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TRASHTECH: IOT & AI-BASED SMART WASTE MONITORING APP FOR CITIES

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ABSTRACT

Waste accumulation is a significant issue in urban areas, where large volumes of waste pile up and often become normalized by the community. In regions like Bogor Regency, with a population of 5,489,539, this problem is especially crucial, impacting both the environment and public health. To address this, the implementation of an automated waste monitoring system based on the Internet of Things (IoT) and Artificial Intelligence (AI) offers a promising solution. This research presents a system that utilizes ultrasonic sensors connected to an ESP32 module to monitor waste volume in real-time, with LED indicators signaling when a trash bin is full. A mobile application is integrated into the system to provide data from the sensors and send alerts when waste levels approach capacity, facilitating timely waste collection. The results of this study demonstrate that the automated system effectively supports waste management, improves efficiency, and contributes to the development of a smart city with an environmentally friendly focus. Furthermore, the system's potential to integrate with regional cleanliness programs underscores its scalability and applicability to other urban areas facing similar challenges, offering a sustainable solution for future waste management strategies.

Keywords: Waste Accumulation, Automated Waste Monitoring, Internet of Things (IoT), Artificial Intelligence (AI), Smart City

INTRODUCTION

Bogor Regency, located in West Java Province, Indonesia, has witnessed rapid urbanization and significant population growth in recent years. According to the Central Statistics Agency (BPS), the regency's population reached 5,489,539 people in 2022, spread across 40 sub-districts. This steady increase in population density has resulted in a growing demand for infrastructure and services, particularly in waste management. With the large volume of waste generated daily, inefficient waste disposal and management practices have become pressing concerns (Mahendra, 2024). Inadequate handling of waste leads to severe environmental issues, including air pollution, water contamination, and the accumulation of garbage in public spaces. The local government has identified waste management as a priority, recognizing its role in promoting sustainability and ensuring the quality of life for residents. Despite its significance, the waste management system in Bogor Regency struggles with inefficiencies. A key issue is the lack of real-time monitoring of waste accumulation, which hinders effective collection and disposal. Waste is often stored in public trash bins and left for collection by cleaning officers, but without proper tracking, it becomes difficult to identify which areas are experiencing waste overflow. This leads to waste piles accumulating in some neighborhoods while others may remain underutilized. Moreover, the manual process of waste collection is both labor-intensive and prone to errors, contributing to delays and a failure to meet the growing demand for waste disposal. As a result, a more innovative and automated waste management solution is needed to optimize the process. To address these issues, this research proposes the development of an IoT-based smart trash bin system, designed to improve waste management in the regency for smart city sustainable (Putra, G. R., Sardjono, W, Nursetiaji, Oktavian et al. 2022). The proposed system integrates proximity sensors and weight detection technology to monitor waste levels in real time. By using an ESP32 microcontroller, the system can send notifications to

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cleaning staff, alerting them to areas where trash bins are full and in need of collection. This IoT-enabled system leverages advancements in artificial intelligence (AI) to process and analyze data collected from the sensors, enabling more efficient resource allocation and reducing the likelihood of waste overflow. By automating waste monitoring, the system aims to streamline the waste collection process, reduce human error, and ultimately contribute to a cleaner, smarter environment.

The adoption of IoT technology in waste management has gained momentum globally, with many cities implementing smart trash bins as part of their efforts to develop sustainable urban environments. Previous studies, such as the work by (Ismail, Abdullah and Abdussamad 2021). have demonstrated the potential of using IoT sensors to monitor waste levels and transmit data to cloud-based platforms for remote management. Similarly, (Ananda and Sujana 2021) employed MQ-2 sensors to detect smoke levels, sending notifications to cleaning staff when bins were full or when waste posed a potential hazard. However, despite these advancements, there is still a lack of comprehensive systems that combine both proximity and weight detection, which would provide a more accurate assessment of trash levels. This research seeks to fill this gap by integrating multiple sensor technologies to enhance the reliability and effectiveness of waste management systems. The integration of smart waste management solutions aligns with the broader concept of smart cities, where IoT-based innovations are leveraged to create more sustainable, efficient, and responsive urban environments. The proposed system not only benefits local governments by providing real-time monitoring data but also empowers communities to take an active role in waste management. By improving waste collection efficiency, reducing environmental impact, and enabling more data-driven decision-making, the system supports the vision of a smarter, cleaner, and more sustainable Bogor Regency. The implementation of such technologies will also help to address the broader issue of urban waste management in Indonesia, offering a scalable model that can be adapted for other regions facing similar challenges.

The primary objective of this research is to design and develop an IoT-based smart trash bin system aimed at improving waste management (Lam K, Huynh N, et.al., Lam KHuynh NNgoc N et al, 2021)**.**, (Olawade Fapohunda, OWada et al., 2024) in Bogor Regency. The system will integrate proximity and weight detection sensors with an ESP32 microcontroller to monitor waste accumulation in real time (Melinda, Ramadhan, Nurdin & Yunidar 2023). By automating the monitoring process, the system will send notifications to cleaning staff, enabling them to efficiently manage waste collection and address areas with higher waste accumulation. This will reduce the reliance on manual checks and minimize the risk of waste overflow.

