

Intelligent Waste Separator

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Abstract: Mixed wet, dry and metal waste is hard to recycle, manual sorting is slow and unhygienic, and bins often overflow because their fill level is not monitored. This paper proposes the Intelligent Waste Separator, a low-cost IoT-based system that automatically separates waste into wet, dry and metal bins and monitors the fill level of each bin. A moisture sensor and a metal sensor read the waste, and an ESP32 microcontroller applies threshold logic and drives a servo or DC geared motor that drops the waste into the correct bin. Ultrasonic sensors track the fill level of each bin, and the ESP32 sends the waste category, fill level, status and time through Wi-Fi and an API to a database. A web dashboard built with HTML, CSS and JavaScript shows the bin status so that bins can be emptied on time. The system is organized into five modules: waste detection and separation, ESP32 programming and monitoring, IoT communication, database management, and testing and validation. This paper presents the architecture, methodology and planned evaluation of the system; the system is at the design stage, and no experimental results are claimed.

Key Word: Waste Segregation, Internet of Things (IoT), ESP32, Moisture Sensor, Metal Sensor, Ultrasonic Sensor, Smart Bin, Web Dashboard

I. INTRODUCTION

Proper waste segregation is an important requirement for clean, healthy and sustainable surroundings. When wet, dry and metal waste are thrown into the same bin, recycling becomes difficult, and mixed waste needs more effort, time and cost to handle. Manual sorting adds to this workload, and bins, collection and monitoring are often poorly coordinated, so bins may overflow and cause bad smells before they are emptied.

The Internet of Things (IoT) offers a practical way to address these problems. Sensors and microcontrollers can detect the type of waste and measure the fill level of a bin automatically, and Wi-Fi allows the readings to be sent to a web application. Moisture sensors can indicate wet waste, metal sensors can detect metallic items, and ultrasonic sensors can measure the distance to the waste surface, while a microcontroller such as the ESP32 can process the readings and drive a motor. Recent studies on smart bins combine such sensors with IoT communication and monitoring [1]–[5]. However, many systems handle only wet and dry waste, and some materials are hard to tell apart with basic sensors.

This paper proposes the Intelligent Waste Separator. Waste enters through an input chute and is read by a moisture sensor and a metal sensor. An ESP32 microcontroller applies threshold logic and drives a servo or DC geared motor, which drops the waste into the wet, dry or metal bin. Ultrasonic sensors check the fill level of each bin, and the ESP32 sends the waste category, fill level, status and time through Wi-Fi and an API to a database. A web dashboard built with HTML, CSS and JavaScript shows the bin status.

The main contributions of this work are: (i) a proposed design for automatic wet, dry and metal waste separation built from low-cost sensors and an ESP32; (ii) live monitoring of the fill level of each bin through a database and a simple web dashboard; and (iii) a planned evaluation covering waste detection accuracy, separation efficiency, bin-level measurement accuracy, response time, communication reliability, error rate and power use. The scope is a prototype separator with dashboard monitoring.

The rest of the paper is organized as follows. Section II reviews the literature. Section III describes the methodology as five modules. Section IV discusses the expected benefits, planned evaluation and feasibility. Section V concludes.

II. LITERATURE REVIEW

Islam et al. [1] presented an IoT-based smart waste segregation and monitoring system built around an ESP32 with moisture, metal and ultrasonic sensors. Alerts are sent through Blynk, and the system is described as low-cost and scalable. Its sensor set is the closest to the proposed system.

Sosunova and Porras [2] carried out a systematic review of 173 studies on IoT-enabled smart waste management systems for smart cities. The review covers smart bins and route optimisation, which gives the wider context for bin

monitoring and collection planning.

Fataniya et al. [3] implemented an IoT-based waste segregation and collection system and built a ground-level segregation prototype. Their work indicates that smart bins can reduce the estimated cost for a ward.

