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Design, Development, and Evaluation of Automatic Waste Segregation with Machine Learning of Aparri Public Market

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ABSTRACT
Waste management is an issue in public markets and needs creative segregation and disposal measures. In this study, the design, implementation, and acceptability of a machine learning and sensor technology-powered Automatic Waste Segregator (AWS) system were explored. A descriptive-evaluative design was utilized through questionnaires adapted from ISO 25010:2011 Software Quality Standards and an extended Technology Acceptance Model (TAM). Participants were 30 vendors, 100 consumers and 10 IT experts chosen through purposive sampling.

Results reflected very high to high ratings for all ISO 25010 quality attributes, with especially good scores in functional suitability, reliability, performance efficiency, and usability. IT professionals confirmed system performance while suggesting improvements in environmental adaptability and maintenance. TAM measures also reflected strong acceptance, particularly in Performance Expectancy, Perceived Ease of Use, and Behavioral Intention.

Keywords: Automatic Waste Segregator, Waste Management, Machine Learning, Environmental Sustainability, Technology Acceptance Model

Introduction

With the fast pace of urbanization and rising population, municipalities like Aparri are in growing need of more efficient ways to deal with waste. Segregating waste traditionally is time-consuming, manpower-intensive, and also prone to human error, and this leads to contamination and increased costs for disposal. And so the segregation of trash necessitates more intelligent and sustainable approaches to managing it.

One potential solution is the implementation of an Automatic Waste Segregation (AWS) system based on machine learning and intelligent sensors that can sort waste more quickly and accurately. These systems can identify materials at the source as recyclable, making the process more efficient and lighter for landfills.

In Aparri, where infrastructure is under development and resources are scarce, there is increasingly a drive towards technologies that are environmentally sound and yet practical and affordable. Yet much of the research is concentrated in major cities and does not take cognizance of the ways in which things work in small communities, where public engagement, local systems, and cultural attitudes determine whether a new technology will be successful or not.

Companies like ZenRobotics and CleanRobotics have already demonstrated the capability of artificial intelligence in enhancing recycling rates and efficiency. Yet incorporating such developments in smaller towns entails looking more intently into town-specific needs, training capacity, and extensive maintenance.

Objectives of the Study

This study aimed to fill that gap by not only evaluating the technical viability of an AWS system but also considering how it fit into the daily realities of municipal garbage management. Beyond being a technical solution, this approach aimed to empower local

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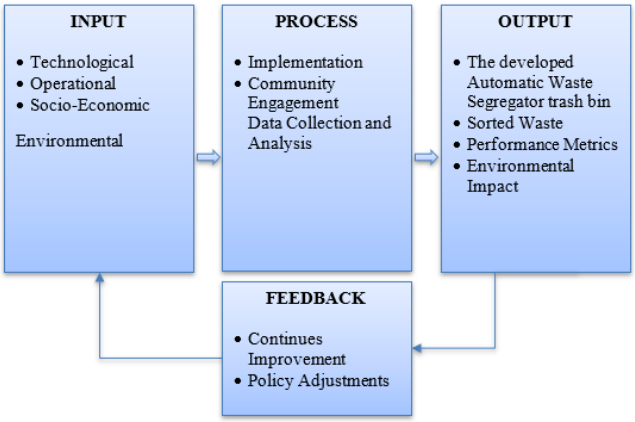
government with solutions that were smart, green, and responsive to the people and systems they were meant to serve.

Conceptual Framework of the Study

Development initiation of the Automatic Waste Segregator (AWS) system is carried out through an integrated process starting from technological innovations in differential inputs in the form of sensors and machine learning, operational logistics for implementation within existing waste management, socio-economic considerations in the form of public acceptance and stakeholders' preparedness, and environmental considerations for sustainability.

Figure 1. Paradigm



The process stage involves deployment of the system in public markets, ongoing community interaction in a bid to establish cooperation, and extensive data collection using ISO 25010:2011 and TAM models to evaluate both technical performance and users' acceptance. The results consist of the functional AWS trash bins, effective waste sorting, confirmed performance metrics, and measurable environmental benefits, all serving to justify the success of the system. Importantly, a feedback system allows for ongoing enhancement and policy development, ensuring the AWS dynamically adjusts to changing requirements and maximizes its influence with the passage of time.