A secondary objective is to enhance the efficiency of waste collection by leveraging artificial intelligence (AI) to process and analyze sensor data. AI will be used to predict waste generation trends and optimize resource allocation for waste collection. By ensuring more accurate data on waste levels, the system will streamline the overall process, reduce delays, and help maintain cleanliness in urban areas. This objective aims to make waste management more responsive, timely, and effective in meeting the growing demands of Bogor Regency's expanding population.

Furthermore, the research seeks to assess the broader impact of implementing an IoT-based waste management system on environmental sustainability. The project will examine how such a system can contribute to reducing pollution, improving waste collection efficiency, and supporting sustainable urban living. Additionally, this study aims to explore the scalability of the system, considering its potential application in other regions with similar urbanization challenges. Ultimately, the research aims to empower communities to engage more actively in waste management practices, fostering a cleaner and more sustainable environment for all residents.

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MATERIALS AND METHODS

This section presents the materials and methods employed in the development of the TrashTech smart waste management system, an innovative IoT-based solution designed to address the challenges of waste accumulation in urban areas. The research adopts the System Development Life Cycle (SDLC) methodology (Jaya, Ardiansya, Adriani, & Ridwang 2024), (Girsang, 2024). to guide the structured progression of the project, ensuring a systematic approach to design, implementation, testing, and deployment. In the materials subsection, we detail the hardware components, such as sensors, microcontrollers, and communication modules, that constitute the core infrastructure of the system. Additionally, we describe the software tools and platforms used for data processing, real-time monitoring, and system management (Muslimin, Andhika,, Ardiantoro and Zahara 2022). The methods section outlines the phases of the SDLC framework applied to the development process, including requirement analysis, system design, prototype development, testing, and deployment. This comprehensive approach aims to ensure that the TrashTech system is not only functional but also scalable and sustainable, providing a practical solution to urban waste management through the integration of IoT (Hidayat and Safitri 2024)and data analytics.

2.1 Architecture System

TrashTech Smart Waste Management System, which is designed to automate and optimize waste collection in urban areas. The system integrates several key components that work together to monitor, manage, and communicate waste data in real time, ensuring efficient waste management and resource allocation. Here's a breakdown of the architecture:

2.1.1 Smart Trash Bin (IoT Devices): The heart of the system is the smart trash bin, which is equipped with IoT devices that monitor waste levels using various sensors:

1.) Proximity Sensors: These sensors measure the distance to the waste inside the

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bin, detecting when the bin is full or close to capacity.

2.) Weight Detection Sensors (Load Cells): These sensors monitor the weight of the waste, providing an additional method to estimate the fill level of the bin.

2.1.2 ESP32 Microcontroller: The ESP32 microcontroller serves as the central processing unit of the smart trash bin. It collects data from the sensors and communicates this information to the central system via Wi-Fi or Bluetooth. The microcontroller is responsible for data processing, triggering notifications when bins are full, and maintaining communication with the backend system.

2.1.3 Cloud-based Data Storage/Server: The data collected from the sensors is sent to a cloud-based platform or a centralized server, where it is stored and processed. Platforms such as ThingSpeak or a custom-built database will receive the data and allow real-time monitoring. This platform will also aggregate data from multiple bins, providing insights such as waste levels in different locations and identifying trends in waste generation.

2.1.4 Data Analytics (AI/ML): In the cloud platform, data analytics tools and artificial intelligence (AI) algorithms can be applied to analyze the collected data. AI can predict waste accumulation trends, optimize waste collection schedules, and provide insights into areas that may need more frequent collection. This predictive analysis will ensure that the waste management process is proactive rather than reactive, reducing inefficiencies and overflows.

2.1.5 Mobile Application (TrashTech App): A mobile application (TrashTech) is used by cleaning staff and administrators to access real-time data. The app provides users with:

a.) Waste Status Alerts: Notifications are sent when a trash bin is full or needs attention.

b.) Real-time Data: The status of bins, including current fill levels and sensor data, can be accessed via the app, helping cleaning staff optimize their routes.

c.) Route Optimization: The app can suggest the most efficient collection routes based on the data collected, ensuring timely collection and reducing operational costs.

2.1.6 Cleaning Staff/Administrator Interface: The system is designed to be user-friendly for the cleaning staff, providing them with real-time notifications and data on waste levels. The administrator interface allows managers to monitor the entire waste management system, track bin statuses across different locations, and make data-driven decisions about resource allocation and operational improvements.

2.1.7 End User/Community: The community plays an important role in the system by using the smart trash bins properly and engaging in responsible waste disposal. Awareness and educational programs can encourage residents to properly dispose of waste, contributing to the effectiveness of the system.