Suvarnamma and Pradeepkiran [4] proposed a SmartBin system with a waste tracking and sorting mechanism that sorts metal, plastic and glass. The bins are tracked using RFID, GPS and GPRS.

Shegokar et al. [5] presented an IoT-based smart bin for waste segregation that uses an ESP32, a moisture sensor and a GSM module to sort dry and wet waste and to report the bin level. It is close to the proposed design but sorts only two categories.

Research gap. The reviewed studies show that automatic segregation and bin monitoring are feasible, but they emphasize different parts of the problem: a multi-sensor ESP32 system with Blynk alerts [1], a review of smart bins and route optimisation [2], ground-level segregation and cost [3], metal, plastic and glass sorting with RFID and GPRS tracking [4], and dry and wet sorting with a GSM module [5]. The proposed work does not claim a new sensing technique. Its aim is a simple, practical and low-cost prototype that joins wet, dry and metal separation, ESP32 threshold logic, ultrasonic fill-level monitoring of each bin, Wi-Fi and API transfer to a database, and a web dashboard, and that is planned to be tested for detection accuracy, separation efficiency, response time and reliability.

III. METHODOLOGY

The proposed system follows a modular pipeline in which each stage passes its output to the next (Fig. 1): waste enters the input chute, the moisture and metal sensors read it, the ESP32 applies threshold logic, the motor drops the waste into the right bin, the ultrasonic sensors check the fill level, and the dashboard shows the bin status. Wet waste goes to the wet bin, metal waste goes to the metal bin, and all other waste goes to the dry bin. The system is organized into five modules (Table I).

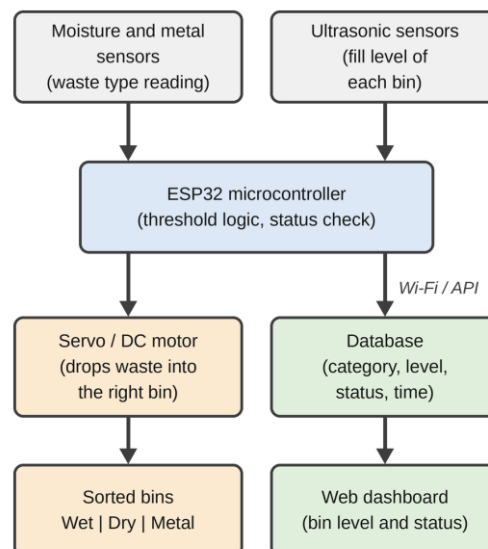


Fig1. Block diagram of the proposed Intelligent Waste Separator. The ESP32 reads the sensors, drives the motor to separate the waste, and sends the bin data over Wi-Fi to the database and the web dashboard.

Module	Function	Key tools
1. Sorting	Moisture and metal sensing; the motor drops waste into the right bin	Moisture sensor, metal sensor, servo/DC motor
2. ESP32	Sensor processing, bin-level monitoring and full-bin check	ESP32, ultrasonic sensor, Arduino IDE
3. IoT link	Wi-Fi and API transfer to the web dashboard	Wi-Fi, API, HTML, CSS, JavaScript
4. Database	Storage of category, fill level, status and time	Database, API
5. Testing	Checks of sensors, motor, data transfer and dashboard	Serial Monitor, web browser

Table1. Summary of the five modules

A. Module 1: Waste Detection and Separation

1) Moisture and metal sensing: The waste entering the input chute is read by a moisture sensor and a metal sensor. The moisture sensor identifies wet waste and the metal sensor identifies metal waste; waste that is neither is treated as dry waste.

2) Classification and separation: The ESP32 compares the sensor readings with thresholds. Wet waste is sent to the wet bin, metal waste to the metal bin and all other waste to the dry bin. A servo or DC geared motor with a motor driver drops the waste into the selected bin. The threshold values are fixed during calibration and testing.

