Development of an IoT-Based Smart Trash Can Monitoring Mobile Application

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Abstract

Waste management on campus still faces challenges, particularly in the manual monitoring of waste bin conditions. This method risks delays in handling and waste accumulation at certain points. This research focuses on the development of a mobile-based smart waste bin monitoring application connected to the Internet of Things technology to help cleaning staff obtain information on waste bin conditions more quickly. The applied approach is prototyping, namely the gradual development of the application through a design process, initial model creation, and iterative evaluation based on user needs. The system is built by utilizing sensors to read waste bin capacity and transmit data to the application. In addition to monitoring capacity, the system also supports waste bin sorting mechanisms. Based on the results of implementation and testing, the application is able to present capacity information, send notifications, and display a history of cleaning activities, thus supporting more organized and efficient waste management.

Keywords: *Internet of Things, waste monitoring, mobile applications, smart trash cans, prototyping*

Introduction

Waste remains a crucial environmental issue, particularly in public facilities such as campuses. Waste is discarded material resulting from human activity that is no longer usable and therefore requires proper management to avoid negative environmental impacts [1]. Suboptimal waste management can lead to waste accumulation and a decline in environmental cleanliness.

Several studies have shown that information technology-based waste management can improve the efficiency of the waste management process. The use of digital technology can help monitor waste bin conditions more effectively and in a structured manner [2]. Other studies have also shown that implementing an Internet of Things-based system in waste management can improve monitoring efficiency and accelerate decision-making [3]. However, in practice, many educational institutions still use conventional methods to monitor waste bin conditions.

Research conducted at Semarang State University shows that waste accumulation still frequently occurs despite the implementation of a waste management system [4]. This condition is caused by delays in waste collection and the lack of an effective monitoring system. A similar problem was also found in research at Esa Unggul University, which stated that monitoring waste bin capacity still requires considerable time and effort because it is still done manually [5].

A similar situation was also found at the Faculty of Industrial Technology at the Islamic University of Indonesia. The waste bin monitoring system is still carried out manually by janitors. Officers must personally inspect each bin to determine its capacity. This method is inefficient, requiring significant time and potentially leading to delays in handling when the bins are full.

Although several previous studies have developed smart trash bin systems using Internet of Things technology, most of them still focus on capacity monitoring or separate data management [5]. In addition, the systems developed are generally not integrated with mobile applications specifically designed to support the activities of cleaning staff in conducting direct monitoring [2]. This shows that there is still a need to develop a trash bin monitoring system that is integrated with a mobile application so that it can be used more practically and efficiently in the campus environment.

Based on these issues, this research aims to develop a mobile-based smart trash bin application integrated with a trash bin capacity monitoring system. Real-time monitoring of trash bin conditions is expected to assist sanitation workers, enabling more effective and efficient waste

management. The developed system also supports two types of trash bins: one with a capacity monitoring feature and one equipped with a waste sorting mechanism.

Literature Review

A. *Internet of Things in Waste Management*

IoT (Internet of Things) can be defined as a concept that enables physical devices to connect to the internet, enabling automatic data exchange between them [5]. In waste management, IoT can be used to monitor trash bin capacity using sensors connected to a digital monitoring system.

Previous research has shown that implementing an IoT-based trash bin monitoring system can improve waste management efficiency and assist sanitation workers in determining waste collection priorities [6], [7], [8].

B. *Mobile Application*

Mobile applications are software designed to operate on mobile devices such as smartphones and tablets. Their main characteristic lies in the flexibility of access to services and information without being tied to a specific location. In the context of monitoring systems, mobile applications act as a medium that makes it easier for users to receive information quickly and practically, so they are very suitable for use as an interface for technology-based monitoring systems [9].

