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Smart Reverse Vending Machine Using ESP32 for Waste Management

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Abstract

Plastic waste has become one of the major environmental concerns due to its increasing accumulation in landfills and water bodies. Conventional waste collection methods often fail to encourage people to recycle recyclable materials effectively. The proposed Reverse Vending Machine (RVM) is an IoT-enabled smart recycling system designed to automate the collection of recyclable plastic bottles and metal cans while rewarding users through a coupon-based incentive mechanism. The system is built using an ESP32 microcontroller, IR sensor, metal sensor, RFID module, LCD display, buzzer, and Thing Speak cloud platform for real-time monitoring. The system is built using an ESP32 microcontroller, IR sensor, metal sensor, RFID module, LCD display, buzzer, and the Things peak cloud platform. The IR sensor detects the presence of an object, while the metal sensor identifies metallic recyclable items. The ESP32 processes the sensor data and controls the overall operation of the system. After successful validation of the recyclable item, the machine authenticates the user through RFID, generates a reward coupon, and uploads transaction details to Thing Speak for real-time monitoring. The LCD display provides status messages, and the buzzer gives audio feedback to the user. The developed prototype successfully demonstrates an efficient, low-cost, and user-friendly recycling solution that promotes environmental sustainability and supports smart waste management. When a user inserts a recyclable item, the sensors verify its validity. If accepted, the ESP32 processes the data, stores the information on the cloud, and generates a reward coupon for the user. The LCD displays the system status while the buzzer provides audio feedback. The developed prototype successfully demonstrates an efficient, low-cost, and environmentally friendly solution for waste management. The proposed system promotes recycling habits, reduces environmental pollution, and supports smart city initiatives.

Keywords: *Reverse Vending Machine, ESP32, IoT, Recycling, Smart Waste Management, Thing Speak, RFID, Sustainability.*

1. Introduction

Rapid urbanization and increasing consumerism have significantly increased the amount of plastic waste generated worldwide. Plastic bottles and aluminium cans constitute a major portion of municipal solid waste, leading to severe environmental pollution if not disposed of properly. Traditional waste collection systems depend heavily on manual segregation, which is inefficient, time-consuming, and often results in recyclable materials being discarded as general waste. A Reverse Vending Machine (RVM) is an intelligent recycling system that encourages people to return used bottles and cans by providing rewards. Unlike conventional vending machines, which dispense products after payment, an RVM accepts recyclable materials and offers incentives such as coupons, reward points, or cashback. The proposed Reverse Vending Machine is developed using an ESP32 microcontroller, which serves as the central processing unit of the system. The machine uses an IR sensor to detect the presence of an inserted object and a metal sensor to identify metallic recyclable materials such as aluminum cans. An RFID module is used to identify registered users and maintain recycling records. The system also incorporates an LCD display to provide instructions and status messages, while a buzzer offers audible feedback for successful or unsuccessful operations. To enable Internet of Things (IoT) functionality, the system uploads recycling data to the Thing Speak cloud platform, allowing real-time monitoring and analysis of recycling activities. The proposed system utilizes an ESP32 microcontroller integrated with IR

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sensors, metal sensors, RFID technology, LCD display, buzzer, and ThingSpeak cloud platform to automate waste collection. The machine identifies recyclable materials, validates the object, stores usage information on the cloud, and rewards users through a coupon generation mechanism. The implementation of such systems in colleges, shopping malls, railway stations, airports, and public places can significantly increase recycling rates while promoting environmental awareness among citizens.

2. Literature Review

Several researchers have proposed automated recycling systems to improve waste management efficiency[1].

- Early reverse vending machines mainly relied on barcode scanners and simple weight measurement techniques. These systems required manually labeled bottles, limiting their flexibility[2].
- IoT-based waste management systems introduced cloud connectivity for monitoring bin status, waste collection schedules, and operational efficiency. However, many systems focused only on waste monitoring rather than rewarding users.
- Recent developments integrate ESP32 and cloud platforms such as ThingSpeak to provide real-time monitoring and data analysis. These solutions improve operational efficiency but often lack affordable designs suitable for educational institutions.
- Reward-based recycling systems have demonstrated higher public participation compared to conventional recycling methods by motivating users through incentives.

The proposed Reverse Vending Machine combines affordable hardware components with IoT technology and coupon-based rewards, making it suitable for educational campuses and public locations.

3. Problem Statement

Improper disposal of plastic bottles and metal cans contributes significantly to environmental pollution and landfill accumulation. Existing waste collection methods do not effectively motivate people to recycle recyclable materials. Manual segregation increases operational costs and reduces recycling efficiency[3]. Therefore, there is a need for an intelligent, automated, and cost-effective recycling system that identifies recyclable materials, rewards users, and enables real-time monitoring through IoT technology,As shown in Figure 1 Reverse Vending Machine.