The automatic waste segregation trash bin designed for Aparri Public Market improved waste management efficiency, reduced environmental harm, and raised community awareness about proper waste disposal. Its automation allowed the Local Government Unit (LGU) to enhance operational efficiency, reduce labor costs, and better comply with environmental regulations. Once implemented, was a regional model, which sustained and enhanced recycling rates that served the community. To researchers, data gathered offered insights on waste trends and behavior change, while technology breakthroughs in sensors and machine learning were highly promising for future improvements. Future researches applied these innovations to schools, which promoted environmental stewardship and enhanced participation in waste segregation.

Scope and Limitations

This research set the design and development of Automatic Waste Segregation Trash-bin with Machine Learning for Aparri Public Market. The AWSTB was designed to bring a solution for the proper segregation and disposal of wastes at the very beginning. The system-device has no web-based software to be publish either IoT technology. The system-device is stand alone because it only automates the daily task in segregation in major waste categories. IT experts evaluated the AWSTB according to ISO 25010 standards, while the end users or waste management personnel, LGU administrators and the community underwent user testing and provided feedback. The study acknowledged limitations such as developing a software connected to the device-system or a GPS tracking location point.

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The system-device was specifically designed for experimentation and implementation in Aparri Public Market and did not involve other external utilization and integration with other institutions although this project has a huge potential as a solution to the environmental compliance. The project required an extensible budget, planning and feasibility studies in different establishments and industries because this changes the waste produced by the people in the market and the like.

This highlighted the range and limitation of the Automated Waste Segregation Trash-bin with Machine Learning. Knowing these aspects, the research thus aimed to provide an effective solution to waste segregation in the Aparri Public Market.

Methodology

Designing an Automatic Waste Segregation Trash-bin using Agile Development Model and System Development Life Cycle was characterized by a formal approach to design, develop, and testing. The Agile Development Model facilitated flexibility and adaptability to change, with the ability to make iterative modifications along the way.

The Automatic Waste Segregation Trash-bin was designed to sort waste into a number of categories, such as recyclables, organics, and non-recyclables, using smart sensors and machine learning algorithms. The system was integrated with a friendly user trash bin frame, allowing easy dumping of waste.

The System Development Life Cycle governed the development process with a broad framework that has stages like planning, systems analysis and requirements, systems design, development, integration and testing, implementation, and operations and maintenance. The Agile model was applied to allow iterative development; thus, the system accommodated changing user needs and expectations.

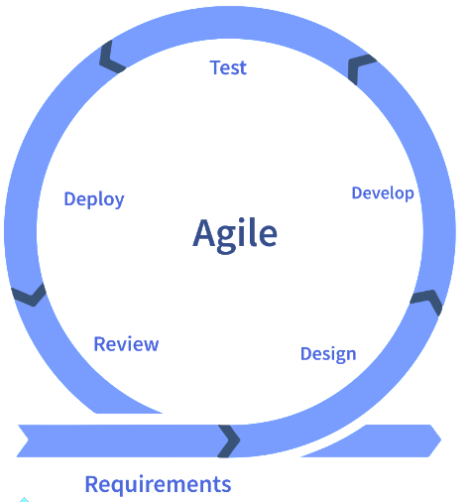

Figure 2. Agile Methodology

Automatic Waste Segregation Trash-bin was equipped with highly advanced waste sensing and alert system with its light indicator. The system can reduce the waste sent to the landfills, decrease greenhouse gas emissions, and encourage sustainable waste management in Aparri Public Market. Creating this innovative system would help achieve a healthier and cleaner environment for the future.

System Device Architecture

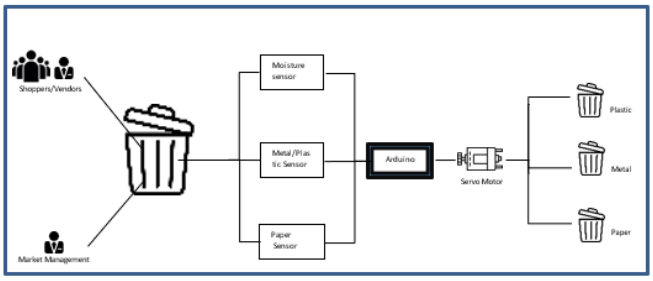

Figure 3. Agile Methodology

The design of the Automatic Waste Segregator, as depicted in Figure 3, was particularly intended to effectively manage waste segregation at the Aparri Public Market, to suit a wide number of users such as market vendors, consumers, and market administrators. At the heart of the Automatic Waste Segregator Trash bin system is a user-friendly interface by which vendors and consumers can interact with the system. Further, a separate admin panel enabled maintenance personnel to track system performance and make adjustments when necessary.