This architecture effectively integrates IoT technology and AI to create a seamless, automated waste management system. By utilizing proximity, weight, and environmental sensors, the system can monitor the fill levels of trash bins in real-time and send automatic notifications to cleaning staff. This ensures that bins are emptied on time, reducing waste overflow and improving cleanliness in urban areas. The cloud-based platform centralizes all the data, allowing for data analysis, predictive maintenance, and efficient resource management. The mobile app provides real-time alerts and routing information, enabling waste collection teams to optimize their routes based on actual waste levels. The use of data analytics, combined with AI, will make waste management more efficient by predicting trends and optimizing collection schedules (Kurniawan and Rahmawati 2024) ultimately contributing to a cleaner, more sustainable urban environment. This system is scalable and can be implemented in various cities, making it a promising solution for smart cities aiming to tackle waste management challenges. Based on the recommendations of domain experts (Rahmansa, Kalsum and Alamsyah 2023), (Nugraha and Desnanjaya 2022), (Syaljumairi, Prabowo and Hanum 2023.), the researcher identified the required data, components, and functions that form the system architecture as shown in Figure 1.

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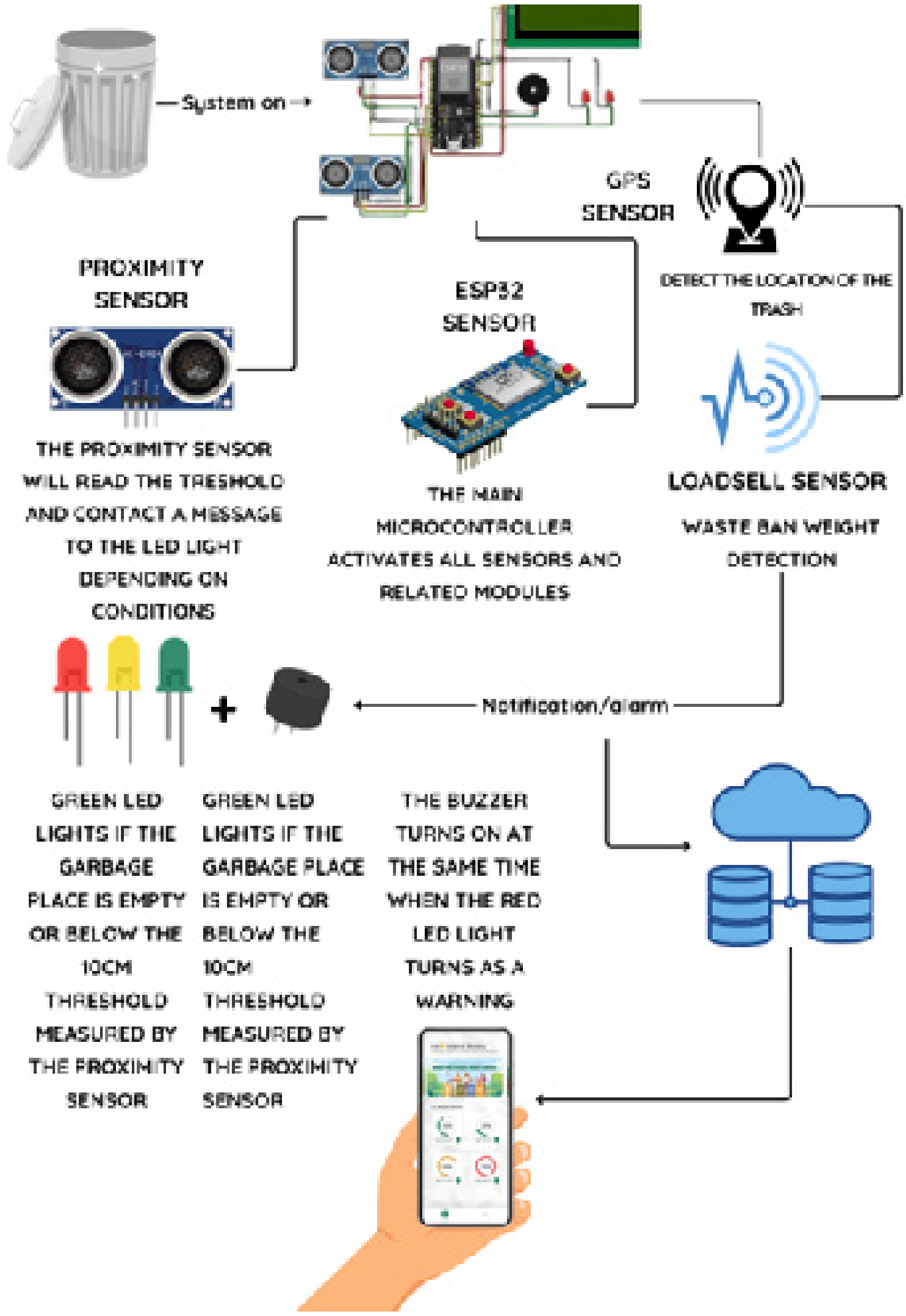

