Internet Of Things (IoT) Based Smart Trash Bin

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ABSTRACT
This study is motivated by the problem of waste scattered around trash bin areas. This issue can be addressed through research on a smart trash bin system. The method used in this study is experimental and design-based, where testing is conducted on sensor distance, waste moisture levels, and data response to the web server. The smart trash bin utilizes ESP32 and Internet of Things (IoT) technology through a web-based system.The system is supported by several components, including an HC-SR04 ultrasonic sensor for object detection and a soil moisture sensor for detecting moisture levels of the waste, which is then used to classify the waste and control the sorting machine. As for the output component, a servo motor is used as the actuator to separate the waste. In addition, a web server is implemented to monitor waste data remotely. This system is expected to help increase public awareness in disposing of waste properly.The results of this study show that the waste sorting mechanism operates based on software settings, where waste with moisture levels below 20% is directed to the left, while waste with moisture levels above 20% is directed to the right. Furthermore, the data transmission results to the web server indicate that all waste levels are successfully detected in accordance with actual field conditions.

Keywords : Internet of Things (IoT), ESP32, Moisture Sensor, Servo Motor, Web Server

INTRODUCTION

The problem of waste scattered around trash bin areas remains a common issue that reflects the low level of public awareness in disposing of waste properly. Conventional trash bins generally do not provide an effective solution for waste sorting, resulting in the mixing of wet and dry waste, which contributes to environmental pollution and inefficiencies in waste management processes. Along with the rapid advancement of technology, particularly in the field of the Internet of Things (IoT), automation systems have been widely implemented to support environmental management through real-time monitoring and intelligent control.

Several studies have demonstrated that the implementation of IoT-based systems can enhance efficiency and accuracy in environmental monitoring and waste management. Microcontroller-based systems, such as those utilizing ESP32, enable data acquisition from sensors, data processing, and remote data transmission through web-based platforms. However, many waste management systems still rely on manual sorting methods, which are time-consuming, inconsistent, and highly dependent on human behavior.

This study proposes the development of a smart trash bin that not only monitors waste but also detects objects, identifies moisture levels, performs automatic sorting, and transmits monitoring data to a web server. as a solution to the problem of scattered waste and

inefficient sorting processes. The system employs an HC-SR04 ultrasonic sensor to detect the presence of objects, a soil moisture sensor to measure the moisture level of waste, and a servo motor as an actuator to automatically separate the waste. The data collected from the sensors are transmitted to a web server, enabling real-time remote monitoring of waste conditions.
The research method applied in this study is experimental and design-based, including system testing on sensor distance accuracy, waste moisture detection, and data transmission responsiveness to the web server. The waste sorting mechanism is implemented based on a predefined moisture threshold, where waste with a moisture level below 20% is directed to one side, while waste with a moisture level above 20% is directed to the opposite side. The testing results indicate that the system is capable of accurately detecting waste conditions and successfully transmitting data to the web server in accordance with actual field conditions.
The implementation of this smart trash bin system is expected to contribute to increasing public awareness of proper waste disposal and to support the development of intelligent technology-based environmental management solutions. The structure of this paper is organized as follows: Section II discusses related works, Section III describes the system design and research methodology, Section IV presents the experimental results and discussion, and Section V provides the conclusions and recommendations for future research.

METHODS

The method used in this study is an experimental method combined with a design approach. The selection of these methods is based on the need to design a system and subsequently conduct several experimental tests to obtain the desired results. In addition, the web server was developed using the ThingSpeak application. ThingSpeak is a ready-to-use web server platform that provides channels for managing incoming and outgoing data, as well as for publishing data. Users only need to access the channel ID to retrieve the required information.

Data Source

The data sources in this study were used as reference/literature source discussing smart trash bins utilizing microcontrollers and Internet of Things (IoT) technology. Additionally, references regarding automated waste management systems were reviewed from related scholarly publications

Data Collection Method

In this study, the author employed observation and literature review methods, as described below:

1. **Observation**
   Observation was conducted openly by directly examining the condition of trash bins in several areas of Medan City and analyzing how scattered waste was handled in those locations.
2. **Literature Review**
   Data collection was carried out by gathering bibliographic sources, journal references, and research methods relevant to this study.