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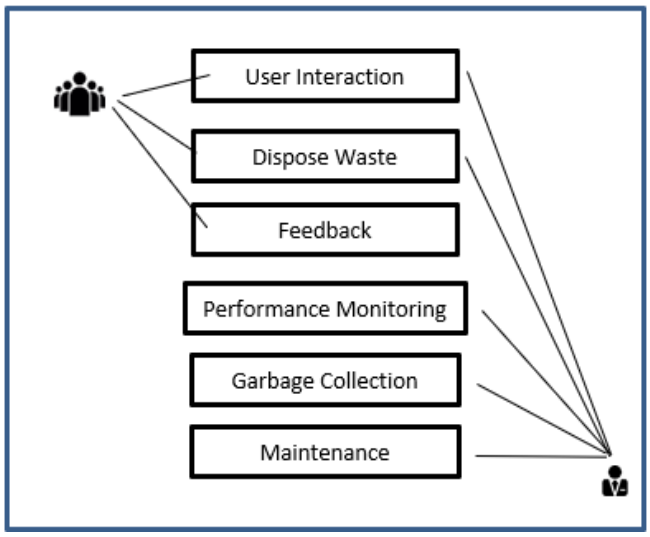
The module for waste detection used ultrasonic sensors to detect and sort out different forms of waste produced within the market. The sorting process then sorts out the waste and channels it into appropriate bins in accordance with its type. Hardware used comprise the sensors, actuators that manually sort the waste, and a control unit responsible for orchestrating the whole process, which effectively and efficiently sorts out the waste within the Aparri Public Market.

Use Case Diagram

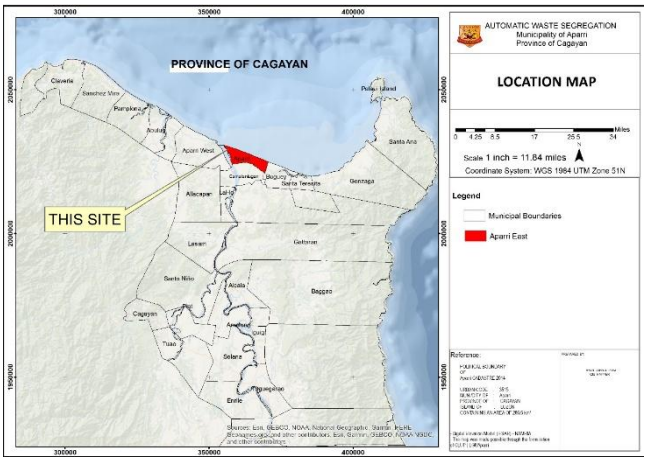
Figure 4. Use Case Diagram of the System



The Automatic Waste Segregator system improved waste management overall by incorporating a wide range of features aimed at users and system administrators. Shoppers and vendors as users were provided with an easy-to-use interface, provides a view of the sorting status at the time, and allows the feedback to help improve operations. The system also provided an educational advantage through improved awareness about proper waste sorting procedures. For market administrators, the system, however, provided an advantage through the performance monitoring feature, which allowed them to measure the effectiveness of operations and adjust settings based on particular requirements. In total, the system was designed to assist users in proper waste disposal while equipping administrators with monitoring and optimizing system performance features.

Locale of the Study

Figure 5. Location Map of Municipality of Aparri



The Aparri Public Market in the province of Cagayan, being a vibrant economic center, is a generator of intensive waste brought about by high daily activity of residents, traders, and tourists. It was thus selected as the best location to pilot-test the efficiency of the Automatic Waste Segregator (AWS). The research wanted to solve the poor practice of waste management such as lack of segregation and low recycling rates jeopardizing public health and environmental sustainability.

Participants of the Study

Table 1. Participants of the Study

Participants	Frequency (n)
Market Vendors	30
Customers/Market shoppers	100
Market Management	2
Local Government Officials	5
IT Expert	10
Estimate Total	147

Market vendors were purposively chosen as primary waste generators to provide relevant insights in waste types and segregation issues. They were given training, utilized the Automatic Waste Segregator, and offered feedback on usability and their waste disposal experiences. Regular market visitors or as shoppers were also recruited to pick up regular user interactions with the system through surveys and interviews. Market administrator, is selected to oversee implementation, training, and monitoring. Their feedback assisted in measuring effectiveness and determining areas for improvement. Local government

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representatives were consulted for their regulatory background, assisting in matching the project with policies and increasing public awareness. IT professionals, selected based on their technical expertise, oversaw system implementation, troubleshooting, and data monitoring in order to maximize performance.