Figure 1. Architecture System

2.2 Specific objectives

a. Develop a waste monitoring application “TrashTech” With the hope that there will be no more piles of waste in the community and can create a beautiful environment free from waste pollution, which can be used to store:
1.) Store data on cleaning staff.
2.) Store data on the location of trash bins.
3.) Store data on application users.
4.) Store data on the condition of trash bins.

b. Create a trash monitoring tool with the ability to provide direct signals/notifications, all related parties can coordinate effectively with each other, enabling more coordinated and targeted waste management, which can be used to detect:
1.) Detect trash bins in full, not full and almost full conditions.
2.)Detect the weight of the trash bin.

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3.)Detect the location of the trash bin.

The benefit of this research is that TrashTech's intelligent system provides efficiency in cleaning services. By monitoring through the device, cleaners can find out information about the pile of waste in the trash in real time, allowing them to pick up trash faster and more efficiently and for the scope based on the formulation of the problems described, the limitations of this study are tools that are stored and applied in community trash bins or other public places so that they can be monitored via the TrashTech application by cleaning staff.

2.3 System Development Life Cycle

The method used in this study is SDLC waterfall, which is a sequential or ordered software development flow approach model.

According to (Musthofa and Haryono 2023)The waterfall system development model has several stages as follows:

a.) Planning
Is the initial stage of system development, this stage aims to identify and prioritize what information systems will be developed, the targets to be achieved, the implementation period and consider the funds available and who will implement it.

b.) Analysis
The analysis process for collecting needs that are carried out intensively for software so that it can be understood what kind of software system is desired and needed by the user. At this analysis stage, it needs to be documented

c.) Design
The process here is focused on the design of making software programs including data structures, software architectures, interface representations and coding procedures. This stage also needs to be documented.

d.) Implementation
After the design stage, it must be translated into a software program. The result of the coding stage is a computer program according to the previously determined design.

e.) Testing and Integration
This process focuses on the software in terms of its function and ensures that all parts have been tested properly. This goal is done to minimize errors in the program and ensure that the output results are as desired.

f.) Support or Maintenance Stage
In a software system, changes can occur when it has been sent to the user. Changes can occur errors that appear and are not detected in testing or the software must adapt to a new environment. In the supporting stage, the development process can be repeated starting from specification analysis to changes to existing software, but does not have to create a new software system.

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RESULT AND DISCUSSION

The way it works starts from the tool that is inserted into the trash can that has been installed with the ESP32 microcontroller. Then for the trash can sensor using proximity, load cell sensor, later the load cell detects whether the object is in a full, almost full and empty condition. there are probably 2 sensors stored above the trash can and below it. The sensor is to ensure the weight is in accordance with the average weight calculation. And GSP, from the results of the data, enter it into the mobile application database to be processed and see if there is a full trash condition, then when there is a full trash condition, the tool will turn on an alarm in the form of a colored LED light and the driver can be notified so that they can immediately search for the location of the full trash can in the trashtech application.

In order for the system to run smoothly, the required hardware requirements must be met. In Table 1, the minimum hardware specifications are shown. Although these specifications are sufficient to run the system, increasing the specifications will significantly affect system execution, thereby improving overall performance and user experience.

Table 1. Hardware Spesification

Type and model	Function	Specification
Sensor proximity	Detect distance or proximity of objects	Detection distance: 0-10 cm (typical), type: infrared/ultrasonic
Microcontroller ESP32	Microcontroller with WiFi and Bluetooth connectivity	CPU: Dual-core 32-bit, RAM: 520 KB, WiFi: 2.4 GHz, Bluetooth: BLE 4.2
Buzzer	Sound indicator	Working voltage: 3-5V, type: piezoelectric, frequency: 2-4 kHz
LED	Visual indicators	Type: Single LED, Working voltage: 1.8-3.3V, Color: Green/Red/Blue
GPS sensor	Determining geographic location	Accuracy: ±2.5 m, Frequency: Hz, protocol: NMEA, interface: UART
Loadcell	Measuring the weight of objects	Capacity: 1-50 kg (depending on type), sensitivity: ±0.02

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Microcontroller ESP32	Microcontroller with WiFi and Bluetooth connectivity	CPU: Dual-core 32-bit, RAM: 520 KB, WiFi: 2.4 GHz, Bluetooth: BLE 4.2
Buzzer	Sound indicator	Working voltage: 3-5V, type: piezoelectric, frequency: 2-4 kHz mV/V, output: analog

In Table 1, the hardware specifications of the system are shown. Regarding the hardware components of the system, this system is built using a proximity sensor, ESP32 microcontroller, buzzer, LED, GPS sensor and loadcell. This system tool is used to create a monitoring tool that is stored in a trash can. The system integrates a proximity sensor (infrared/ultrasonic) to detect waste in a smart bin (0-10 cm range), an ESP32 microcontroller (dual-core 32-bit, WiFi 2.4 GHz, BLE 4.2) for processing and wireless communication, and LEDs/buzzer for status notifications. A GPS sensor (±2.5m accuracy, 1 Hz) enables location tracking, while a loadcell (1-50 kg) measures weight, converting analog output to digital via ADC. This setup ensures real-time monitoring, data-driven optimization, and efficient system management.

