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DESIGN AND DEVELOPMENT OF A PLASTIC BOTTLE AND METAL WASTE SORTER WITH REWARD EXCHANGE COINS

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ABSTRACT

Waste management is a critical issue that requares innovative solutions, particulary in the sorting of waste at its source. This study present the design and development of an automatic waste sorting device based on the ESP32 microcontroller, capable of distinguishing between metalic and non-metallic (plastic) waste. The system utilizes two main types of sensors for object detection and the inductive proximity sensor for identifying metalic materials. The MG90S servo motor is used to direct waste to the apporiate path,. In addition to its physical operation, the device in addition to its physical operation, the device is equipped with IoT-bassed connectivity, enablingreal-time data transmission of waste types and quantities to a web platfor. The system is integrated with RFID technology to allow users to earn digital coupons as a reward, which can be exchanged for prizes. This solution aims to encourage public participation in waste sorting and support systematic and integrated recycling efforts.

Keywords: automatic waste sorter; ESP32; Infrared sensor; inductive proximity sensor; Digital Coupon.

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INTRODUCTION

Waste is the residue of objects that are no longer used by humans. Waste can come from households as well as from industry. According to Law Number 18 of 2008, waste is the residue of humans' daily activities or natural processes in solid or semi-solid form. Waste can consist of organic or inorganic materials, which can decompose, and is considered no longer useful (Yasiri et al., 2025) .

The main difference between organic and inorganic waste lies in how long they take to decompose. Organic waste, such as food scraps or leaves, decomposes easily, while inorganic waste, such as plastic or metal, is difficult to break down and takes a long time. If these two types of waste are separated, we can prevent pollution and make it easier to recycle waste. Therefore, organic and inorganic waste bins should be separated (Akbar et al., 2021).

Technological developments in the era of globalization, particularly in the fields of microcontrollers and sensors, have a significant impact on human life. Various new technological innovations continue to emerge to facilitate and assist with daily activities. One of them is the utilization of microcontroller and sensor technology to create devices that can increase public awareness of the importance of maintaining environmental cleanliness(Kombe, 2025)

The ESP32 microcontroller is used as the controller for the automatic waste-sorting device. It was developed by Espressif Systems. One of the ESP32's advantages is its built-in Wi-Fi and Bluetooth, making it suitable for Internet of Things (IoT) systems that require wireless connectivity. It is also relatively low-cost and energy-efficient. Its integrated Wi-Fi module and dual-mode Bluetooth support make the ESP32 flexible and economical.

An infrared proximity sensor detects the presence of an object using infrared light, through reflection or reflection-based sensing. When an object enters a certain range, infrared light is reflected toward the receiver and registered as a signal indicating that an object is passing the sensor. An inductive proximity sensor, meanwhile, detects the presence of metal, including ferrous and non-ferrous metals. It identifies whether a metal object is present within its detection area (Xie et al., 2025)

The ESP32 is a microcontroller module developed after the ESP8266. It uses an Xtensa LX6 CPU with a 32-bit architecture and features a dual-core design. The ESP32 is equipped with 128 KB of ROM, 418 KB of SRAM, and 64 MB of flash memory for storing programs and data (Rajabi-Kafshgar et al., 2025) .

One advantage of the ESP32 is its integrated Wi-Fi and Bluetooth, which allow users to connect to the internet without additional hardware. This provides broad opportunities for developing IoT projects. The ESP32 also has more pins and ports than the Arduino and NodeMCU ESP8266, making it more flexible for systems requiring multiple connections (Rianmora et al., 2023). It is known for its low cost and power consumption and includes high-speed Wi-Fi and dual-mode Bluetooth Low Energy. These features reduce the need for additional communication devices and save cost and space. Consequently, the ESP32 is widely used in research and the development of IoT-based systems (Herry Syaifullah et al., 2026).

Infrared Proximity Sensor

An infrared proximity sensor is a sensing device that functions as a switch or detects objects without direct contact. It generally uses solid-state technology with a tightly sealed insulating layer, protecting it from external influences such as corrosion, chemicals, liquids, and excessive vibration(Budiman et al., 2025).An infrared proximity sensor can detect small or soft objects and can be used to detect non-metallic waste, particularly plastic bottles, allowing the sorting system to operate automatically and accurately (Meraj et al., 2024).

Inductive Proximity Sensor

An inductive proximity sensor detects the presence of metals, both ferrous and non-ferrous. Its operating principle is based on an inductive coil that generates a high-frequency magnetic field. When a metal object approaches this field, electromagnetic induction causes a change in the electrical current in the detected metal(Romero, Oscar Jr. O et al., 2026) . This change is processed as a signal indicating the presence of a metal object near the sensor. In this study, the inductive proximity sensor is used to detect metal waste. It plays an important role in automatically distinguishing plastic bottles from metal waste. The detected data can then be converted into points or coupons that can be redeemed for rewards (Herry Syaifullah et al., 2026).

