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Sound Activated Sorting Bin

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Abstract

Excessive waste generation and inefficient recycling processes are among the serious environmental concerns. The study developed a Sound Activated Sorting Bin (SASB) to automate waste sorting using sound recognition technology. The process aims to improve recycling rates by effectively sorting paper, plastic, and metal waste without human intervention. The proof of concept uses an ESP32 microcontroller to process sound using a microphone, an E18 IR sensor to identify objects, and servo motors for mechanical sorting. It is powered by an 11.1V LiPo battery, features a three compartment modular setup, and includes real-time audio feedback. The system was tested with 300 sorting attempts under laboratory conditions. Results indicated 75% overall classification accuracy which means only 25% error rate, with error rates decreasing from 29% to 21% across trials. The system also achieved a consistent processing time of 0.41 seconds in later trials, and a mean of 2.27 seconds per item overall. This research introduces an innovative waste management system that reduces manual sorting requirements, demonstrates the viability of sound-based separation, and provides a scalable solution for diverse environments. As the SASB is compact and energy-efficient, it is suitable for installation in homes, offices, and public spaces, with much potential to streamline recycling habits and augment sustainability efforts.

1. Introduction

As cities grow, waste generation increases, creating major challenges for waste management [1]. It is not just about maintaining cleanliness; waste management impacts daily life and puts significant pressure on local resources. Landfills are filling up fast, making it harder to handle the growing volume of trash [2]. Inconsistent waste-disposal practices, such as illegal dumping and poor recycling, only make the situation worse. These issues not only make the neighbourhoods look unattractive but also result in expensive cleanup efforts for local governments. Many cities still rely heavily on landfills because maintaining the entire waste management system to cope with the increasing waste is both difficult and costly [3]. The growing amount of waste produced by city residents is becoming a major problem for waste disposal systems, leading to pollution and significantly contributing to the greenhouse effect [4]. As landfills fill up and reach their maximum capacity, they can release harmful gases such as methane, which accelerate climate change by releasing toxins into the environment and increasing the carbon footprint of waste management [5].

This situation not only threatens ecosystems but also raises serious concerns about public health. It is a pressing issue that affects everyone and demands urgent attention. This study focuses on developing a smart bin that uses sound-based classification to automatically sort waste. The system is designed to identify three main types of materials which are plastics, metal and paper by analysing the unique sound it produces when they hit the bin. These materials were chosen because this study are common in daily waste and have high recycling potential. By incorporating advanced sound recognition technology, the system aims to improve sorting accuracy, minimize contamination in recycling streams and support more efficient waste management practices [6]. The SASB is an innovatively created bin specifically to enhance the sorting of recyclables. This bin uses sound recognition technology to deliver audible cues to help users recognize and properly sort recyclables, ensuring the materials are well organized for processing. Because the bin focuses only on recyclables, it helps maintain the integrity and quality of the materials, thereby increasing their potential for reuse. This auditory guidance not only attracts users but also develops the habit of recycling and increases awareness, ultimately improving the effectiveness of the recycling system.

The studies also focused on optimizing the system's performance through testing in real-world scenarios. The prototype was developed in a controlled environment, allowing for precise monitoring of its classification accuracy. The system was tested with real waste items to evaluate how well it identified and sorted materials based on their impact sounds. Factors like background noise, overlapping audio signals and techniques applied to enhance classification reliability [7]. Additionally, system efficiency was assessed by measuring processing time using a stopwatch; the time from waste disposal to successful sorting was recorded across multiple trials to establish an average processing time and identify areas for improvement. These tests provided valuable insights into the system's accuracy, speed and overall functionality. By fine-tuning the classification algorithm and optimizing hardware integration, this study aimed to improve waste sorting precision and enhance the efficiency of automated recycling, contributing to more effective and sustainable waste management practices [6].