Research Instrument

The facilities used in completing this research include the following:

1. **Hardware**

   The hardware used in this project development includes:

   a) Acer laptop with Windows 10 operating system, with specifications:
      1. Intel® Core™ i3-5005U CPU
      2. 2 GB RAM
      3. 64-bit operating system

   b) Mi 8 Lite smartphone, with specifications:
      1. MIUI 10 Global version 9.6.27 Beta
      2. 4 GB RAM / 64 GB internal storage

2. **Software**

   The software used in this project includes:
      1. Google Chrome
      2. Windows 10 Ultimate 64-bit operating system
      3. Web server (ThingSpeak platform)
      4. Android drivers

System Design

To clarify the development of the proposed smart trash bin system using ESP32 and Internet of Things (IoT) technology, with an output in the form of waste management monitoring system, the author presents a block diagram illustrating the general working principle of the system, as shown in the figure

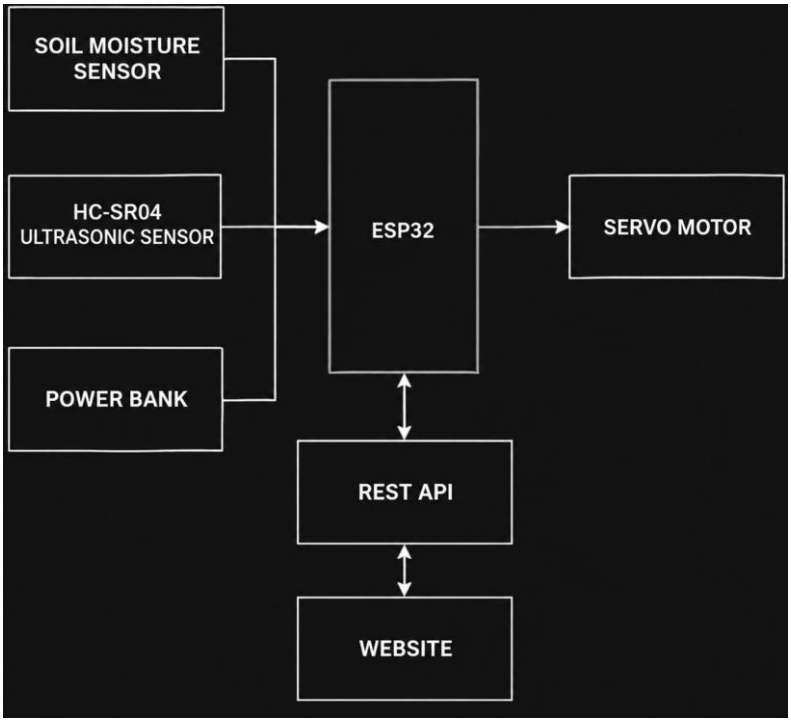


Figure 1. Smart Trash Bin System Block Diagram

From this system design, each block can be generally explained according to its function as follows:

1. **ESP32**: Functions as the microcontroller and data processing unit of the system, responsible for managing and controlling all connected components, in accordance with [10].
2. **Message Broker (MQTT)**: The message broker serves as a data transmission manager. It regulates the sending of data by temporarily storing unsent data caused by unstable network conditions. Once the network becomes stable, the message broker retransmits the stored data completely and reliably.
3. **RESTful API**: RESTful API is a technology that acts as a communication bridge between machines. The web service interface design openly utilizes HTTP (Hypertext Transfer Protocol) to enable communication between devices.
4. **Web Server**: The web server is software that functions to receive requests for web pages through HTTP or HTTPS protocols via a browser. It also processes and responds to these requests by returning the requested data or information.
5. **HC-SR04 Sensor**: In accordance with previous studies, the block diagram shows HC-SR04 sensors because the sensor itself has function, namely detecting objects using ultrasonic waves (distance measurement). Sensor detects objects located in front of the trash bin.
6. **Power Bank**: Functions as the electrical power supply for the system.
7. **Servo Motor**: Acts as the actuator for the trash bin lid. When an object is detected by the distance sensor, the servo motor automatically opens the trash bin lid.
8. **Moisture Sensor**: A device used to detect the moisture level of the waste. The detected data are processed by the microcontroller to determine the waste category, which is then used to control the servo motor for sorting purposes.

RESULTS

Research Workflow Stages

The research workflow consists of several conceptual frameworks that reflect the research methodology and illustrate the sequence of processes, as shown in the figure.