MP3 Module

An MP3 module is a small electronic device used to play MP3 audio files from storage media, such as a microSD card or USB flash drive. It is commonly used in Arduino-based projects, IoT systems, voice-assistance devices, and automatic audio-notification systems

Speaker

A speaker is an audio-output component used in waste-sorting systems that employ an MP3 module, such as the DFPlayer Mini. It provides audio feedback and information to users, making interaction with the system easier through voice notifications.

Servo Motor

A servo motor is an actuator designed with a closed-loop control system, allowing the output shaft angle to be adjusted and maintained according to a command. Its main components include a drive motor, gears, a potentiometer, and a control circuit. The potentiometer acts as a position sensor, providing feedback to the control system so that the shaft angle can be checked against the target. It has three wires: two for power and one for the control signal. When the servo receives a control signal, the gears rotate the potentiometer and output shaft. The motor stops when the target angle is reached. If the position is not yet correct, the potentiometer feedback helps adjust the movement until the desired angle is achieved.

Switching Power Supply

A switching power supply, or switched-mode power supply (SMPS), converts an input voltage into a stable output through high-frequency switching. Compared with a linear power supply, an SMPS is more efficient, more compact, and able to provide current according to the load requirements.

Buzzer

A buzzer is an electronic component that produces sound through diaphragm vibration in response to an electrical stimulus. Based on its operating principle, buzzers are divided into two types: active buzzers, which produce sound when voltage is applied, and passive buzzers, which require a frequency signal from the control circuit.

Jumper Wires

Jumper wires are small electrical conductors used to connect components or modules in an electronic circuit without soldering. They are commonly available as male-to-male, male-to-female, and female-to-female wires, depending on the connection requirements of a breadboard circuit.

Radio-Frequency Identification (RFID)

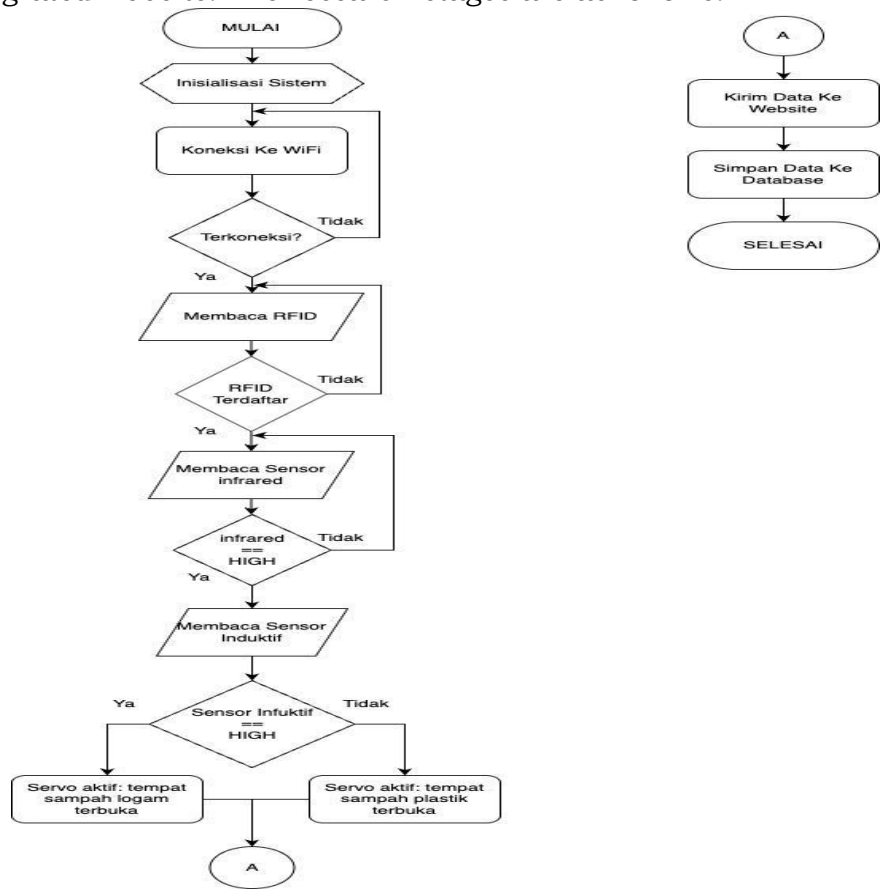
Radio-frequency identification (RFID) is an automatic identification technology that uses radio waves to read or store data on a tag without requiring direct physical contact. An RFID system consists of two main components: an RFID tag, which stores data, and an RFID reader, which reads the tag and sends the information to the microcontroller.