C. *Software Development*

Software development is a structured series of processes that include needs identification, implementation, system design, testing, and maintenance with the aim of producing software that has an adequate level of quality and can optimally meet user needs [10]. This process does not only focus on writing program code but also involves analytical and systematic aspects in each stage. In practice, software development is carried out sequentially and in an organized manner through the Software Development Life Cycle (SDLC) approach, which aims to improve the quality, efficiency, and success of system development [10]. Therefore, software development is an important foundation in developing mobile applications that are integrated with technology-based monitoring systems.

D. *Prototyping Method*

The prototyping method is an approach in software development that places the initial system model as a means of communication between developers and users to provide an overview of the functions, workflows, and appearance of the system to be created. Through a prototype, developers and users can have a common understanding of the system so that user needs can be better identified. The development process begins with the collection of initial general requirements, then continues with the creation of a prototype as an initial representation of the system, which is then evaluated by users to determine the suitability of functions and appearance. The results of this evaluation are used as a basis for refinement and improvement of the system iteratively to meet user needs. This method prioritizes user involvement throughout the development process so that changes can be made from the early stages without having to repeat the entire process and is able to increase the suitability of the system to user needs and minimize implementation errors [11].

Methodology

This research applies a prototyping model to software development. The research was conducted at the Faculty of Industrial Technology, Islamic University of Indonesia, with the research subjects being janitors tasked with managing and monitoring the condition of waste bins. Field observations and direct interviews were conducted to explore system requirements and user issues. Descriptive data analysis techniques were used to formulate system requirements as the

basis for application development.

The prototyping method is an approach to software development that involves creating an initial system model, which is then repeatedly evaluated and refined until it aligns with user needs. This model was chosen because it allows users to be directly involved in the system development process. The stages of the prototyping method include communication, quick planning, modeling, quick design, prototype construction, and deployment, delivery, and feedback [12].

A. Communication

The communication phase was conducted through observation and interviews to obtain a more detailed picture of the system's requirements. Direct observations were made of the cleaning staff's activities, while interviews were used to explore system requirements. The data obtained was analyzed as the basis for developing system solutions. This phase aligns with the prototyping concept, which emphasizes user involvement from the beginning of system development [4].

B. Quick Plan

The quick plan stage involves analyzing observation and interview results to formulate system requirements. These requirements are divided into functional and non-functional requirements, which serve as a guideline for the application development process. Functional requirements relate to the features that must be available in the application, while non-functional requirements encompass aspects of system performance, security, and usability.

C. Modeling Quick Design

The quick design modeling stage is carried out by designing the system using a user interface framework (wireframe), UML (Unified Modeling Language), and ERD (Entity Relationship Diagram). The purpose of this design is to provide an initial overview of the system flow and user interactions. UML is used to model system processes, while ERD is used in data structure design. Wireframes are used to depict the application interface in a simple manner. This design aims to provide an overview of the system flow before the implementation phase.

D. Construction of Prototype

The prototype construction stage is the process of building a system based on the design results. The application was developed using Flutter as a mobile development framework and Firebase as a backend service. The system was also integrated with IoT devices to detect and transmit real-time trash bin capacity data. This stage allows for gradual improvements to be made according to user needs [4].

E. Deployment Delivery and Feedback

The final stage in the prototyping method is deployment, delivery, and feedback, which is carried out by implementing applications to users to be tested directly in real conditions. The black box testing method ensures that all system functions run according to the designed needs. In addition, the ease-of-use aspect is assessed using the System Usability Scale (SUS) through a questionnaire containing ten statements with a Likert scale. The SUS calculation is carried out by converting the score of each item, namely for odd statements minus 1 and even statements minus 5. Then all scores are added up and multiplied by a factor of 2.5 to obtain a final value in the range of 0 to 100 [12]. The final SUS value obtained is then classified into usability categories to determine the level of system acceptance [2]. Interpretation of the SUS test results in this study refers to the following assessment categories [13].