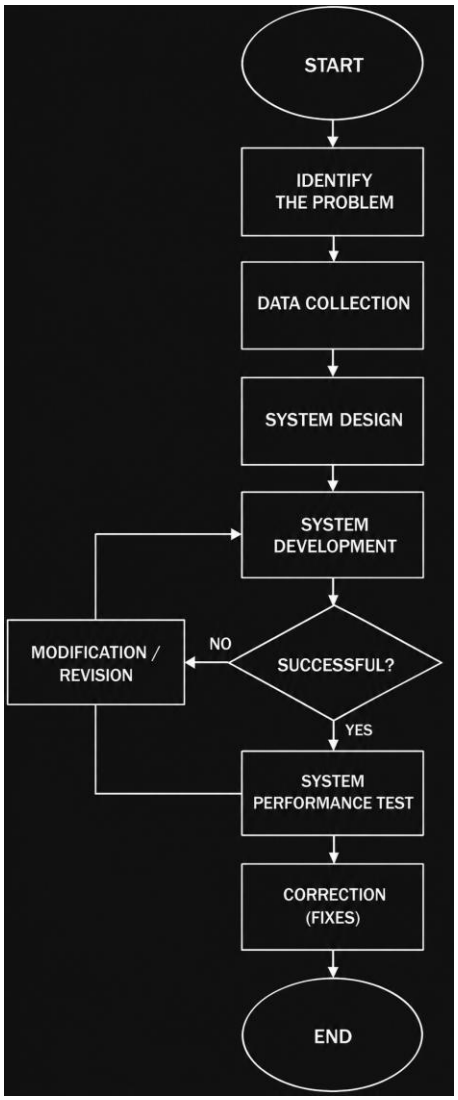


Figure 2. Research Process Flow Diagram

The explanation of the research stages can be briefly described as follows:

1. Problem identification involves analyzing the issues obtained from the conducted research.
2. Data collection is carried out through observation and an in-depth literature review to ensure that the identified problems can be addressed through a proposed system solution.
3. The design and planning stage involves designing the proposed system, including both its functional and structural aspects.
4. System development refers to the construction and implementation of the smart trash bin system.
5. Performance testing is conducted to evaluate the functionality and effectiveness of the developed system. The system is considered successful when the HC-SR04 ultrasonic sensor detects objects within the predefined range of 0–60 cm and remains inactive for distances beyond 60 cm. The moisture sensor must provide measurements that can be used to classify waste according to the predefined moisture threshold, while the

servo motor must direct the waste to the corresponding sorting side. In addition, the data displayed on the web server must be consistent with the sensor measurements..

6. Evaluation is performed to identify any system errors or failures that require improvement.
7. Modification involves revising and refining the system to achieve the desired performance.
8. The final stage is the successful completion of the smart trash bin system using the ESP32 microcontroller integrated with an information technology system.

Overall System Circuit Design



Figure 3. The Overall Physical Form Of The Smart Trash Bin.

In this Figure, the relationship among all system components can be explained. The operation of this circuit is interconnected. The term “interconnected” means that when the HC-SR04 sensor detects an object within its range, it sends a command to the ESP32 to initiate the sorting procedure. The moisture sensor then determines whether the waste falls into the predefined category. This classification affects the operation of the servo motor, which functions to direct the waste by rotating the mechanism toward the designated side.

The overall hardware design of the smart trash bin system integrates information technology within its operational framework.

As shown in the figure, the physical structure of the smart trash bin consists of several hardware components, including:

1. One trash bin
2. One equipment box
3. One ESP32 microcontroller
4. One ultrasonic sensor
5. One moisture sensor
6. One servo motor
7. One PCB board

All hardware components are interconnected using jumper wires, which are soldered onto the PCB board to ensure stable electrical connections.

Overall System Testing Results

The overall testing process begins with the activation of the ESP32. The function of this device is to control all components connected to the GPIO pins of the ESP32. The testing results start with the ultrasonic sensor as the object detection device, which is capable of detecting approaching movement. When an object is detected, the ultrasonic sensor triggers the system, after which the moisture sensor determines the waste category. Subsequently, the servo motor is commanded to direct the waste to the predetermined side, as shown in the figure.The servo motor used in this system is a metal gear MG996R with a load capacity of 1 kilogram for laboratory-scale implementation. If applied in public areas, a servo motor with a higher load capacity should be used to accommodate heavier operational loads.



Figure 4. Test Results.

The web server serves as the output of the smart trash bin system. In other words, the web server displays the data results obtained from the waste level sensor measurements. The data on the web server are presented in the form of a line graph, which is updated every 10 minutes, as shown in the figure.