Table 1 provides an overview of the various smart bin technologies developed in previous studies. These technologies employ a range of components, including IoT sensors, wireless communication networks, machine learning algorithms, and image or audio processing systems. All the methodologies differ in terms of characteristics depending on the system purpose such as to measure waste volume, operate collection management, sort wisely or notify the concerned authorities. Apart from their benefits, each of these systems also has demerits like high energy usage, integration complexity and reliance on stable network infrastructure. The table also includes the ongoing work, which proposes a novel approach based on sound recognition and audio classification using artificial intelligence for intelligent waste sorting.

Table 1 *Comparative overview of smart bin technologies*

Technologies	Key Features	Technological Components	Applications	Challenges
IoT-based Smart Waste Management [8]	Utilizes sensor nodes for remote bin monitoring, measuring weight and waste level. Target overflowing bins	Sensors (weight, height), LoRaWAN, IoT Network	Smart Cities, Waste Monitoring	Energy optimization issues; focus on overflow detection
IoT and ML-based SMW [9]	Uses IoT, machine learning, and graph theory for efficient waste management. Predicts garbage levels in bins.	LoRaWAN, IoT devices, Machine Learning algorithms (e.g., Logistic Regression, SVM, Random Forest)	Waste Management Prediction, Waste Collection Optimization	Feasibility tests required for practical deployment; complex setup
AI and Image Processing [10]	Applies deep learning (CNN, ResNet) for waste categorization into biodegradable and non-biodegradable. Uses hybrid pooling and batch normalization for enhanced accuracy	Convolutional Neural Networks (CNN), Deep Neural Networks, Transfer Learning	Waste Segregation, Smart Sorting for Recycling	Requires large datasets for training; high processing power required

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Table 1 *Continued*

Technologies	Key Features	Technological Components	Applications	Challenges
Smart Sensor-based Systems [9]	Leverages IoT sensors, RFID, and LoRaWAN for waste handling automation	IoT sensors, RFID, LoRaWAN, Cloud Computing	Waste Collection, Segregation, and Treatment Automation	Dependence on network stability; integration complexity
IoT-based Household Waste Management [11]	Targets household waste management with IoT solutions. Implements efficient collection and waste value enhancement	IoT Sensors, State-of-the-art Collection Methods	Household Waste Management, Efficient Garbage Collection	Lack of optimization for energy use; reliance on household participation
Android-based IoT Trash Management [12]	Uses an Android app for bin status monitoring, connected to a web server for notifications to city officials.	Arduino UNO, Ultrasonic Sensors, Android App, Web Server	Citywide Waste Monitoring, Urban Garbage Collection Notification	Requires mobile app support; user adoption can be a limiting factor
Wireless Communication for City Waste Collection [13]	Uses wireless communication with location information through GSM for urban waste management.	GSM, Wireless Communication	Urban Waste Collection and Monitoring	Limited to urban applications; dependent on reliable network coverage
IoT-based Garbage Monitoring [14]	Focuses on monitoring the garbage levels and notifying authorities for timely waste collection.	IoT Sensors, Notification System	Urban Waste Management, Notification-based Collection	Dependence on network infrastructure; low energy solutions needed for scalability.
Sound Activated Sorting Bin (Present Study	Uses AI audio classification to identify and classify different types of waste based on sound recognition.	AI algorithms, Audio Sensors, Microphones, Machine Learning, Sound Processing Algorithm	Efficient Recycling Sorting, Smart Waste Management	Requires accurate sound data training; limited to specific waste types; environmental factors impact accuracy.

2. Materials and Methods

The study was carried out according to the flow chart in Fig. 1. The procedure followed during this study is indicated in the diagram. The research methodology plays a vital role in achieving the study's objectives as outlines the methods, processes, and techniques applied throughout the project. It involves a systematic approach to designing, developing, and evaluating the system based on relevant criteria. This section describes the overall research process, including the planning, construction, and testing phases, to ensure the reliability and effectiveness of the outcome.

