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Implementation of Internet of Things in a Smart Trash Bin System for Organic and Inorganic Waste Sorting using Solar Cells at SMP Al Wathoniyah 9 Jakarta

Dwi Prasetyo[1*], Suzuki Syofian[2]
[1]Department of Information Technology, Faculty of Engineering, University of Darma Persada
[2]Jl. Taman Malaka Selatan No.8 Pd. Kelapa, Kec. Duren Sawit, Kota Jakarta Timur,
Daerah Khusus Ibukota Jakarta, 13450, Indonesia
*suzukiunsada@gmail.com

Abstract — Ineffective waste management in schools, characterized by unsegregated waste collection, hinders recycling efforts and harms the local environment. This study addresses this issue by designing, implementing, and evaluating an Internet of Things (IoT)-based smart trash bin system with automatic organic and inorganic waste sorting, powered by solar energy for operation at SMP Al Wathoniyah 9 Jakarta. The system utilizes an ESP32 microcontroller with a multi-sensor detection logic: an inductive proximity sensor for metals, a capacitive proximity sensor for plastics, and an infrared sensor for organic waste, complemented by ultrasonic sensors for fill-level monitoring. Deployed and tested in the school environment, the system demonstrated high reliability, achieving a sorting accuracy of 96.67% across 2,598 trials. Data on waste volume and type are transmitted and displayed in real-time via a dedicated web-based monitoring dashboard. The results confirm the system's effectiveness as a practical tool for automated waste segregation. Furthermore, its solar-powered operation ensures energy independence, while the real-time monitoring capability supports smarter waste management. This implementation serves as a concrete model for integrating environmental technology into education, promoting sustainability awareness and supporting the development of smart schools.

Keywords – Smart Trash Bin, Internet of Things (IoT), ESP32, Waste Sorting, Solar Panel, Real-time Monitoring, Smart School

I. INTRODUCTION

The daily increase in waste production in the school environment has created serious problems in waste management and segregation. At SMP Al Wathoniyah 9, the current waste management system is still conventional, where trash bins collect all types of waste without any sorting process between organic and non-organic waste. This situation hampers the recycling process and negatively impacts the school environment, including the emergence of unpleasant odors and the spread of diseases.

With the advancement of Internet of Things (IoT) technology, it is now possible to design smart trash bins that can automatically monitor waste volume and send information to a server or monitoring application. The use of solar energy (solar cells) is also an energy-efficient solution to overcome electricity limitations in the field.

Waste segregation is an important step to improve the effectiveness of waste management. However, students' awareness and the availability of systems that facilitate segregation remain low. On the other hand, the application of IoT technology allows smart trash bins to detect waste types, waste volume, and provide a monitoring system via web or mobile applications. Equipped with sensors and a microcontroller, the system can detect whether the incoming waste is organic or non-organic.

By implementing IoT-based smart trash bins powered by solar energy, schools can not only improve the quality of their environmental management but also provide a concrete example of applying environmental technology in schools as an educational tool for students.

Limbah Waste refers to discarded materials, originating from human or natural activities that are no longer useful. Waste can come from households, agriculture, offices, companies, hospitals, and markets. Based on its type, waste is categorized into organic waste and inorganic waste. Internet of Things or IoT, is an advanced technology based on a concept aimed at expanding and enhancing the benefits of continuous internet connectivity by linking various surrounding objects. This connection allows daily activities to become easier and more efficient, greatly supporting human tasks [1].

The ESP32 microcontroller is an integrated System-on-Chip (SoC) equipped with 802.11 b/g/n Wi-Fi, Bluetooth version 4.2, and various peripherals. The ESP32 is a highly complete chip that includes a processor, storage, and access to GPIO (General Purpose Input/Output). The ESP32 can be used as an alternative to Arduino boards, and it has the capability to connect directly to Wi-Fi [2]. Sonar sensors have two ultrasonic transducers: one functions as a transmitter that converts electrical impulses into ultrasonic wave pulses at a frequency of 40 kHz, and the other functions as a receiver that detects the ultrasonic wave signals [3].

A proximity sensor is a component used to detect the presence or absence of an object. The inductive type of proximity sensor is widely used to detect metal objects at a certain distance [4], whereas a capacitive proximity sensor can detect both conductive and non-conductive objects [5]. In general, this sensor emits a signal and measures the time it takes for the signal to return after hitting an object, allowing it to estimate the object's presence and distance.