Table 2. Software Specification

Type and model	Specification
Operating system	Microsoft windows 10 or higher
Programming software	Dart
Database	SQL database

In Table 2, the system software specifications are shown. Regarding the system software components, the system is built using the Dart programming language with the Flutter framework. Considering the system development platform, the system is used in the Windows 10 environment.

3.1 Flowchart

The system will be stored in the trash can and will detect when the trash can is full. The sensor will detect and send a signal in the form of an alarm/notification in the application and the trash can will light up the LED.

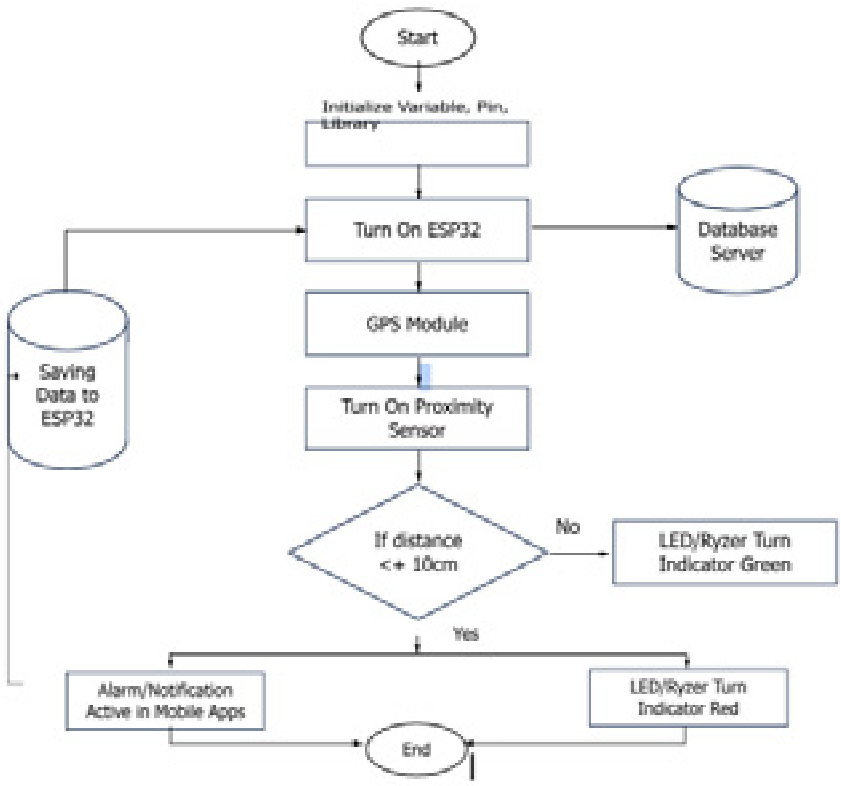

Figure 3. Flowchart System

The flowchart illustrates in figure 3, how a system that uses ESP32 to control LEDs and alarms/notifications based on the distance measured by the proximity sensor works. Here is a detailed explanation of the system's workflow:

a.) Start: From this point, the system is activated.
b.) Turning on ESP32: The first process is to turn on the ESP32 module. ESP32 is a micro controller that is often used for IoT (Internet of Things) applications.
c.) Turning on the proximity sensor: After the ESP32 is activated, the proximity sensor is activated. The proximity sensor is used to detect the distance of objects around it.
d.) Decision - if distance <= 10cm: The proximity sensor measures the distance. The system then checks whether the detected distance is less than or equal to 10 cm.
    1.) If Yes: If the distance is less than or equal to 10 cm:
    2.) Red LED/rayzer lights up: The red LED or rayzer lights up, indicating that an object is very close.

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3.) Alarm/notification lights up in the application: An alarm or notification is sent to the connected application as a warning.
4.) Save Data to ESP32: The detected distance data is saved to ESP32.
5.) If No: If the distance is more than 10 cm:
6.) Green LED/rayer on: The green LED or rayer is on, indicating that there is no object too close.

e.) DB Server: The data collected from ESP32 can be sent to the database server for further storage and analysis.
f.) End: The process ends.
g.) In short, this system activates ESP32 and proximity sensor to measure distance. Based on the measurement results, the system will turn on the red LED and send an alarm/notification if the distance is less than or equal to 10 cm, or turn on the green LED if the distance is more than 10 cm. The data from the measurement is stored in ESP32 and can be sent to the database server.