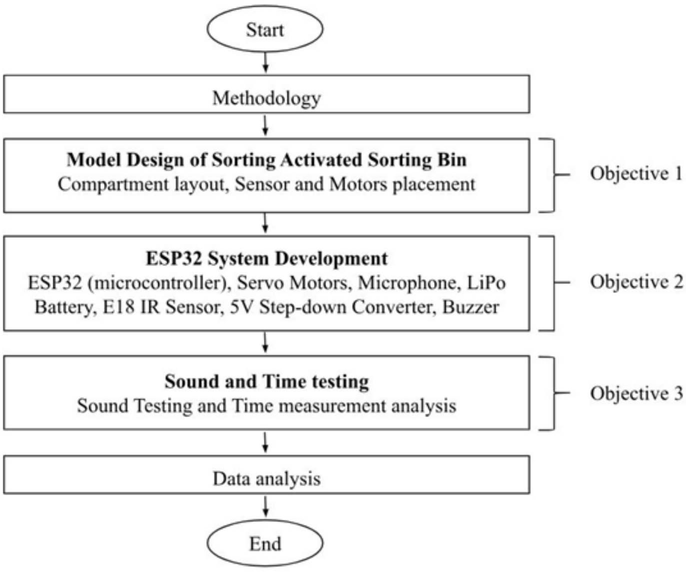

Fig. 1 *Flowchart of the study*

2.1 Materials

Various components such as ESP32, servo motors, E18 IR Sensor, 5V Step Down Converter, Microphone, Buzzer and a LiPo 11.1V battery were utilized in the development of the Sound Activated Sorting Bin (SASB). The system integrates sound recognition technology with mechanical automation to enable accurate, hands-free waste classification. Table 2 presents the materials and their perspective functions in the SASB project.

Table 2 *Materials and functions of Sound Activated Sorting Bin*

Material	Function
ESP32	Acts as the main controller that processes sensor input and controls servo motors waste sorting based on sound.
Server Motor MG995	Operates smaller mechanical movements like opening flaps or lids for guided waste entry.
Server Motor 25kg	Rotates the main sorting mechanism to align with the correct waste compartment.
Microphone	Detects voice commands or sound signals to identify the type of waste being disposed.
LiPo 11.1V Battery	Supplies portable power to the ESP32, sensors, and motors for continuous operation.
E18 IR Sensor	Detects presence of an object by emitting an infrared beam and detecting its reflection.
Aluminium Profile	Forms the sturdy structural frame of the bin, supporting all components securely.
5V Step Down Converter	Takes the high voltage from the LiPo battery and steps down to a safe 5V for other components.
Buzzer	Produces sound when triggered by ESP32 as a confirmation by producing audio feedback.

In conclusion, the Sound Activated Sorting Bin (SASB) combines electronic controls, structural materials, and sensor technology to achieve efficient and automated waste classification. The ESP32, in conjunction with voice recognition and servo motors, enables real-time sorting without manual intervention. Transparent and modular structural elements, such as acrylic and aluminum, contribute to user-friendly design and ease of maintenance. Together, these components form a smart, eco-friendly solution for modern waste management.

2.2 Methods

This section explains how the Sound Activated Sorting Bin (SASB) was designed, built, and tested. It includes the steps taken to assemble the hardware, set up the sensors, programming code, and carry out the trials used to measure how well the system performs in sorting waste based on sound.

2.2.1 Model Design of Sound Activated Sorting Bin (SASB)

The automated sorting bin has been highly designed to combine functionality with aesthetics in support of advanced waste classification. The structure consists of a robust metallic frame, transparent collection chambers, and a central AI processing unit. The frame was made up of durable metallic beams arranged in a rectangular layout. A solid vertical black cylinder was positioned at the top section of the bin to guide items and act as a barrier, minimizing external interference and environmental noise that could affect the accuracy of the data. A cylindrical bin divided into three compartments is attached inside the frame and made of semi-transparent material to allow easy monitoring of the levels of waste.