Figure 1 Reverse Vending Machine

4. Objectives

The major objectives of the proposed Reverse Vending Machine are:

- Design and develop an IoT-enabled Reverse Vending Machine.
- Automatically detect recyclable plastic bottles and metal cans[4].
- Validate recyclable objects using IR and metal sensors.
- Process sensor data using the ESP32 microcontroller.
- Identify users through RFID technology.
- Reward users with coupons after successful recycling.
- Upload recycling data to the ThingSpeak cloud platform.
- Encourage environmental awareness and

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sustainable recycling practices.

5. Proposed System

The proposed Reverse Vending Machine (RVM) is an IoT-based automated recycling system that accepts recyclable plastic bottles and metal cans while rewarding users with coupons. The system is designed around the ESP32 microcontroller, which acts as the central processing unit by collecting data from multiple sensors and controlling the overall operation. The machine detects the presence of an object using an IR sensor and identifies metallic objects using a metal sensor. An RFID reader is used to authenticate users before awarding coupons. After successful verification, the ESP32 uploads the transaction details to the ThingSpeak cloud platform, where recycling data can be monitored in real time. The LCD displays system status messages, while the buzzer provides audio feedback to indicate successful or unsuccessful operations. The proposed system provides a low-cost, user-friendly, and environmentally sustainable solution for improving recycling efficiency in educational institutions, shopping malls, railway stations, airports, and other public locations[5].