B. Module 2: ESP32 Programming and Monitoring

- 1) Sensor processing: The ESP32 acts as the main controller. It is programmed with the Arduino IDE, reads the moisture and metal sensors and drives the motor, and the Serial Monitor is used to debug the code.
- 2) Bin-level monitoring: An ultrasonic sensor on each bin sends waves towards the waste surface and measures the echo time, from which the distance d to the waste is obtained ($d = v \cdot t/2$, where v is the speed of sound and t is the echo time). The ESP32 uses this distance to track the fill level of the bin and to check whether it is full.

C. Module 3: IoT Communication

- 1) Wi-Fi and API transfer: The built-in Wi-Fi of the ESP32 sends the waste category, fill level, status and time to the database through an API.
- 2) Web dashboard: A dashboard developed with HTML, CSS and JavaScript shows the bin level and status in a simple, easy-to-use page that can be opened in a web browser, so that bins can be emptied on time.

D. Module 4: Database Management

The database stores the waste category, fill level, status and time sent by the ESP32 through the API. The dashboard uses these records to show the current status of the bins.

E. Module 5: System Testing and Validation

Each part of the system is checked in turn: the sensors, the motor mechanism, the transfer of data to the database and the dashboard. The Arduino Serial Monitor is used for debugging and a web browser for testing the dashboard.

The prototype is planned with an ESP32 development board, a moisture sensor, a metal sensor, an ultrasonic sensor, a servo or DC geared motor with a motor driver, a power supply, jumper wires and bins, with a Wi-Fi link to the dashboard. Software tools are the Arduino IDE for ESP32 programming, Visual Studio Code for the HTML, CSS and JavaScript dashboard, and an API and database for the sensor data. The system is built stage by stage.

IV. EXPECTED BENEFITS AND EVALUATION PLAN

A. Expected Benefits

Based on the design and the literature, the system is expected to: sort wet, dry and metal waste without manual effort; reduce manual sorting work and keep the surroundings clean; reduce overflowing bins and bad smells by showing the bin level and status on a public dashboard; allow smarter collection with fewer trips and less time and fuel; and support recycling. These are design goals, not measured results.

Because the system uses low-cost components and a simple dashboard, it can be useful wherever wet, dry and metal waste need to be collected separately.

B. Planned Evaluation

After implementation, the system will be evaluated on the following measures:

- waste detection accuracy of the moisture and metal sensors;
- separation efficiency, that is, how often waste reaches the correct bin;
- bin-level measurement accuracy of the ultrasonic sensors;
- system response time from sensing to display on the dashboard;
- communication reliability of the Wi-Fi and API transfer from the ESP32 to the database;
- error rate and power use of the system;
- reliability over repeated tests.

C. Feasibility and Scope

The project is technically feasible because it uses commonly available parts: the ESP32, sensors and a motor. It is economically feasible because the components are low-cost, and operationally feasible because the dashboard is easy to use and can be made public. It can be implemented stage by stage within the project schedule, it supports recycling and so the environment, and it is easy to maintain because the parts are simple to replace. Its scope is a prototype that separates wet, dry and metal waste; other categories such as plastic, paper and glass, mobile alerts and GPS-based collection routes are left for future work.

V. CONCLUSION

This paper proposed the Intelligent Waste Separator, an IoT-based system that separates waste into wet, dry and metal bins using a moisture sensor, a metal sensor and an ESP32 that drives a servo or DC geared motor, tracks the fill level of each bin with ultrasonic sensors, and shows the bin status on a web dashboard. The five-module design lets each part be built and tested stage by stage and uses low-cost parts that are simple to replace, so it can serve as a practical prototype for automatic segregation with live monitoring. The expected outcomes are less manual sorting, fewer overflowing bins and bad smells, and fewer collection trips with less time and fuel; these are design goals, not measured results.

Future work includes completing the implementation, evaluating the system as planned in Section IV, and adding AI/ML image classification for plastic, paper and glass, cloud storage and mobile alerts, GPS-based collection routes, solar power, and Python and Power BI analytics.

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