

## Smart Segregator Recycle Bin

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sustainability.

### Abstract

This study presents the development of a Smart Segregator Recycle Bin to address waste management challenges and promote environmental sustainability. The device integrates advanced sensors, including PIR motion, ultrasonic, inductive proximity, and infrared (IR) sensors, to automate waste segregation and accurately classify materials such as plastics, metals, and paper. Powered by an Arduino-based microcontroller (NodeMCU ESP8266) and servo motors, the system ensures precise sorting while minimizing human intervention and errors. A user-friendly interface via the Blynk IoT platform provides real-time monitoring of bin levels, enabling timely maintenance and offering insights into waste patterns to optimize management strategies. By reducing landfill usage, labor costs, and contamination in recyclables, the system contributes to environmental conservation and supports a sustainable approach to waste disposal. This innovative solution aims to revolutionize waste management, fostering a cleaner environment and encouraging responsible recycling practices.

## 1. Introduction

Among various waste management challenges, improper segregation and contamination of recyclables remain significant issues, particularly in urban areas with rising waste generation. As recycling becomes a cornerstone of sustainable practices, innovative solutions like smart recycling bins have gained prominence globally. According to the International Trade Administration, Malaysia disposes of more than 39,000 tons of municipal solid waste daily, equivalent to about 1.17 kg per person, with over 30% being food waste.

This highlights the need for automated systems that can enhance waste sorting efficiency while minimizing human error. Traditional recycling methods often fall short in achieving this efficiency, as manual sorting is labour-intensive and prone to mistakes. Studies by the National Recycling Initiative (2023) revealed that 28% of recyclables in mixed waste streams are contaminated due to incorrect disposal. This emphasizes the importance of technology-driven systems like the Smart Segregator Recycle Bin, which can automatically classify and sort materials such as plastics, metals, and paper at the source.

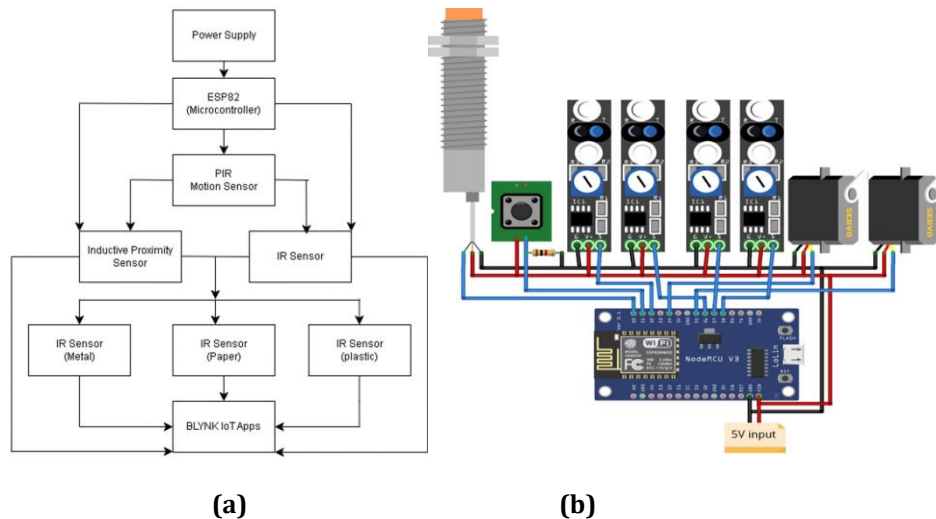
Additionally, the integration of IoT-enabled monitoring tools addresses the challenges of overflow and irregular maintenance. Reports by the Environmental Technology Association (ETA, 2024) show that IoT-enabled waste systems reduce collection delays by 25%, enhancing operational efficiency. By providing real-time data on bin levels and user-friendly interfaces for analysis, these systems facilitate timely interventions and promote sustainable waste management.

## 2 Methodology

The methodology for developing the Smart Segregator Recycle Bin involves a systematic approach, combining hardware and software components to achieve efficient waste sorting and monitoring. The system is built around the NodeMCU (ESP8266 V3) microcontroller, which serves as the central control unit. The system design is centered around the ESP8266 microcontroller, which interfaces with various sensors and actuators to perform waste sorting. The key components include the inductive proximity sensor, which detects metallic objects and distinguishes them from non-metallic materials, and the IR sensors, which detect non-metallic materials, specifically plastic and paper, and monitor bin fill levels. The servo motors control the sorting mechanism, directing waste into the appropriate bins, while the Blynk IoT platform provides real-time monitoring and notifications for bin status and waste types.