Summary of Findings

The Current conditions of waste segregation and disposal in Aparri Public Market

Solid waste disposal in Aparri Public Market remains mostly manual and laxly implemented. Although the local government has a scheduled frequency of wastes picked up, this is not sufficient to address the more significant problems of segregation and disposal of wastes.

Most critical is the absence of properly labeled waste bins. The observations showed that most of the bins do not have signage or proper classification, causing constant contamination of biodegradable with non-biodegradable waste. In most parts of the market, there is an average of one bin per area, to which all sorts of waste are disposed of indiscriminately. This situation not only defeats segregation efforts but also limits the potential for recycling and proper waste treatment.

There is currently no Waste Analysis and Characterization Study (WACS) conducted to support the development of a long-term solid waste management plan. The absence of such data restricts informed policy-making and the implementation of targeted interventions.

Additional challenges include: Low awareness and participation from vendors and shoppers in proper waste practices. Limited infrastructure, with insufficient bin quantity and instructional materials. Manual waste sorting, which is labor-intensive and vulnerable to human error.

These conditions strongly indicate the need for an automated waste segregation system to promote compliance, enhance efficiency, and support the Municipality of Aparri's transition to a more sustainable and modern waste management framework.

The Current conditions of waste segregation and disposal in Aparri Public Market

Waste in the Aparri Public Market is now collected indiscriminately biodegradable, non-biodegradable, and recyclable waste all go into one container and are hauled by a single dump truck. Not only does this disorganized practice hinder effective recycling and composting, but it also leads to ecological contamination, pungent smells, and health hazards for vendors and the public at large. Even after successive cleanup operations, the underlying causes poverty of information, insufficient infrastructures, and lax implementation of segregation rules are still not being attended to. (See appendices page 84-86).

Manual sorting of waste is rarely done because of its tediousness and lack of relevant tools or systems to aid it. Therefore, waste management at the marketplace continues to be inefficient, unhygienic, and unsustainable.

For a relief from all these problems, this study proposed a twofold solution:

1. The design and creation of an Automatic Waste Segregator Trash Bin utilizing sensor-based technology with machine learning used for waste segregation placed in-front of stalls and in any garbage pickup points with decreased dependence on labor.
2. The planning of a programmed waste collection system wherein each type of waste (recyclable, biodegradable, non-biodegradable) is kept separate and collected separately following a set routine. It continues to segregate waste from its very first collection phase itself, which supports a cleaner, efficient, and eco-friendly waste disposal system.

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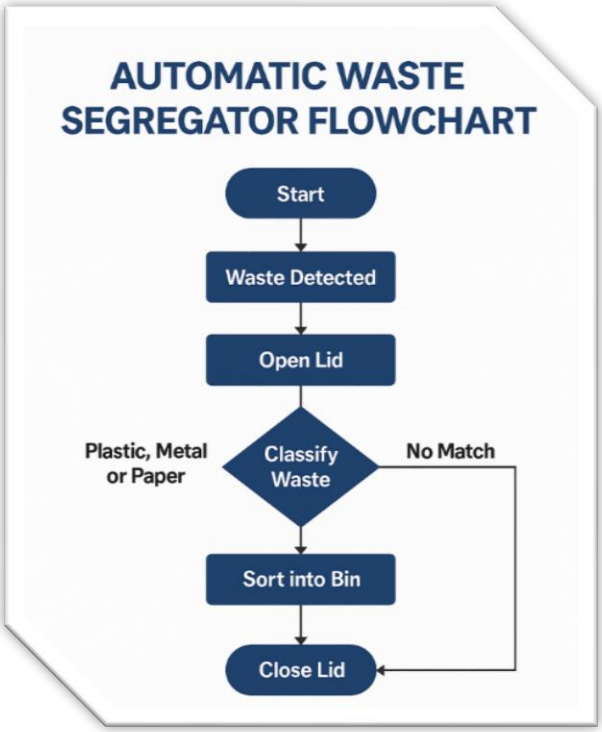
The Design of Automatic Waste Segregator with Machine Learning