3.2 Mobile Application

TrashTech is a smart trash bin system that allows real-time monitoring of trash fullness. Each trash bin is equipped with an ultrasonic sensor to detect distance, a weight sensor, and GPS to determine the location of a full trash bin. Through a mobile application, users can check the fullness of each trash bin, so that waste management services can optimize collection schedules and prevent trash overflow.

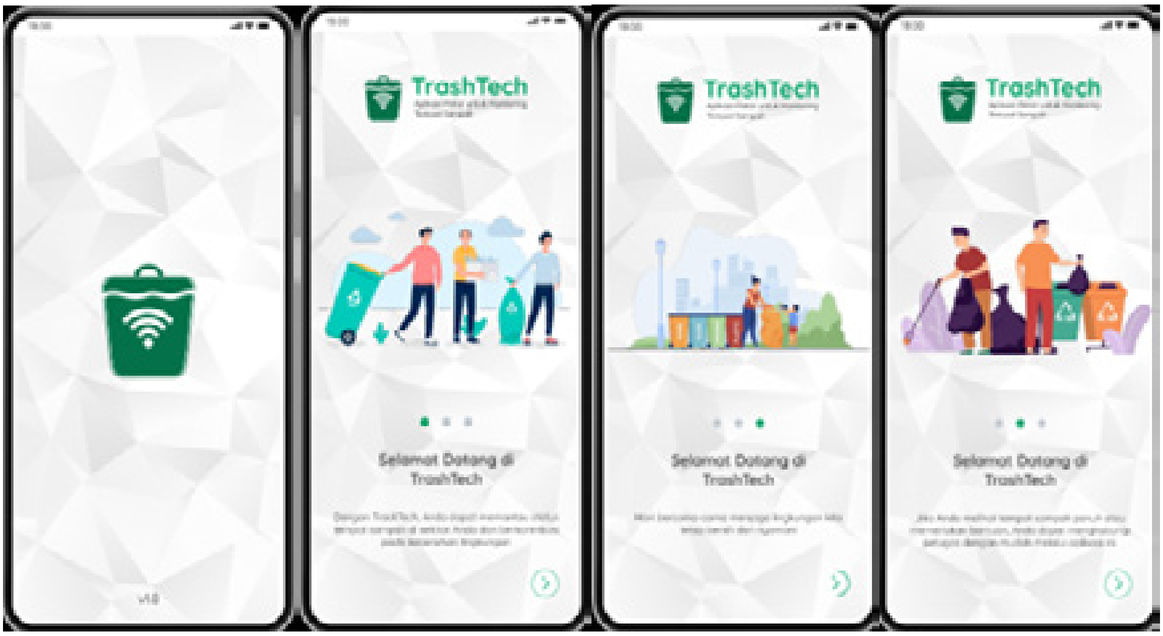

Figure 4. Splash Screen

When the application is opened, it will display the splash screen logo of the TrashTech application.

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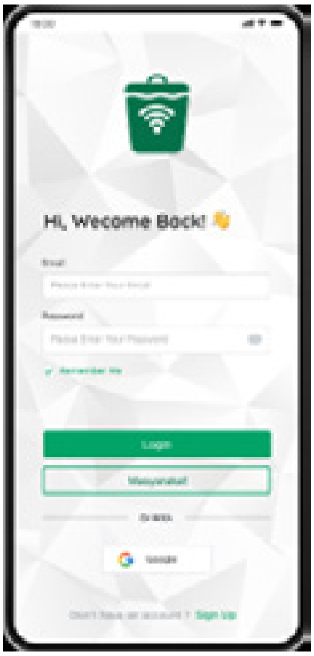

Figure 5. Login

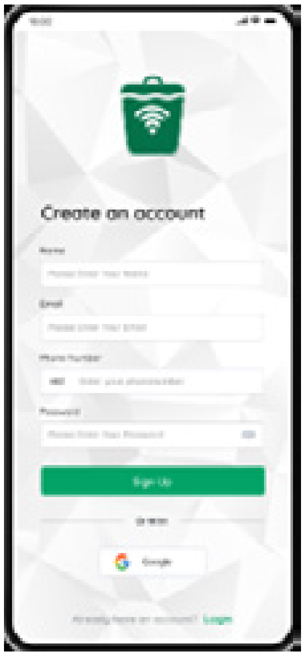

Figure 6. Register

Users who already have an account can directly fill in their email and password on the login page. Login can be done using a Google account or phone number and click the sign in button. If a new user will be directed to the registration page by filling in the name, telephone number, email and password then click the signup button. And return to the login page to enter the next page.

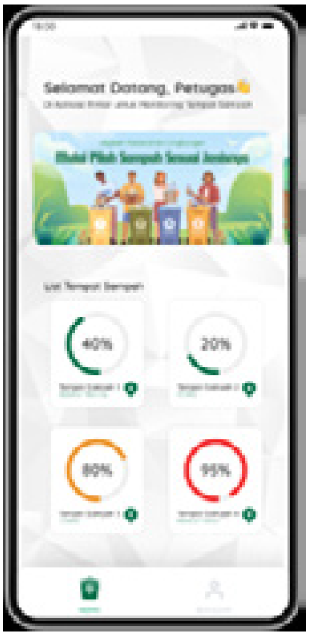

Figure 7. Homepage

On this page there is a list of locations that have been connected to the device that has been stored in the trash to detect if the trash is full. There are 3 conditions, namely, the trash can is full, the trash can is not full, and the trash can is empty.