Table 1. SUS Assessment Categories

Score Range	*Grade*	Category
> 81	A	*Excellent*

68 – 81	B	*Good*
68	C	*OK/Fair*
51 – 67	D	*Poor*
< 51	F	*Worst*

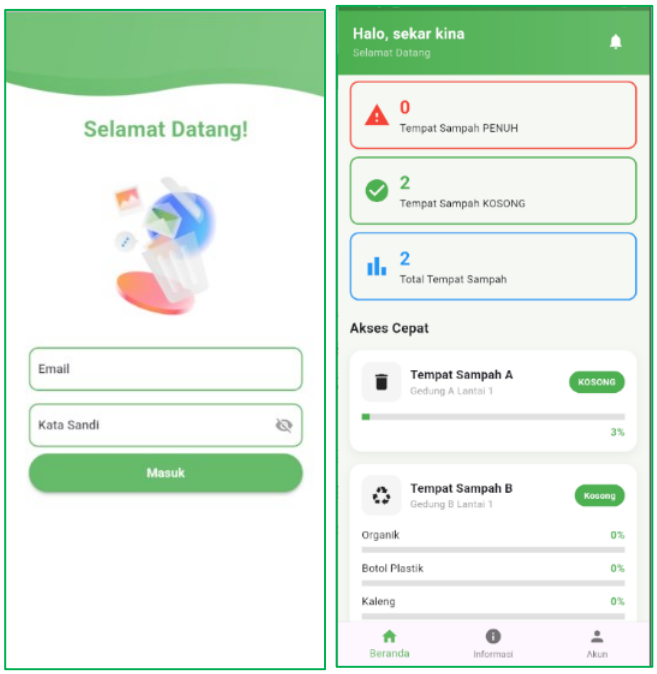
Results

A. System Implementation Results

This research presents the system implementation and testing results of the developed mobile-based smart trash bin application. The system consists of several key features: login, a trash bin capacity monitoring dashboard, notifications, activity history, and account settings. The application displays real-time trash bin capacity information based on data sent by IoT devices and provides automatic notifications when the trash bin capacity reaches a certain limit.

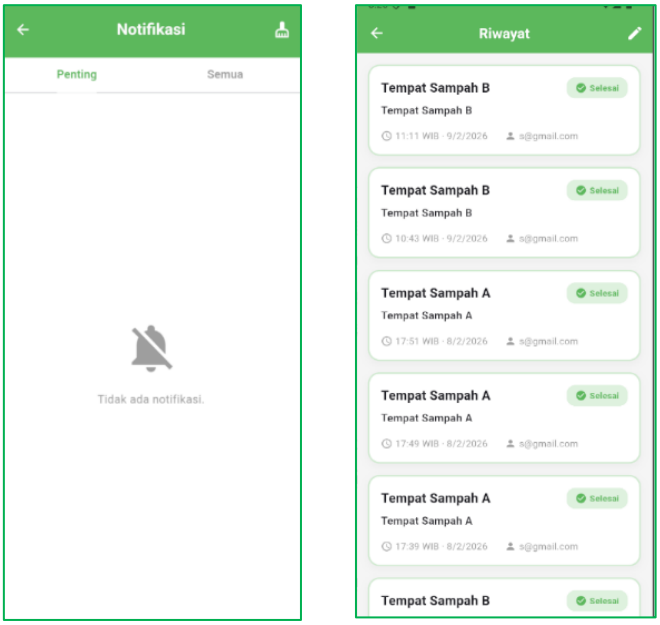
The developed system supports two types of trash bins: one that only monitors capacity and one equipped with a waste sorting feature. In the former, the system monitors capacity levels in real time. In the latter, the system not only monitors capacity but also supports waste sorting by type, enabling more effective waste management.