Internet of Things (IoT)

The Internet of Things (IoT) is a concept in which physical devices are connected to the internet so that they can communicate, exchange data, and be controlled remotely. IoT enables the integration of sensors, actuators, and computing systems to produce information that can be accessed in real time.

RESEARCH METHODS

This study aims to produce a prototype for sorting plastic bottles and metal waste using an infrared sensor to detect plastic bottles and an inductive proximity sensor to detect metal, with points checked through an IoT-integrated website. The research stages are as follows:



Component Selection and Specifications

The components were selected according to the system's requirements and functions, as follows:

a. ESP32 microcontroller as the controller
b. Infrared proximity sensor to detect plastic-bottle waste
c. RFID (Radio-Frequency Identification) sensor to identify user cards
d. MG90S servo motor to drive the sorting mechanism
e. Buzzer to provide signals to users
f. 4 V, 5 A switching power supply to convert AC power to DC

Assembly and Integration

At this stage, all components were assembled according to the design:

a. Connecting the ESP32 to the infrared sensor, inductive sensor, and other electronic components.
b. Installing a PVC pipe frame as the waste collection structure.
c. Synchronizing all components to ensure that the system operates properly.

Programming and IoT Configuration

a. Programming the system using the Arduino IDE.
b. Developing the Smart Trash website for checking points.
c. Testing connectivity to ensure that points are sent to the website in real time.

System Testing

Testing was conducted to verify system performance:

a. Infrared and inductive proximity sensor testing—to detect plastic bottles and metal waste.
b. Servo motor testing to move the sorting container toward the plastic-bottle or metal waste bin.
c. IoT testing to verify that points appear on the website in real time.

RESULTS AND DISCUSSION

System Design Results

The prototype system for sorting plastic bottles and metal waste, with data converted into points or coupons redeemable for rewards, was successfully designed and implemented. The system consists of:

a. ESP32 microcontroller
b. Infrared proximity sensor for detecting plastic bottles
c. Inductive proximity sensor for detecting metal waste
d. RFID (Radio-Frequency Identification) sensor for detecting user cards
e. Switching power supply
f. Buzzer for providing signals
g. Speaker for system audio output
h. IoT connection between the device and the websit

MG90S Servo Motor Testing

Testing was conducted using plastic bottles and metal waste.

0^0	Metal direction
90^0	Neutral position
180^0	Plastic direction

The results showed that the MG90S servo motor rotated precisely and could receive sensor data in real time.

Infrared and Inductive Sensor Test Results\

This test aimed to evaluate the automatic waste-sorting device's ability to identify waste materials, namely metal and plastic.

No.	IR Sensor Detection	Inductive Sensor Detection	Identification Result	Detection Time (ms)
1	Detected	Detects metal	Metal	805
2	Detected	Does not detect	Plastic	537
3	Detected	Does not detect	Plastic	649
4	Detected	Detects metal	Metal	912
5	Detected	Detects metal	Metal	958

RFID (Radio-Frequency Identification) Card Reading Test

This experiment examined communication between the RFID card-reading system and the server through the serial terminal. Three RFID cards were tested to determine whether the system could detect each card's UID (unique identifier), send the UID to the server, and receive a response from the server.

No.	Card UID	Status Sent to Server	Response Code	Server Message
1	0xDE AD BE EF	Sent	200 OK	Card 1 accepted
2	0xA1 B2 C3 D4	Sent	200 OK	Card 2 accepted
3	0x11 22 33 44	Sent	200 OK	Card 3 accepted

Discussion

The test results indicate that the sorting system, which uses an infrared proximity sensor to detect plastic bottles and an inductive proximity sensor to detect metal, is reasonably effective. Sensor accuracy in distinguishing plastic from metal is adequate for a prototype, although errors may occur when bottle shapes or sizes are non-standard.

The ESP32 microcontroller enables the system to connect to the internet. Sorting data can be sent to a server or website, allowing users to view the numbers of plastic bottles and metal items sorted.

Converting the amount of sorted waste into digital points or reward coupons is an innovative way to encourage the public to dispose of waste correctly. The points can form the basis of a reward system, such as redeeming goods, vouchers, or discounts.

CONCLUSIONS

Based on the design, implementation, and testing results, it can be concluded that the automatic waste-sorting system successfully distinguishes metal and plastic waste using inductive and infrared proximity sensors. The system improves sorting efficiency by accelerating and simplifying the process compared to manual methods, making it suitable for schools, households, and public facilities. The integration of sensors and a servo motor enables automatic operation with minimal human intervention, reducing workload and improving sorting accuracy. Furthermore, the ESP32 successfully transmits sorting data to a website in real time, allowing users and administrators to monitor activities and maintain records. The RFID system also accurately identifies users through their card UIDs and sends the information to the server, enabling the tracking of individual participation and supporting the potential implementation of a reward-based waste management system.

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