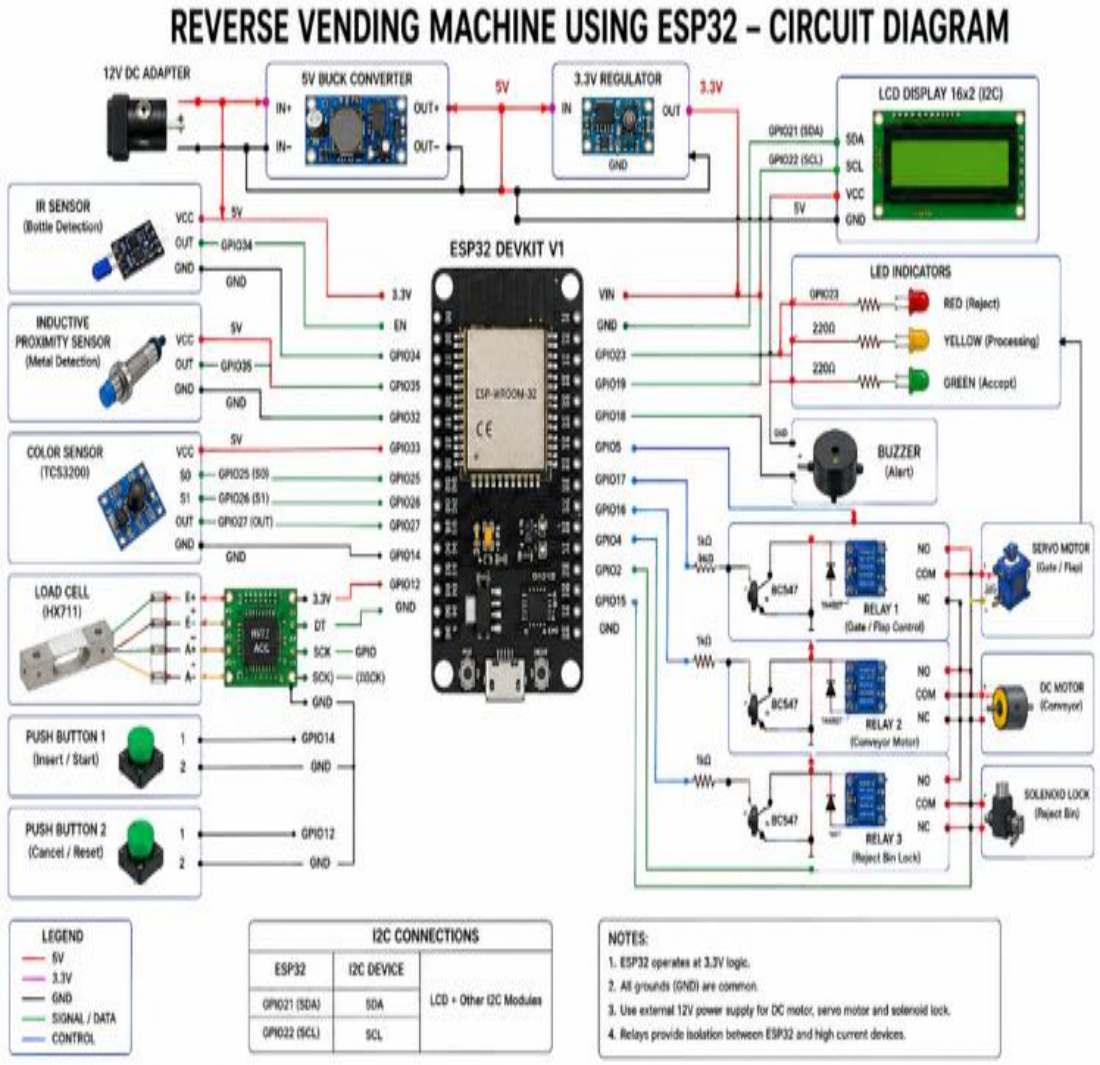

Figure 2 Reverse Vending Machine Using ESP32 – Circuit Diagram

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6. System Architecture

The Reverse Vending Machine consists of the following major modules:

6.1.Input Unit

- IR Sensor
- Metal Sensor
- RFID Reader

6.2.Processing Unit

- ESP32 Development Board

6.3.Output Unit

- LCD Display (16×2 with I2C)
- Buzzer
- Coupon Generation

6.4.Communication Unit

- ESP8266 Wi-Fi Module
- ThingSpeak Cloud Platform

6.5.Power Supply Unit

- 12V DC Adapter
- Buck Converter
- DC-DC Converter
- The ESP32 continuously monitors all sensors and processes their data. Based on the sensor readings, the controller determines whether the inserted object is recyclable. If valid, the machine updates the cloud server, generates a reward, and stores the recyclable material inside the collection bin[6].

7. Hardware Components

7.1.ESP32 Development Board

The ESP32 is the main controller used in this project. It processes sensor data, controls peripherals, communicates with the cloud platform, and manages the complete recycling process. The ESP32 offers built-in Wi-Fi, multiple GPIO pins, low power consumption, and high processing capability.

7.1.1. Specifications

- Operating Voltage: 3.3V
- Dual-Core Processor
- Built-in Wi-Fi and Bluetooth
- Multiple GPIO Pins
- Low Power Consumption

7.2.IR Sensor

The IR sensor detects the presence of a bottle or can when the user inserts the object into the machine.

7.2.1. Functions

- Detects inserted object
- Sends detection signal to ESP32
- Starts the recycling process

7.3.Metal Sensor

The metal sensor detects metallic recyclable objects such as aluminum cans. It helps distinguish between metal and non-metal waste[7].

7.3.1. Advantages

- Fast detection
- High accuracy
- Reliable operation

7.4.RFID Module

The RFID module identifies registered users before generating reward coupons.

7.5.Functions

- User Authentication
- Reward Allocation
- User Identification

7.6.LCD Display

The 16×2 LCD with I2C interface displays important system messages such as:

- Welcome
- Insert Bottle
- Object Accepted
- Coupon Generated
- Thank You

7.7.Buzzer

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The buzzer provides audible feedback after every successful or unsuccessful operation.
Functions include:

- Successful recycling indication
- Error notification
- System alert

7.8.ESP8266 Wi-Fi Module

The ESP8266 connects the ESP32-based system to the internet and uploads recycling information to the ThingSpeak cloud platform[8].

7.8.1. Functions:

- Internet connectivity
- Cloud communication
- Real-time data transfer

8. Software Requirements

The software tools used in this project include:

Table 1 Software and Purpose

Software	Purpose
Arduino IDE	Programming ESP32
ThingSpeak	Cloud Data Monitoring
Embedded C	Firmware Development
Serial Monitor	Debugging

9. Methodology

The working methodology of the Reverse Vending Machine consists of the following steps:

- **Step 1:** The system initializes all sensors, LCD display, RFID module, Wi-Fi communication, and ESP32 controller.
- **Step 2:**The user inserts a recyclable bottle or metal can into the machine.
- **Step 3:** The IR sensor detects the presence of the object.
- **Step 4:**The metal sensor identifies whether the inserted object is metallic.
- **Step 5:** The ESP32 receives sensor data and verifies whether the object is acceptable.
- **Step 6:** The RFID reader authenticates the user.
- **Step 7:**After successful verification, a coupon reward is generated.
- **Step 8 :**The recycling information is uploaded to the ThingSpeak cloud platform.