Figure 6. Flow Chart



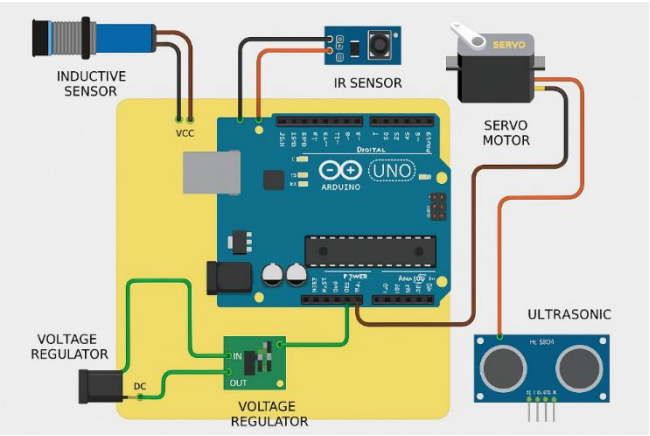
The Automatic Waste Segregator system follows a structured process that enables efficient sorting of waste materials using sensor-based technology. The flowchart illustrates the step-by-step logic used in the device, ensuring automated classification and disposal of waste. The entire process is outlined as follows:

1. The system starts when powered on or when the lid is triggered by an input mechanism.
2. A user then inserts waste into the input slot of the device.
3. Once the waste is inside, the system proceeds to detect the type of material using a set of sensors:
    a. An inductive sensor detects metallic waste by responding to its magnetic properties.
    b. An infrared (IR) sensor helps identify plastic or paper based on the reflectivity and surface characteristics of the material.
4. After detection, the waste is classified into a specific category:
    a. If metal is detected, the waste is directed to the Metal Bin.
    b. If plastic is detected, it is directed to the Plastic Bin.
    c. If paper is detected, it is directed to the Paper Bin.
    d. If no material is recognized, it is considered General Waste, which may be manually handled or directed to a separate bin.
5. The system then activates a servo motor mechanism that moves a diverter or arm to guide the waste into the correct bin based on its classification.
6. Once sorted, the waste falls into the corresponding compartment, completing the segregation process.
7. The system then resets and returns to standby, ready to process the next waste item.
8. Additionally, a three-day collection schedule is proposed to align with the segregation process:
    a. Day 1: Collection of plastic waste
    b. Day 2: Collection of paper waste
    c. Day 3: Collection of metal waste

This flow ensures that waste is automatically sorted with minimal human intervention, improving both efficiency and environmental compliance in public settings like the Aparri Public Market.

Circuit Design and Parts/Functions

Figure 7. Circuit Design



1. Arduino Microcontroller (Uno/Nano)

Acts as the brain of the system.

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a) Reads inputs from the IR and inductive sensors.
b) Makes a decision about the type of material (metal, plastic, paper).
c) Sends commands to the servo motor to mechanically sort the waste.
d) If used, it also monitors the ultrasonic sensor for detecting inserted waste.

2. Sensors

a) Inductive Sensor (Metal Detection)
b) Works on electromagnetic induction.
c) When a metal object is nearby, the inductive sensor detects it and outputs a HIGH signal.
d) Connected to one of Arduino's digital pins.
e) If metal is detected, the waste is routed to the Metal Bin.
f) IR Sensor (Plastic vs. Paper Detection)
g) Uses infrared light to determine the reflectivity of materials.
h) Paper and plastic reflect light differently—this allows the sensor to distinguish them.
i) Typically connected to either an analog pin (to measure reflectivity level) or a digital pin (if the sensor module has a comparator).
j) If plastic is detected, the waste is sent to the Plastic Bin; if not, it's assumed to be Paper.