At the centre of the design beside the cylinder is a controller box representing the core mechanism of AI classification. The controller box contained a microcontroller, a power component, and also advanced sensors and algorithms, which guide waste into the appropriate bin according to AI classification. This bin has a compact size and modular design, therefore making it suitable for urban areas and also easy to assemble, disassemble, and transport. Table 3 outlines the functions of each major component of the Sound Activated Sorting Bin design. Overall, this design enhances environmental sustainability by embedding AI into automated waste sorting, drastically reducing human error and improving recycling efficiency while supporting eco-friendly waste management practices. Fig. 2 shows the 3D model of the automated sorting bin, created in AutoCAD.

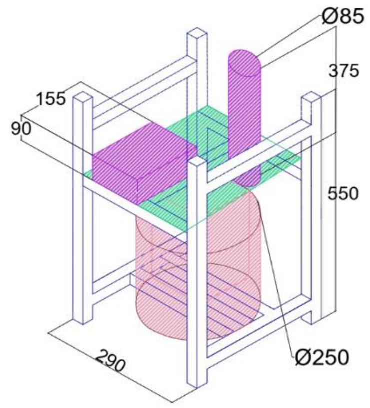

Fig. 2 *Structure design of the Sound Activated Sorting Bin*

Table 3 *Component functions of the Sound Activated Sorting Bin*

Component	Description	Function
Vertical Small Cylinder	Solid black tube at the top section with diameter of 85mm and height of 375mm	Guides waste items and minimize external noise interference
Controller Box	Rectangular box beside small cylinder at the top section with 155mm in length and 90mm in height	Houses the microcontroller and power components
Frame Structure	Rectangular structure with 550mm in height and 290mm in width	Provides structural support and houses all internal components
Large Cylinder	Diameter of 250mm, vertical integrated within the frame structure divided into three compartments	The waste container for sorted item
Middle Green Frame	Horizontal rectangular platform connecting all four vertical beams	Houses the trap door mechanism that open to allow sorted waste to fall into the appropriate compartment

2.2.2 ESP32 System Development

The Sound Automated Sorting Bin uses the ESP32 microcontroller as its control unit to manage all the operations. It receives input from a microphone and an E18 IR sensor to detect sound signals and the presence of an object. After receiving confirmation of both inputs, the ESP32 sends control signals to two servo motors. The first one to open the lid of the bin and another to tilt the bin for sorting. A buzzer provides audible feedback, letting the user know that an action has been performed. This arrangement allows the system to perform sorting actions based on sensor input in a timely and coordinated way.

The entire system is powered by an 11.1V LiPo battery, decreased to 5V through a voltage converter for safely powering the ESP32 and accessories. Power flow is regulated through a manual switch, offering ease of operation.

The ESP32 is utilized for different purposes in the project, ranging from sensing and sound input processing, mechanical movement control, user feedback management and controlled power consumption. Its real time response capability, low power consumption and versatility qualify it for such an automated sorting tool.

2.2.3 Sound and Time Testing

To stimulate real-world conditions, real-time waste sound was used during testing in a controlled noise-free environment to guarantee consistency. The system detected and analyzed impact sounds as waste is discarded into the SASB, classifying and responding in real-time. Testing recorded system responses to evaluate accuracy, respond time, and error causes. The system's ability to handle simultaneous waste disposal was also tested. Data from sound testing guided refinements to improve performance and reliability. Misclassification or delays were analyzed to adjust algorithms or sensors. The sorting error rate will serve as a key metric for performance evaluation and is calculated using the formula; number of unsuccessful attempts divided by total attempts, multiplied by one hundred (Eq. 1). Sound testing was conducted to confirm SASB's ability to function accurately and efficiently in real-world conditions, reducing sorting errors and supporting sustainable waste management.
Processing time was measured using a stopwatch, tracking from when an item drops until it settled in the correct compartment. This method recorded data on speed and precision to assess performance and efficiency. The process will be repeated at three times to ensure reliability and detect inconsistencies. A stopwatch provided a proper and straightforward method to measure time processing in an automated sorting bin. Average processing time was calculated to assess efficiency, highlight inconsistencies, and determine where improvements were needed. The average processing time was calculated by dividing the sum of the processing times by the number of trials (Eq. 2).