Based on the Figure 1 (a), the system workflow begins with waste detection, where the inductive proximity sensor and IR sensors are activated to identify the material type. The inductive proximity sensor detects whether the waste is metallic (metal) or non-metallic, while the IR sensors further classify non-metallic waste into plastic or paper. Based on the sensor input, the servo motors direct the waste into the appropriate bin (metal, plastic, or paper). The Blynk IoT platform displays the type of waste and bin fill levels, sending notifications when bins are full. The circuit design integrates the inductive proximity sensor and IR sensors with the NodeMCU microcontroller. The inductive proximity sensor detects metallic objects, while the IR sensors identify plastic and paper materials. The servo motors are controlled by the NodeMCU to sort the waste into the appropriate bins. The Blynk IoT platform is connected via Wi-Fi, enabling remote monitoring and control.

Following on the figures 1(b) the Smart Segregator Recycle Bin's circuit integrates the NodeMCU (ESP8266 V3) as the central controller, connected to an inductive proximity sensor for detecting metal and IR sensors for identifying plastic, paper, and monitoring bin fill levels. The inductive sensor and IR sensors send signals to the NodeMCU, which processes the data and controls servo motors via PWM pins to sort waste into the correct bins. The IR sensors also alert the NodeMCU when bins are full, triggering notifications on the Blynk IoT platform via Wi-Fi. A 5V DC power supply powers the NodeMCU, sensors, and servos, with connections made using jumper wires and a breadboard for a compact layout. This setup ensures accurate waste sorting and real-time monitoring.



**Fig. 1:** Project Description (a) System Block Diagram (b) Project Circuit Diagram

Referring Figure 2 (a), it shows the interface of the system includes a display box that shows the type of recyclable trash (such as plastic, metal, or paper). This box provides visual feedback to the user, indicating which type of waste is currently being processed or identified. Alongside the box, there are three circles, each representing a different waste category (plastic, metal, and paper). These circles will light up when a bin for each category reaches its capacity, indicating that the bin is full and needs to be emptied. This feature allows users to quickly identify which bin is full and ensures timely maintenance of the system. The combination of the display box and illuminated circles helps manage the recycling process efficiently.

The Figure 2 (b) shows the Smart Segregator Recycle Bin uses a NodeMCU (ESP8266 V3) to control the system. An inductive sensor detects metal, while IR sensors identify plastic, paper, and monitor bin fill levels. The NodeMCU processes sensor data and directs servo motors to sort waste into the correct bins. When bins are full, the NodeMCU sends alerts via the Blynk IoT platform over Wi-Fi. A 5V power supply powers all components, and connections are organized using a breadboard and jumper wires for efficient operation.