3. Servo Motor

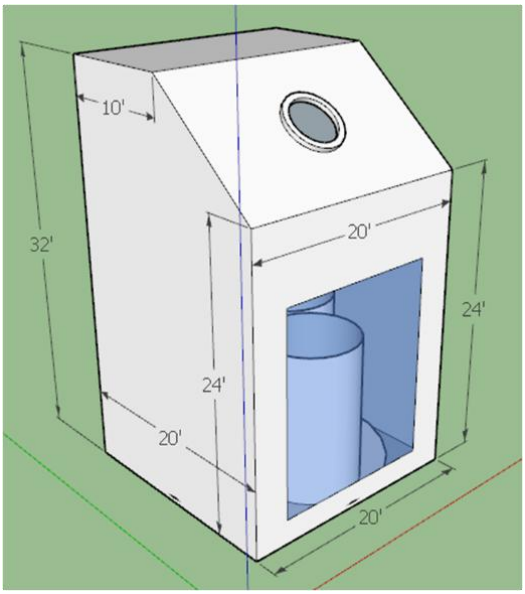
a) Rotates between three or four fixed angles:
b) One for metal
c) One for plastic
d) One for paper
e) Controlled by a PWM signal from the Arduino.
f) The diverter or flap physically guides the waste into the correct compartment.

4. Power Supply

a. The entire system needs stable power to operate:
b. Arduino and IR sensors operate at 5V.
c. Inductive sensors may require 12V, so a voltage regulator or level shifter is needed.
d. Servo motors need a separate 5V-6V power source to avoid drawing too much current from the Arduino.
e. All components must share a common ground to avoid erratic behavior.

The develop Automatic Waste Segregator Trash-bin with Machine Learning Power Suppl

Figure 8. 3D Model



The figure 8 shows the precise measurements of the unit. The overall height of the unit is 32 inches, with depth and width both 20 inches, and the sloping section is 10 inches from the top. These measurements confirm that the unit is compact but large enough to hold its internal components.

The solution of the issue of improper waste segregation in the Aparri Public Market, the researcher developed an Automatic Waste Segregator (AWS) using machine learning.

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Waste was typically collected indiscriminately and dumped into a single truck, leading to environmental risks and inefficient disposal. The AWS was designed to automatically classify common waste types—paper, plastic, and metal—at the point of disposal using a combination of sensors and a lightweight machine learning model. An inductive sensor detects metal, while an infrared sensor distinguishes paper from plastic. The system, built on an Arduino platform, uses decision trees or TensorFlow Lite models optimized for real-time, low-power processing without internet connectivity. A servo motor then directs each waste item into its appropriate bin. The device features a simple interface requiring minimal user interaction, making it accessible for vendors and shoppers. This low-cost, smart solution promotes proper waste disposal, reduces the need for manual sorting.

Evaluation of the Extent of Compliance Using ISO 25010:11 Software Quality Standards

ISO 25010 Quality Attribute	Vendor Mean	Vendor VI (30)	Shopper Mean	Shopper VI (100)
Functional Suitability	3.97	High Extent	4.17	High Extent
Reliability	4.75	Very High Extent	4.53	Very High Extent
Performance Efficiency	4.0	High Extent	4.6	Very High Extent
Usability	4.43	High Extent	3.98	High Extent
Security	4.58	Very High Extent	4.25	High Extent
Compatibility	3.93	High Extent	4.43	High Extent
Maintainability	4.75	Very High Extent	3.98	High Extent

Table 2. ISO 25010 Quality Attribute by shoppers and Vendors

Based on the ISO 25010 evaluation, shoppers rated Reliability as the highest quality attribute of the Automatic Waste Segregator system, with a mean score of 4.53 and a verbal interpretation of "Very High Extent." This indicates that users found the system stable, dependable, and consistently functional in real-world market conditions.

The highest level in Reliability indicates the excellent performance of the system in providing reliable and consistent functionality even when used by non-experts. This makes it comfortable with consumers and reflects that the AWS performed to its intended configuration successfully without repeated glitches or breakdowns.

The lowest-rated attribute was Maintainability, which had a mean rating of 3.98 and possessed a "High Extent" interpretation. Though the rating remains positive, it shows a relatively lower level of perceived maintainability or repairability of the system. This can be explained by the low technical interaction and lack of visible maintenance activities of the shoppers, which can affect their information and confidence in the long-term operability of the system.

Evaluation of the Automatic Waste Segregator based on the ISO 25010:11 Software Quality Standards

ISO 25010 Quality Attribute	Mean	Verbal Interpretation (VI)
Functional Suitability	4.00	High Extent
Reliability	4.60	Very High Extent
Performance Efficiency	3.60	High Extent
Usability / Maintainability	3.70	High Extent
Security	3.60	High Extent
Compatibility	3.90	High Extent
Maintainability (Additional)	3.80	High Extent

Table 3. Software Quality Attributes by IT Experts

Based on the ISO 25010 quality attribute assessment, the highest-rated attribute was Reliability, with a mean score of 4.60 and a "Very High Extent" interpretation. Meanwhile, Performance Efficiency and Security received

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the lowest mean scores of 3.60, though still interpreted as "High Extent."