$$Sorting\ Error\ Rate\ (\%) = \frac{(Number\ of\ incorrect\ Sorts)}{(Total\ Number\ of\ Tests)} \times 100 \tag{1}$$

$$Average\ Processing\ Time = \frac{Number\ of\ Trial}{Sum\ of\ Processing\ Time} \tag{2}$$

3. Results and Analysis

This section presents the technical outcomes of the SASB system after full assembly and testing. It highlights how well the system performed in real-time sorting tasks based on sound input, as well as its error rates and component functionality.

3.1 Results

The Sound Activated Sorting Bin (SASB) model as illustrated in Fig. 3 includes an ESP32 microcontroller powered by 11.1V 5000 mAh LiPo battery with a step-down converter to regulate the voltage to 5V. The system featured an E18 IR sensor to detect object presence and uses two servo motors to control the opening and sorting mechanism of the bin. A microphone module is integrated for sound detection, enabling sound-activation response, while a buzzer provides audio feedback. A main power is included to control the system's power flow.

Fig. 3 *The Sound Activated Sorting Bin Model*

3.2 Analysis of Sound Testing and Time Measurement

The testing procedure was conducted over three sessions, with each trial consisting of 100 sorting attempts using a combination of plastic, paper, and metal waste. Each trial was conducted in a controlled indoor environment to minimize background noise and ensure consistent sound detection. The error rates for each trial are presented in Fig. 4, which clearly illustrate the results of three separate trials conducted to test the system's classification accuracy. Trials 1, 2, and 3 correspond to points 1,2 and 3, respectively, on the x-axis. The y-axis indicates the error rate percentage for each trial. The classification error analysis across three trials, as shown in Figure 4, reveals a decreasing trend in error rates from 29% in Trial 1 to 25% in Trial 2 and 21% in Trial 3, resulting in an average error rate of 25%. The high initial error rate suggests early-stage limitations in system calibration or inconsistent acoustic responses from the materials. Improvements in later trials may indicate sensor performance stabilization, improved environmental conditions, or greater operator consistency. Despite achieving an average success rate of 75%, the system's performance remains below practical expectations for autonomous waste-sorting applications, where accuracy is critical. The findings highlight the need for enhanced signal processing, noise filtering, and, if feasible, the integration of auxiliary sensors to reduce misclassification and improve sorting reliability.