10. Working Principle

The Reverse Vending Machine operates by combining sensor technology, IoT communication, and embedded system control. When the user inserts a recyclable object, the IR sensor first detects its presence. The metal sensor then checks whether the object contains metallic material. The ESP32 processes these sensor inputs and determines whether the object meets the acceptance criteria. After successful validation, the RFID reader identifies the user, and a coupon reward is generated. Simultaneously, the ESP32 uploads recycling information to the ThingSpeak cloud platform through Wi-Fi. The LCD display informs the user about the current operation, while the buzzer provides audible confirmation. Finally, the recyclable item is deposited into the storage compartment, completing the recycling cycle.As shown in Figure 3 Reverse Vending Machine

Figure 3 Reverse Vending Machine

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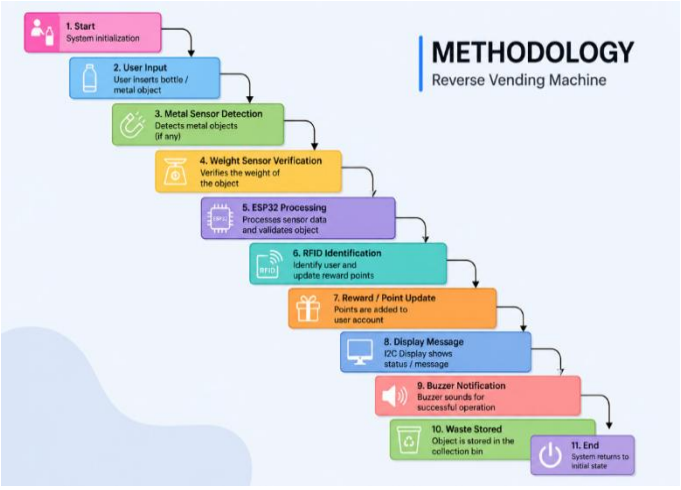
11. Algorithm

11.1. Algorithm for Reverse Vending Machine

- **Step 1:** Start the system.
- **Step 2:** Initialize the ESP32, LCD display, RFID reader, IR sensor, metal sensor, Wi-Fi module, and ThingSpeak connection.
- **Step 3:** Display "Insert Bottle or Can" on the LCD.
- **Step 4:** Wait for the user to insert a recyclable object.
- **Step 5:** Detect the object using the IR sensor.
- **Step 6:** Check whether the object is metallic using the metal sensor.
- **Step 7:** If the object is valid:
  - Authenticate the user using RFID.
  - Generate a coupon/reward.
  - Display "Accepted" on the LCD.
  - Sound the buzzer.
  - Upload transaction details to ThingSpeak.
  - Store the recyclable object.
- **Step 8:** If the object is invalid:
  - Display "Invalid Object".
  - Activate the buzzer.
- **Step 9:** Return to the initial state and wait for the next user.
- **Step 10:** Stop.



12. Advantages

The proposed Reverse Vending Machine offers several advantages:

- Encourages recycling through reward-based incentives.
- Reduces environmental pollution caused by plastic waste.
- Automates waste collection and segregation.
- Provides real-time monitoring through ThingSpeak.
- Low-cost implementation using ESP32.
- User-friendly interface with LCD and buzzer.
- Suitable for Smart City applications.
- Reduces manual labor and operational costs.
- Supports sustainable waste management practices.

13. Applications

The Reverse Vending Machine can be deployed in

- Educational Institutions
- Shopping Malls
- Railway Stations
- Airports
- Bus Stations
- Public Parks
- Government Offices
- Smart City Projects
- Corporate Campuses
- Residential Communities

14. Future Scope

The system can be further improved by incorporating the following features

- AI-based image recognition for automatic waste classification.
- Mobile application for reward tracking.
- UPI and digital wallet integration for cashback rewards.
- Solar-powered operation for improved energy efficiency.
- Automatic bottle crushing mechanism to increase storage capacity.
- Integration with municipal recycling databases.

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- GPS tracking for smart waste collection.
- Machine learning algorithms for predictive maintenance.
- Multi-language LCD interface.
- Remote monitoring using a dedicated web dashboard.

Conclusion

The Reverse Vending Machine presented in this paper provides an effective and intelligent solution for modern waste management challenges. The system successfully combines IoT technology, embedded systems, cloud computing, and automation to promote recycling through a reward-based approach. The integration of ESP32, IR sensor, metal sensor, RFID module, LCD display, buzzer, and ThingSpeak cloud platform enables reliable detection, monitoring, and management of recyclable materials. The working prototype demonstrated efficient operation during testing and project presentation. The proposed system not only improves recycling efficiency but also increases public awareness regarding environmental conservation. It represents a practical, affordable, and scalable solution that can contribute to cleaner cities and sustainable development.

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Use IEEE-style references such as:

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