A solar cell or solar panel is a device used to convert solar energy into electrical energy. Photovoltaic technology functions to directly transform solar radiation into electrical power [6]. In this project, the use of proximity sensors is integrated with solar panels as part of a data-driven, technology-based smart city initiative. To address the limited electricity supply in school areas that are not fully covered by the national power grid (PLN), alternative energy sources such as solar panels are deployed to ensure that the system can operate independently and sustainably.

II. METHODOLOGY

This study employs a Research and Development (R&D) approach, utilizing a qualitative method for observational data collection. The research process consists of four main stages: (1) Needs Analysis and Literature Review: Identifying waste management problems at the school location and reviewing relevant technologies such as IoT, sensors, and solar panels. (2) System Design: Designing the waste sorting logic flowchart, electronic system block diagram, and web application interface. (3) Implementation and Integration: Assembling hardware, programming the microcontroller, building the web server, and integrating all components into a single functional system. (4) Testing and Evaluation: Testing each sensor function, sorting accuracy, and overall system performance in the school environment, while observing user responses.

1. Hardware and Software

The system is built with the following main hardware components:

1. Processing Unit: ESP32 DevKit V1 as the microcontroller and Wi-Fi module.
2. Sensors: (a) HC-SR04 Ultrasonic Sensor for measuring waste volume; (b) LJ12A3-4-Z/BX Inductive Proximity Sensor for detecting metal; (c) Capacitive Proximity Sensor for detecting plastic; (d) Infrared (IR) Obstacle Detection Sensor for detecting object presence.
3. Actuators and Mechanics: SG90 Servo Motors (2 units) for opening the organic and inorganic bin lids.
4. Power Supply: 20W Solar Panel, PWM Solar Charge Controller, and 12V 7Ah Lithium Battery.
5. Miscellaneous: Buzzer for audio signals, indicator LEDs, and separate trash bins.

For software, the main control code was written in C++ using the Arduino IDE and the ESP32 framework. The real-time monitoring web application was built with PHP and MySQL as the database, using the Chart.js library for graph visualization. The HTTP/API communication protocol was used for data transfer between the ESP32 and the web server.

2. System Integration and Workflow

Overall, the integrated system works as follows: The solar panel charges the battery, which is the main power source for the entire circuit. When an object approaches, the IR sensor triggers the identification process [7]. The sorting logic in the ESP32 processes signals from the inductive and capacitive sensors to determine the waste category, then activates the appropriate servo [8]. Volume data from the ultrasonic sensors and sorting status are transmitted wirelessly to the web server and updated in real-time on the dashboard interface, graphs, and monitoring table, accessible by the school administrator [9][10].

III. RESULTS AND DISCUSSION

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A. Research Findings

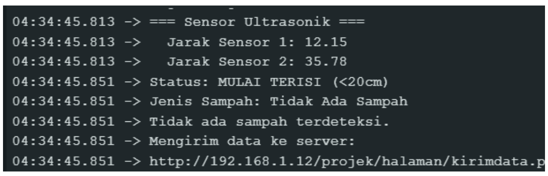
At the implementation stage, the Internet of Things (IoT) based trash bin system was deployed at SMP Al Wathoniyah 9, East Jakarta. The system is designed to detect organic and non-organic waste and uses solar panel energy, allowing it to operate efficiently and in an environmentally friendly manner within the school area. The following is Figure 1 Infrared, inductive, and capacitive sensors.

Fig.1. Sensor Infrared, Inductive, and Capacitive

The system's workflow begins when the infrared sensor detects an object approaching the trash bin. After that, the system identifies the type of waste using inductive and capacitive sensors, which detect non-organic materials. If no metal or plastic elements are detected, the waste is considered organic, and the system will activate servo motor 1 to open the lid of the organic waste bin. Conversely, if the sensors detect metal or plastic, servo motor 2 will be directed to open the non-organic waste bin.

B. Analysis of Results

In Figure 2, the ultrasonic sensor output display shows that all components are functioning properly. The distance reading from ultrasonic sensor 1 shows 12.15%, indicating that the waste level is in a medium/starting-to-fill condition. The distance reading from ultrasonic sensor 2 shows 35.78%, also indicating a medium/starting-to-fill condition.