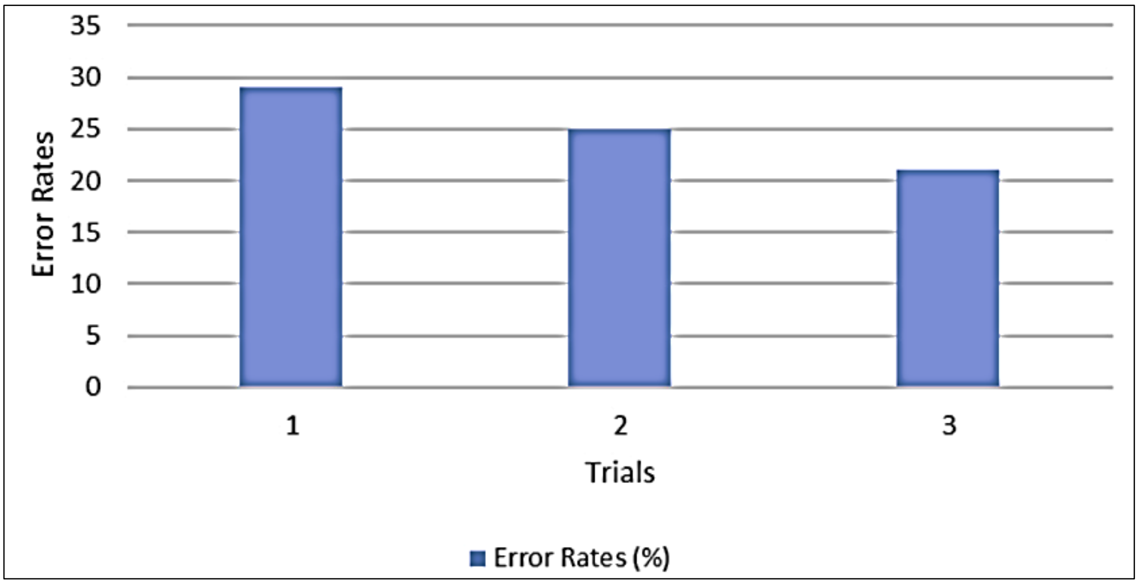

Fig. 4 *Analysis of sound testing*

The graph effectively highlights the variation in error rates across trials, although all error rates remained below the 30% threshold. Notably, achieving an overall success rate of 75% demonstrates that the system is already capable of correctly sorting a significant majority of materials, reflecting a promising level of functionality and effectiveness in sound-based classification and indicating fast, responsive operation. To assess the sorting bin model's efficiency, three trials were conducted. In each trial, the time required for the system to identify and classify the waste item from the point of insertion to successful or unsuccessful sorting was recorded. The result is summarized in Table 4 (see Appendix A) and was analysed to determine the average processing time. These results show that while the Smart Bin generally performs consistently, some variation can occur between trials. Trial 1 recorded the slowest processing time (0.51s), possibly due to differences in sound signal clarity or background noise during classification, whereas Trials 2 and 3 were faster with an average processing time of 0.41s each. It can be concluded that Trial 2 and 3 demonstrated the highest efficiency whereas Trial 1 showed the slowest processing time. This suggest that the product generally performs efficiently but may benefit from further refinement to minimise variability and ensure consistent operation across trials.

4. Conclusion

In conclusion, the Sound Activated Sorting Bin (SASB) project was initiated in response to the increasing difficulties in contemporary waste management, specifically the enduring problems of inappropriate waste disposal, recyclable contamination and excessive dependence on landfills. By designing and implementing an intelligent, automated waste-sorting system that uses sound-based classification, this study sought to address these issues. Moreover, based on the distinct audio signatures produced upon impact with the bin, the SASB successfully demonstrated its ability to recognize and classify three common recyclable materials: paper, plastic, and metal. The ESP32 microcontroller technology served as the foundation for the system, which integrates servos, buzzers, IR sensors, and microphones to enable responsive waste sorting and real-time data processing. The system demonstrated improvement in classification performance throughout testing. It showed the capability to correctly identify and sort waste materials. All in all, this project achieved its objectives by producing a useful and effective prototype that uses audio classification to automate waste sorting. The system can perform real-time or near-real-time sorting, meeting practical operational requirements. To promote sustainable environmental practices, SASB offers a promising platform for the future development of more intelligent, scalable waste management systems that could be integrated into both residential and public infrastructure.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design, data collection, analysis and interpretation of results, and draft manuscript preparation:*** *Muhamad Akmal Hakimi Azhar, Nur Syazwani Nabila Mohd Sulaiman, Nur Saidatul Zalikha Mohamad Isa, Siti Nooraiin Mohd Razali and Nor Baizura Hamid. All authors reviewed the results and approved the final version of the manuscript.*

Appendix A

Table 4 *Processing time result*

Trial	Number of trials	Sum of processing time (s)	Average processing time (trials/seconds)
1	100	193.60	0.52
2	100	243.95	0.41
3	100	242.48	0.41

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