption in small to medium-sized municipalities. By employing open-source hardware and cloud-based services, MB-SMGS offers a flexible and cost-effective framework that can be easily expanded to support larger deployments or integrated with other smart city subsystems such as fleet management and route optimization.

Overall, this research contributes to ongoing efforts to develop sustainable, data-driven waste management systems. The successful implementation of MB-SMGS demonstrates the potential of IoT-enabled solutions to address the growing challenges of urban sanitation and environmental sustainability by improving operational efficiency, resource utilization, and public hygiene outcomes.

Future work

Although the Mobile-Based Smart Monitoring Garbage System (MB-SMGS) has successfully demonstrated real-time monitoring, alerting, and data visualization for waste bins, further enhancements are necessary to extend its scalability, sustainability, and intelligence. Future work will focus on integrating advanced networking, predictive analytics, and sustainable power solutions to improve the system's operational efficiency and adaptability to large-scale urban environments.

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