The Reliability of the system was highest, and it was ranked to show that the Automatic Waste Segregator (AWS) performed steadily and reliably under actual operating conditions. It reflects a solid and sound system design, which is what is necessary in public spaces with users with different technical skills and where waste input is always unpredictable. Conversely, Performance Efficiency and Security were rated lowest (both at 3.60), suggesting issues with the system's speed of processing and whether or not it has the capability to guard against tampering or misuse. These lower marks could be the result of occasional lags in operation or a lack of apparent safety features, like notification or status displays, that assure users of system integrity.

Sensitivity Test Results

Criteria	Successful Detections (out of 50)	Success Rate
Metal waste detection	49	98%
Plastic waste detection	48	96%
Paper waste detection	47	94%
Correct sorting to respective bin	46	92%
Mixed waste detection and classification	44	88%
Small item detection (e.g., clips, wrappers)	45	90%
Large item detection	50	100%
Near-range object detection	48	96%
Far-range object detection	46	92%
Rejection or misclassification of glass	43	86%

Table 4. Sensitivity Result

The system had high detection and sorting efficiency for the majority of types and situations of wastes. Large item detection attained a 100% success rate, which indicates robust ability in detection and processing of bulky waste items. Metal, plastic, and paper detection were also effective at 98%, 96%, and 94% respectively, reflecting the reliability of the system in differentiating from typical waste materials.

Correct sorting into the respective bins achieved a 92% success rate, which reflects the overall integration of detection and actuation. Near-range (96%) and far-range (92%) object detection results suggest that the sensor system maintains consistent performance at varying distances, essential for real-world variability in waste disposal behavior.

The lowest score was recorded in glass item rejection or misclassification, at 86% success rate. This suggests a need for improvement in the fine-tuning of the model's capacity to recognize glass over other items, perhaps owing to its reflective or glassy nature. Likewise, mixed waste classification (88%) and detection of small items (90%) register slightly poorer performance, perhaps because the materials overlap or the surface features are very small.

I. Conclusion

The Automatic Waste Segregator design, development, and evaluation using machine learning and sensor technology, this research concludes that the existing practices of waste management in the Aparri Public Market show that the dumping of waste is usually done with no segregation, leading to waste management inefficiency and ecological damage. The designed Automatic Waste Segregator successfully identifies and sorts out usual waste categories like plastic, paper, and metal via the use of sensors suited to them (inductive sensor for metal, infrared for plastic/paper).

ISO 25010:2011 software quality standards assessment reported extremely high to high functional suitability, reliability, performance efficiency, usability, security, compatibility, and maintainability. Both shoppers and Vendors deemed the system reliable and convenient. With the Technology Acceptance Model (TAM), the system also achieved high on performance

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expectancy, perceived usefulness, ease of use, and behavioral intention. This indicates positive public acceptance and adoption willingness for the device. The design of the machine fulfills the essential needs of public market waste disposal systems and indicates that automated measures can significantly alleviate manual effort and environmental dirtiness.

II. Recommendations

The researcher suggest that the LGU increase the deployment of the Automated Waste Segregator to wider portions of the Aparri Public Market and surrounding public areas in order to facilitate large-scale performance testing and supply important data for future researchers. In terms of increasing efficiency, the LGU can synchronize the operation of the device with a scheduled waste collection plan—like plastics on Mondays and Fridays and paper on Wednesdays—to avoid congestion at disposal areas.

The improvement of the device through the inclusion of a moisture sensor and a more powerful motor will assist in segregating wet and dry waste more effectively, enhancing recycling and hygiene, and providing future prospects for research into high-tech waste management. I also recommend performing brief training sessions for vendors, market personnel, and the public to secure correct usage and extend the life of the device, supporting both LGU maintenance activities and accurate data gathering. Including the device in the LGU's 10-Year Solid Waste Management Plan would be necessary through proper inclusion to institutionalize computerized waste handling and inform future policy and study deliberations.

Moreover, setting up simple feedback mechanisms will enable the LGU to continuously improve and facilitate researchers in determining areas of further improvement. Lastly, regular coordination with local government units and waste management organizations is required to provide the policies, funding, and infrastructure that will help maintain deployment and foster regular innovation and research.

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