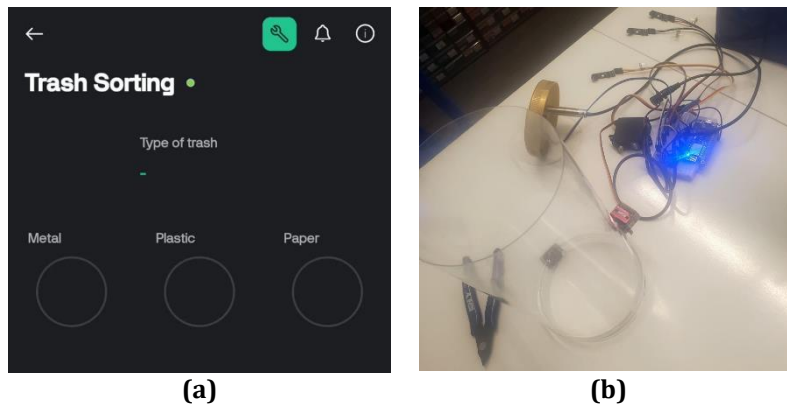


Fig. 2: Project Interface (a) User Interface (b) Project Connection

### 2.1 Project Flowchart

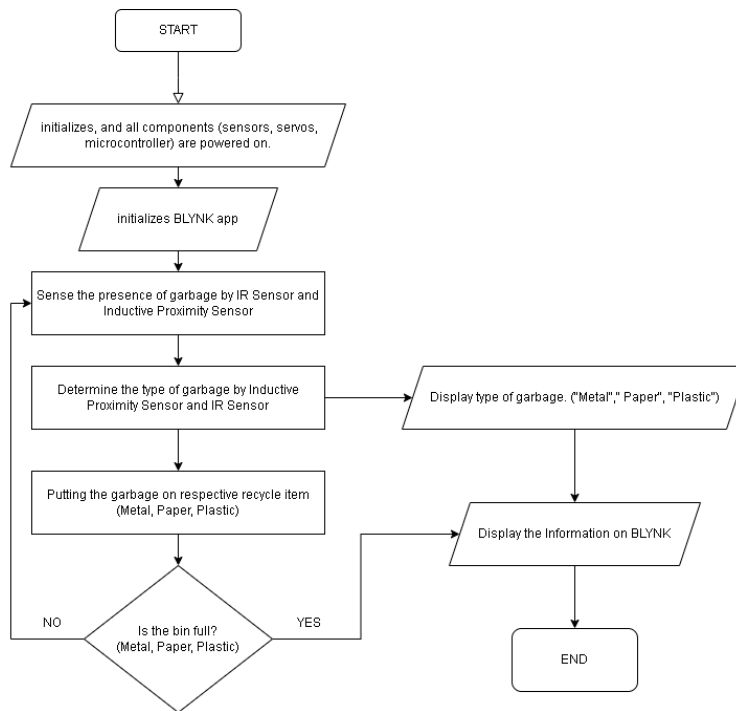


Fig. 3: Project Flowchart

Based on Figure 3, shows an automated waste sorting system powered by a Power Supply that energizes the ESP8266 Microcontroller and sensors. The microcontroller processes data from Metal, Plastic, and Object Detectors, as well as Bin Full Sensors, to identify waste types and monitor bin levels. It then controls Servo Motors to sort waste into the correct bins, with LED Indicators providing visual feedback on bin statuses. The system is connected to the Blynk IoT Platform, enabling remote monitoring via a mobile or web app, where users can view real-time data, receive alerts, and manage the system efficiently, reducing manual intervention and promoting sustainability.

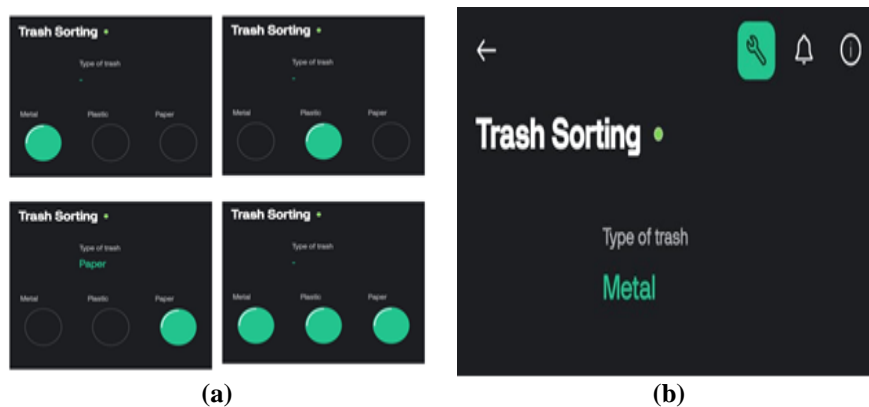
### 3. Result

#### 3.1 Data Collected

Figure 4 showing on how the system collects data on waste types and bin fullness, which is displayed on the Blynk IoT app. This app provides real-time updates, allowing users to monitor the classification of waste materials and the fill levels of each recycling bin. With this data, users can track waste trends, optimize recycling practices, and ensure timely bin maintenance. The Blynk app simplifies access to waste management insights, promoting more effective and efficient recycling efforts.

Based on Figure 4(a), it shows how the system uses sensors, such as IR sensors, to monitor the fill levels of recycling bins. This provides real-time data on bin capacity, ensuring bins are emptied before they overflow. By analyzing bin fullness patterns, the system can optimize bin placement and maintenance schedules, ensuring efficient waste management.

Next, for Figure 4(b), it illustrates how the system collects and categorizes waste into materials like plastic, metal, or paper. Sensors and automated sorting mechanisms identify the material as waste is placed in the bin. This data helps track waste disposal trends, providing insights into commonly disposed materials. These insights can enhance recycling processes, optimize bin placement, and encourage better waste separation and recycling habits.



**Fig. 4:** Data Collected (a) Fullness of each Bins (b) Type of Trash

#### 3.2 Analysis

Based on Table 1, 1 presents the reaction times for identifying three types of recyclable materials—metal, plastic, and paper—across 10 trials. Each trial measures how quickly the system can classify the material, with times provided in seconds. The reaction times for each material type are consistently under 1.9 seconds, demonstrating the system's efficiency in accurately identifying and sorting recyclables.