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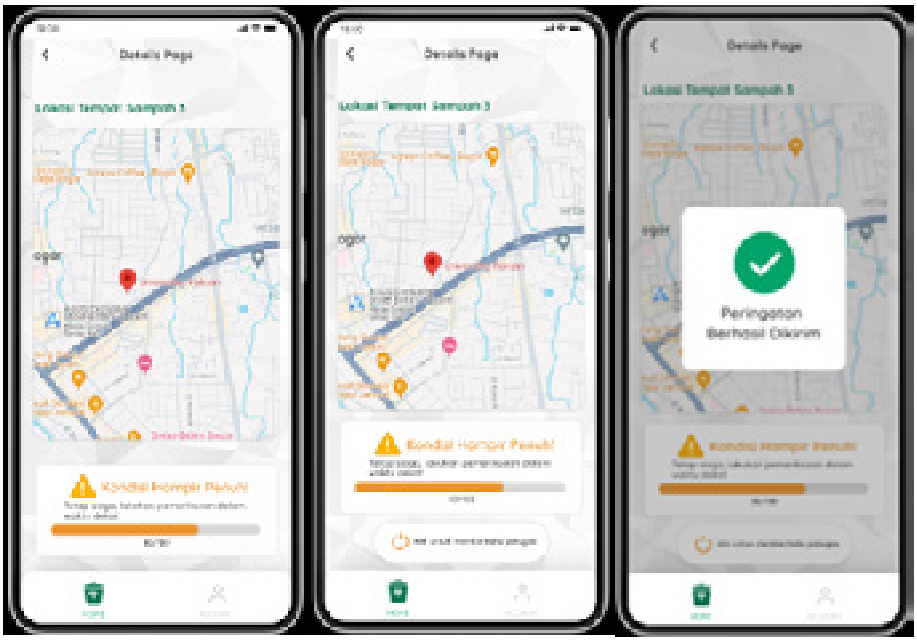

Figure 8. Condition Location Almost Full

On the page there is a map of the location of trash bins with conditions almost full percentage of 80% marked in orange. If in that condition then the public can notify the officer on the power button.

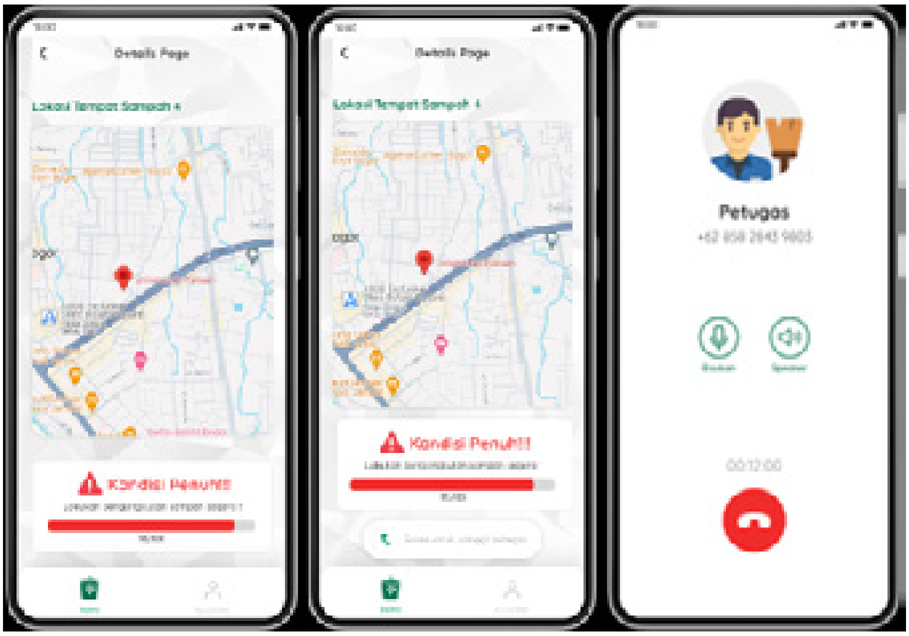

Figure 9. Condition Location Full

On the page there is a map of the location of trash bins with a full condition of 95% which is marked in red. If in that condition, the public can make a call to the officer.