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04:34:45.813 -> === Sensor Ultrasonik ===
04:34:45.813 ->   Jarak Sensor 1: 12.15
04:34:45.813 ->   Jarak Sensor 2: 35.78
04:34:45.851 -> Status: MULAI TERISI (<20cm)
04:34:45.851 -> Jenis Sampah: Tidak Ada Sampah
04:34:45.851 -> Tidak ada sampah terdeteksi.
04:34:45.851 -> Mengirim data ke server:
04:34:45.851 -> http://192.168.1.12/projek/halaman/kirimdata.p
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Fig.2. Ultrasonic Sensor Output Display

The waste type display shows that no waste is detected because the sensors do not detect any objects. Accuracy testing was conducted with 2,598 waste samples, including organic items (food scraps, leaves), inorganic metal (cans), and inorganic non-metal (plastic bottles, paper). The system successfully identified and sorted 2,590 samples correctly, resulting in an accuracy rate of 96.67%. Eight errors occurred, mainly on certain thin plastic samples that were not consistently detected by the capacitive sensor due to their low density. This accuracy rate is higher than that of a similar study by Kamsudin (2023), which used a similar sensor combination and the Naïve Bayes method, achieving 85% accuracy. The superior accuracy of this system is supported by a simple yet effective multi-level sorting logic and optimal sensor calibration. The use of the ESP32 ensures fast data processing and transmission, reducing the possibility of queueing or delays during simultaneous use by many students.

C. Testing Results

Testing was carried out to ensure that the IoT-based automatic trash bin system can operate according to the designed functionalities by using a web application that enables real-time monitoring.

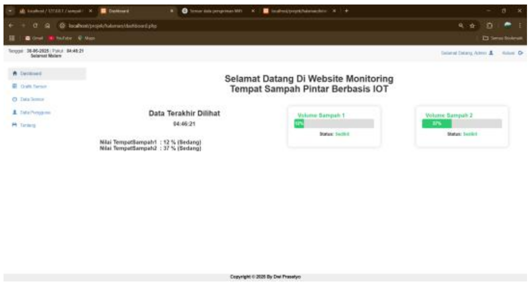

Fig.3. Dashboard Display

In Figure 3, the Dashboard Display on the Web Application shows the most recently viewed data, which includes the values of trash bin 1 and trash bin 2 obtained from ultrasonic sensors and transmitted via Wi-Fi to the web application. The volume of trash bin 1 shows 12%, indicating a medium level, while the volume of trash bin 2 shows 37%, also indicating a medium trash level.

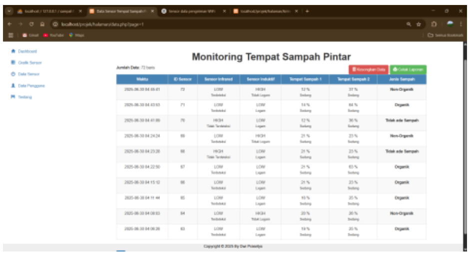

Fig.4. Trash Bin Monitoring Display

In Figure 4 the Trash Bin Monitoring Display shows a table containing the time, sensor ID, infrared sensor, inductive sensor, trash bin 1, trash bin 2, and the type of waste. If the infrared sensor reads low and the inductive sensor reads low, the waste is classified as organic. If the infrared sensor reads low and the inductive sensor reads high, the waste is classified as non-organic. Meanwhile, if the infrared sensor reads high and the inductive sensor reads low, the system indicates that no waste is detected because the sensors do not detect any object or material.

IV. CONCLUSION

The Internet of Things (IoT)-based automatic trash bin system that has been designed and implemented demonstrates good performance. The device is capable of identifying waste types and sorting them into the categories of organic, inorganic metal, and inorganic plastic, in accordance with the predetermined logical flow. This research successfully designed, implemented, and tested an IoT-based smart trash bin system integrated with solar panels for automatic organic and inorganic waste sorting at SMP Al Wathoniyah 9 Jakarta. The system's core functionality is based on a multi-sensor detection logic utilizing an infrared sensor for object presence, an inductive proximity sensor for metals, a capacitive proximity sensor for plastics, and ultrasonic sensors for fill-level monitoring, all controlled by an ESP32 microcontroller. The main findings and conclusions of this study are as follows:

1. High Functional Performance and Accuracy: The implemented system demonstrated effective and reliable operation in a real school environment. Based on extensive testing with 2,598 samples, the system achieved a high average sorting accuracy of 96.67%. This indicates that the chosen sensor combination and the hierarchical decision logic (metal > plastic > organic) are highly effective for basic waste categorization.
2. Successful System Integration and Sustainability: The project proved the technical viability of integrating IoT automation with renewable energy. The solar panel system provided a stable and sustainable power source, enabling the device to operate independently without relying on the main electricity grid (PLN). This addresses a practical constraint in many school settings and enhances the system's environmental benefits.
3. Tangible Educational and Practical Impact: Beyond its technical success, the system serves as a practical educational tool. It raises students' awareness about waste segregation through direct interaction with automated technology and provides school administrators with a real-time web-based monitoring dashboard for better waste management decisions. This aligns directly with the goals of developing a smart school environment.

However, this study has certain limitations that indicate directions for future development. The system's detection logic is currently optimized for common waste types like food scraps, metals, and plastics, and may face challenges with complex or composite materials. Furthermore, long-term durability under varying weather conditions and the economic feasibility of large-scale replication were not extensively evaluated.

Therefore, it is concluded that this solar-powered IoT smart trash bin is a viable, effective, and educational solution for improving waste management at the school level. For future work, it is recommended to explore integrating more advanced object recognition technologies (e.g., image sensors with simple machine learning) to handle a wider variety of waste, improve the mechanical design for robustness, and conduct a comprehensive cost-benefit analysis for broader implementation.

REFERENCES

[1] A. Selay et al., “INTERNET OF THINGS,” 2022.
[2] M. Nizam, H. Yuana, and Z. Wulansari, “Mikrokontroler ESP32 sebagai Alat Monitoring Pintu Berbasis Web,” 2022.
[3] P. Estu Broto, J. Fisika, and U. Islam Negeri Alauddin Makassar, “Perbandingan Persentase Kesalahan Sensor Sonar Pengukur Jarak Berbasis Hc-Sr04 dan Hy-Srf05,” vol. 4, no. 1, pp. 1–10, 2024, [Online]. Available: http://journal.uin-alauddin.ac.id/index.php/sainfis
[4] J. Sistem and K. Tgd, “Implementasi Sensor Proximity Induktif Pada Sistem Pemilah Sampah Logam Menggunakan Metode Counter Berbasis Arduino,” vol. 2, no. 4, pp. 229–235, 2023, [Online]. Available: https://ojs.trigunadharma.ac.id/index.php/jskom
[5] Y. Lianawati, C. Mahendra, G. M. Sugianto, S. J. Mendrofa, A. L. Setiani, and B. Y. Baraga, “Sistem Monitoring dan Controlling ‘Smart waste’ berbasis Internet of Things menggunakan modul ESP 32,” Journal of Telecommunication Electronics and Control Engineering (JTECE), vol. 6, no. 2, pp. 163–175, Jul. 2024, doi: 10.20895/jtece.v6i2.1400.
[6] Asqalani, M. A. H., & Arda, A. L. (2023). Sistem Monitoring Bak Sampah Berbasis IoT.
[7] [8] Budiarti, R. P. N., Maulana, J., & Sukaridhoto, S. (2018). Aplikasi DIY Smart Trash berbasis IoT Open Platform. Applied Technology and Computing Science Journal
[8] Ma’arif, R. A., Fauziah, F., & Hayati, N. (2019). Sistem Monitoring Tempat Sampah Pintar Secara Real-time Menggunakan Metode Fuzzy Logic Berbasis IOT. Jurnal Infomedia: Teknik Informatika, Multimedia, Dan Jaringan.
[9] Putra, T. A., Assiddiq, M., & Basri, B. (2022). Sistem Monitoring Bak Sampah Berbasis Internet of Things. Journal Peqguruang.
[10] Rahayu, S., & Ferdian, S. (2022). Sistem Monitoring Volume Tempat Sampah Berbasis IoT Menggunakan Metode Fuzzy. SEMNASTERA (Seminar Nasional Teknologi Dan Riset Terapan).