The data shows some variation in the reaction times for each material type. For example, the reaction time for identifying metal ranges from 1.05 to 1.89 seconds, while plastic identification times span from 1.03 to 1.90 seconds. Paper identification times vary between 1.06 and 1.87 seconds. The results indicate that the system is capable of quickly and accurately categorizing recyclables in a short amount of time, which is crucial for optimizing the sorting process in real-time waste management systems. The table highlights the efficiency and reliability of the sorting system across multiple trials and material types.

**Table 1:** Reactions Time Identifying the recyclable materials

<b>Trials</b>	<b>Metal (s)</b>	<b>Plastic (s)</b>	<b>Paper (s)</b>
<b>1</b>	<b>1.18</b>	<b>1.80</b>	<b>1.57</b>
<b>2</b>	<b>1.64</b>	<b>1.12</b>	<b>1.73</b>
<b>3</b>	<b>1.43</b>	<b>1.90</b>	<b>1.49</b>
<b>4</b>	<b>1.57</b>	<b>1.81</b>	<b>1.97</b>
<b>5</b>	<b>1.12</b>	<b>1.03</b>	<b>1.30</b>
<b>6</b>	<b>1.05</b>	<b>1.81</b>	<b>1.41</b>
<b>7</b>	<b>1.89</b>	<b>1.76</b>	<b>1.06</b>
<b>8</b>	<b>1.56</b>	<b>1.53</b>	<b>1.76</b>
<b>9</b>	<b>1.54</b>	<b>1.83</b>	<b>1.61</b>
<b>10</b>	<b>1.95</b>	<b>1.79</b>	<b>1.69</b>

For table 2, it showing the total time taken for each material—metal, plastic, and paper—was calculated by summing the reaction times across all 10 trials. For metal, the reaction times ranged from 1.05 to 1.89 seconds, resulting in a total time of 14.93 seconds. Plastic had reaction times between 1.03 and 1.90 seconds, totalling 16.83 seconds, while paper ranged from 1.06 to 1.87 seconds, with a total time of 15.49 seconds.

These totals reflect the system's efficiency in identifying and sorting each material. Shorter total times, like those for metal, indicate consistent efficiency, while longer times, such as for plastic, may highlight areas for improvement. Comparing these times helps identify which materials take longer to process, offering insights for optimizing the sorting system.

**Table 2:** Total Time Taken(s)

<b>Materials</b>	<b>Time (s)</b>
<b>Metal</b>	<b>14.93</b>
<b>Plastic</b>	<b>16.38</b>
<b>Paper</b>	<b>15.49</b>

Based on table 3, The average time taken to identify each material—metal, plastic, and paper—was calculated by dividing the total time for each material by the number of trials (10). For metal, the average time is 1.49 seconds, while plastic has an average of 1.64 seconds, and paper averages 1.55 seconds. These values reflect the typical response time of the system for each material.

The average times help assess the system's efficiency, with lower averages (like metal) indicating faster and more consistent performance, and higher averages (like plastic) suggesting potential areas for improvement. By analysing these averages, patterns in the system's performance can be identified, ensuring the sorting process operates optimally.

**Table 3:** Average Time Taken(s)

<b>Materials</b>	<b>Time (s)</b>
<b>Metal</b>	<b>1.49</b>
<b>Plastic</b>	<b>1.64</b>
<b>Paper</b>	<b>1.55</b>

#### 4. Conclusion

The smart segregator recycle bin system is an innovative solution designed to tackle the challenges of household waste management by automating the identification and sorting of recyclable materials such as metal, plastic, and paper. Using advanced sensors and real-time monitoring, the system ensures accurate categorization of waste, reducing reliance on manual intervention and significantly improving recycling efficiency. By minimizing human error, it addresses the critical issue of contamination in recycling streams, ensuring that materials remain pure and suitable for reuse, thereby supporting sustainable environmental practices. A standout feature of the system is its integration with the Blynk IoT platform, which enables real-time monitoring of bin fill levels and material types. This connectivity allows for remote management, timely maintenance, and prevention of overflow, while also providing valuable data that can optimize waste collection schedules and support integration into larger smart city waste management networks. Despite its effectiveness, there are opportunities for further enhancement, such as incorporating more advanced sensors to improve accuracy, expanding the range of materials it can handle, and increasing energy efficiency to ensure long-term sustainability. Additionally, integrating the system with broader smart city initiatives could amplify its impact, making it a key component of urban sustainability efforts. Overall, the smart segregator recycle bin system represents a significant advancement in recycling automation, offering a scalable and efficient solution that has the potential to revolutionize waste management practices and contribute to a more sustainable future.

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