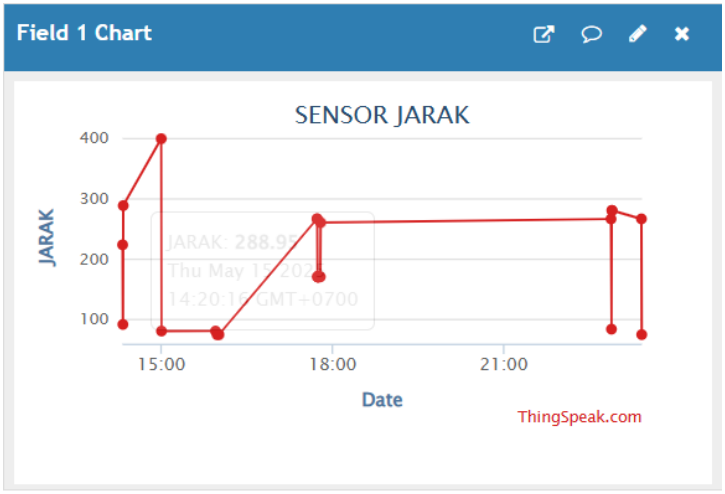


Figure 5. Web Server Data Display Output

As shown in the table, the ultrasonic sensor was tested to determine whether the predetermined distance corresponds to the calculated output distance measured by the sensor.

It can be observed that the distance determined by the researcher is 60 cm. If the object detected by the sensor is beyond 60 cm, the sensor will not send any command to the ESP32.

Table 1. Object Detection Sensor Testing in Front of the Trash Bin

No	Object Detection Sensor Testing in Front of the Trash Bin		Description
	Determined Distance	Sensor Calculation Results	
1.	60 cm	45 cm	ACTIVE
2.		60 cm	ACTIVE
3.		70 cm	INACTIVE

Data Transmission Testing to the Web Server

The testing of the web server, as shown in the table, was conducted to determine whether the sensor's output distance corresponds accurately to the value displayed on the web server.

Table 2. Waste Level Detection Sensor Testing

No	Waste Level Detection Sensor Testing		Description
	Sensor Calculation Results	Web Server Display Results	
1.	9 cm	9 cm	Appropriate
2.	14 cm	14 cm	Appropriate
3.	49 cm	49 cm	Appropriate

The explanation of this testing is that the input data displayed on the web server are derived from the sensor measurements of the waste level. In other words, the output data generated from the sensor calculations must correspond exactly to the data presented on the web server.

DISCUSSION

Based on the research results, the discussion indicates that the object detection sensor was tested with a predetermined distance of 60 cm in front of the trash bin. This was verified through sensor testing to initiate the system operation, where the sensor detects objects within a range of 0 to 60 cm. When the distance exceeds 60 cm, the sensor does not provide any instruction to activate the trash bin system.The testing of the waste moisture detection sensor categorized the results into two levels: moist and non-moist. The moist level is defined when the waste moisture exceeds 20%, while the non-moist level is identified when the moisture is below 20%. Furthermore, the web server display results were consistent with the sensor measurement calculations.

CONCLUSION

The conclusion of this article is that the smart trash bin system utilizes ESP32 and Internet of Things (IoT) technology integrated with an information system that transmits data to a web server and processes it through the ThingSpeak application, which can be set as private or public. This system enables the identification of issues related to scattered waste. The integration of the system with information technology allows the trash bin to be monitored remotely. Furthermore, the implementation of an automatic servo motor as a waste sorting actuator facilitates the community in categorizing waste more efficiently.

LIMITATION

This study has several limitations that should be acknowledged when interpreting the obtained results. The primary limitation lies in the scale of system testing, which was conducted in a limited and laboratory-controlled environment. Therefore, the operational conditions do not fully represent real-world usage in public environments with more diverse variations in waste types, sizes, and moisture levels. In addition, the determination of the waste moisture threshold was based on a single predefined value, meaning that the accuracy of the sorting process may be influenced by sensor characteristics and surrounding environmental conditions, such as temperature and non-uniform waste moisture levels.

Another limitation concerns internet network connectivity, as the stability of data transmission to the web server heavily depends on the quality of the available network. These limitations may affect the consistency of system performance and the accuracy of the data displayed on the web server. Nevertheless, this study provides an initial and relevant insight into the implementation of Internet of Things (IoT) technology in a smart trash bin system and can serve as a foundation for further development and future research improvements.

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