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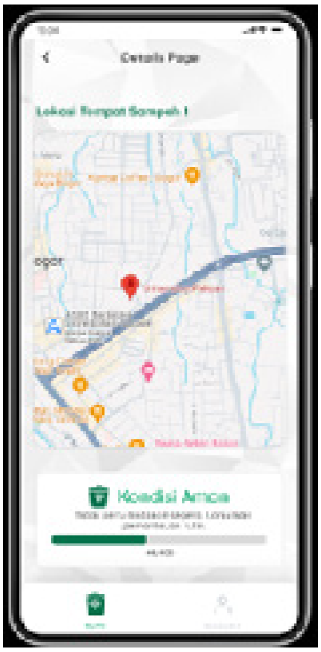

Figure 10. Condition Location Safe

On this page there is a map of the location of trash bins with a safe condition percentage of 40% which is marked in green.

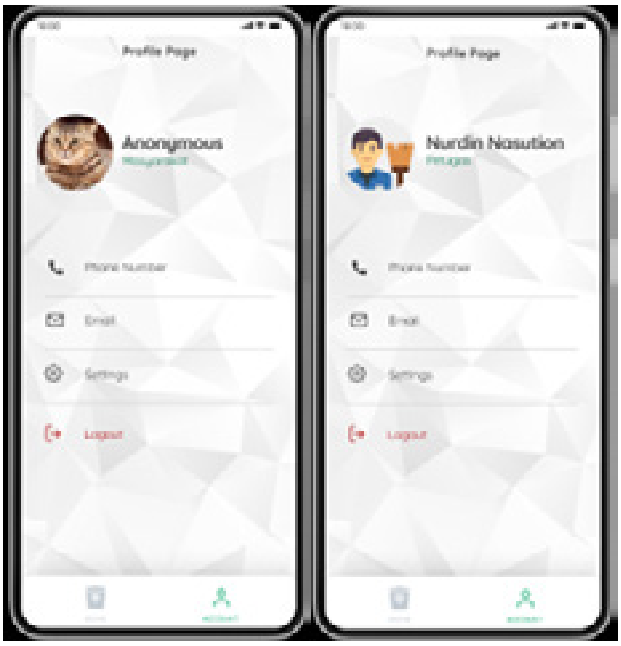

Figure 11. Profile

On the page displays the user profile as filled in on the register page. Users can use personal photos on their profile photos. There are additional menus such as settings and account logout.

CONCLUSION

This research presents the design and implementation of an innovative, IoT-based waste management system for Bogor Regency, leveraging the ESP32 microcontroller and proximity sensors to provide real-time waste level monitoring. The system utilizes distance measurements to determine the waste levels within bins: a red LED and alarm are activated when the measured distance is less than or equal to 10 cm, signaling the need for immediate attention, while a green LED is triggered when the distance exceeds 10 cm, indicating that the waste bin is within the optimal range. Additionally, the system enables data storage on the ESP32 microcontroller, with the potential for remote transmission to a centralized database server for further analysis and reporting. Contributes to the growing body of knowledge in the domain of smart waste management by demonstrating the practical application of IoT and microcontroller-based solutions in addressing urban waste challenges. By providing a cost-effective, scalable solution, the system offers an efficient mechanism for monitoring waste levels, optimizing collection schedules, and minimizing the risk of overflowing waste bins—problems commonly faced in urban areas. The integration of real-time alerts, coupled with data analytics, significantly improves operational efficiency and responsiveness, ultimately contributing to a cleaner, more sustainable urban environment.

The system's potential for scalability and adaptability within the framework of a smart city is a key strength. As part of a larger IoT ecosystem, this waste management solution can be expanded to include additional sensors and features, such as air quality monitors or temperature sensors, to further enhance its capabilities. These advancements could enable the detection of issues such as waste decomposition or hazardous materials, which would enhance the overall safety and efficiency of waste management operations. Moreover, the integration of the system with centralized databases facilitates the long-term tracking of waste data, providing valuable insights into patterns of waste generation and collection. This data-driven approach allows municipal authorities to optimize resource allocation, improve waste collection schedules, and implement targeted interventions in areas where waste accumulation is more frequent or more problematic. The ability to analyze and respond to real-time data contributes to the creation of more efficient, adaptive, and sustainable waste management systems in urban settings. From a broader perspective, this research demonstrates the applicability of IoT-based solutions in the development of smart city infrastructures. The system's use of low-cost, energy-efficient technology such as the ESP32 ensures its feasibility for widespread deployment in resource-constrained environments, making it an accessible solution for cities aiming to integrate IoT technologies into their urban management frameworks. Furthermore, the system's design can serve as a model for future smart city initiatives, where technology can be leveraged to address a variety of urban challenges—from waste management to traffic control, environmental monitoring, and public safety.

In conclusion, this research presents a robust, scalable, and innovative solution to the persistent challenges of urban waste management in Bogor Regency. By incorporating IoT and microcontroller technology, the system provides significant improvements in operational efficiency and contributes to the realization of a smarter, more sustainable urban environment. Moving forward, this system has the potential to be integrated with other smart city technologies, fostering a more connected, data-driven urban ecosystem. The findings underscore the critical role of technology in shaping the future of waste management and urban sustainability, with the potential for broader applications in cities across the globe.

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