Figure 1. IoT-Based Smart Trash Can Implementation



a. Login b. Dashboard

Figure 2. Login and Dashboard on the Application



a. Notifications b. History

Figure 3. Notifications and History in the Application

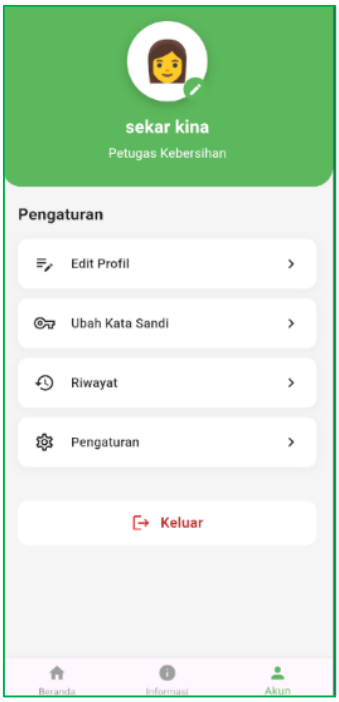


Figure 4. Account Settings in the Application

B. Testing Results

Usability testing was conducted using the SUS method, involving respondents as application users. Respondents were asked to complete a questionnaire based on their experience using the application.

Table 2. SUS Test Results

Respondents	Score										Number of responders	Number of responders *2,5
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10		
R1	5	1	5	1	4	1	5	1	5	1	39	97.5
R2	5	3	5	3	5	1	5	3	5	1	34	85
R3	5	5	5	5	5	2	5	1	5	3	29	72.5
R4	5	1	5	1	5	1	5	1	5	1	40	100
R5	5	5	4	5	4	4	5	4	5	5	20	50
R6	5	1	5	4	4	3	5	1	5	4	31	77.5
R7	1	5	5	3	5	3	5	1	5	5	24	60
R8	4	2	4	2	4	2	4	2	4	2	30	75
R9	5	1	5	3	5	1	5	1	5	1	38	95
R10	3	3	3	2	2	3	2	2	3	2	21	52.5
Rata-rata												76.5

The average SUS score obtained was 76.5. Based on the System Usability Scale assessment category, this value indicates that the system is in the Good (B) category.

Discussion

The research results show that a mobile-based smart trash bin application can assist in monitoring trash bin conditions more effectively than previously used manual methods. Through this application, information regarding trash bin capacity can be accessed in real time by cleaning staff without the need for on-site inspections [5]. This demonstrates that digitizing the monitoring process can improve work efficiency and reduce the time required to check trash bin conditions.

The implementation of an IoT-based monitoring system allows trash bin capacity data to be automatically sent to a mobile application, resulting in faster and more accurate information received by users. This aligns with previous research, which suggests that the use of IoT technology can improve efficiency in waste management because the monitoring process can be conducted digitally and integrated [5]. The developed system not only focuses on capacity monitoring but also supports waste sorting, thus providing new value compared to previous research. Compared with previous research, the system developed in this study not only focuses on IoT devices but also integrates a mobile application as a monitoring medium, making it easier for users to directly access information.

The notification feature is a crucial component of the application because it helps janitors prioritize waste management. When the trash bin capacity reaches a certain limit, the system automatically notifies users, expediting the waste collection process. Therefore, the system developed in this research can be a solution to improve the effectiveness of technology-based waste management [6].

The test results, with a SUS score in the Good category, indicate that the application not only functions functionally but is also quite easy to use for janitors as field users. This ease of use is crucial because the system is designed for field users who require a simple and easy-to-understand application. These findings reinforce the belief that integrating IoT technology and a mobile application designed with usability in mind can enhance the success of system implementation in a campus environment.

Conclusion

This research resulted in a mobile-based smart trash bin application that can help sanitation workers monitor trash bin conditions more effectively. The application displays real-time capacity information, provides notifications, and provides a history of cleaning activities, supporting a more organized and efficient waste management process. The developed system has been operating according to user needs and has a high level of ease of use.

Further development can be carried out by adding data analysis features, expanding IoT device integration, and implementing the system in a broader environment to optimize its benefits.

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