TRASHYBOT: An Intelligent Trash-Picking Robot with Waste Classification

A study presented to the faculty of

School of Engineering, Computer, and Library Studies

Holy Cross College

Sta. Lucia, Sta. Ana, Pampanga

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science in Computer Engineering

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CHAPTER I

INTRODUCTION

Societal life has progressively witnessed the failure of individuals' discipline, expressed in the increasing disrespect for elders, authority, and above all in the environment. Littering has become a major issue, with small pieces of waste being randomly thrown in public places, water bodies, and coastal regions, leading to environmental degradation. This growing problem highlights the need for proper waste management measures to promote environmental responsibility and ensure sustainable practices. Up to 63,700 tons of plastic, or equivalent of more than 10,600 elephants' weight, are dumped into the ocean annually by the Pasig River. (Arcega, 2017)

Littering is also remains one of the most persisting environmental problems in present society. Improper waste disposal on streets, into water streams, or public places creates dangers for human health as well as ecosystems. Awareness campaigns and policies targeted at reducing littering do not seem to help because of the absence of discipline and understanding by individuals. Discarded plastic bottles and paper bags clutter the roadsides everywhere, pointing toward the need to find innovative ways to solve such problems. "The increasing mismanagement of plastic waste has resulted in serious environmental impacts, emphasizing the necessity for better waste collection and classification systems. (Jambeck, et al., 2015)"

Modern technologies have opened doors to more systematic and efficient ways of managing waste. Among these technologies, automation is promising in addressing environmental challenges. Automated systems can streamline the collection and sorting of waste, reduce reliance on human intervention, and significantly improve the efficiency of waste management operations. Robotics stands out as a transformative solution with the potential to redefine how societies approach waste disposal. Our research was conceived as a reaction to the recurrent problems of waste management, specifically the ineffectiveness of waste segregation, collection, and disposal. Conventional waste management processes use manual methods, which are not only time-intensive but also subject to inaccuracies in classifying the wastes. Knowing these setbacks, we aimed to create an intelligent, automated system that would improve the efficiency of waste management systems. This gap led us to conceptualize TrashyBot; a smart, AI-based waste collection and segregation system that employs image processing for precise classification.

TrashyBot works through a blend of AI-powered image processing, sensors, and an automated robotic system. The device comes with a USB Camera that takes photos of the trash objects, and they are processed via a software (TensorFlow) to identify the type of trash. After identification, the robotic arm or collection system separates the trash into separate compartments.

Background of the Study

Waste disposal has long been a significant environmental issue globally. Traditional methods like landfilling, open dumping, and incineration, while widely used, often result in severe environmental and health complications. The increasing urbanization and population growth exacerbate the inefficiency of these approaches in managing modern waste challenges. Although green practices such as recycling, composting, and advanced waste segregation technologies have emerged, they still face major drawbacks, including inefficiencies in waste segregation, reliance on manual processes prone to errors, and the absence of real-time monitoring. To address these limitations, the study introduces TrashyBot, an innovative waste management system aimed at automating waste detection, classification, and segregation using AI-based image processing. TrashyBot classifies waste into biodegradable, non-biodegradable, recyclable and hazardous types and includes features such as autonomous movement. By integrating automation with intelligent technologies, TrashyBot seeks to improve current waste management systems' efficiency while providing scalable solutions for urban waste issues.

At the Barangay of San Nicolas Sta Ana Pampang, improper waste segregation and the absence of an efficient, modernized waste disposal system have led to challenges in maintaining cleanliness and environmental sustainability on barangay. Waste is often disposed of without proper sorting, reducing the potential for effective recycling and increasing the risk of health hazards. This study will deploy TrashyBot within the barangay as a localized solution to these problems. It will evaluate the system’s effectiveness in automating waste classification and improving overall waste management practices in the institution. Additionally, it aims to enhance environmental awareness among students by demonstrating how technology can play a crucial role in sustainability efforts within academic settings.

The research is supported by existing literature highlighting robotics, AI, and sensorbased technologies in enhancing waste management. Studies such as those by Liu, Zhang, & Chen (2020) and Shi & Zhang (2018) emphasize automation's role in waste recognition and collection. Research by Bahrami & Abolhasani (2017), Jang & Park (2020), and Shirode & Mehta (2019) underscore the efficiency and environmental benefits of robotic systems for waste segregation and collection. Additional studies, including those by Reyes & Santos (2019) and Mendoza & Ramos (2018), focus on improving recycling levels and reducing landfill reliance through automated technologies.

Further analyses, such as those by Yao & Li (2021) and Tan (2020), emphasize robotics' contribution to sustainability and urban waste collection efficiency. Studies by De la Cruz (2019) and Rodriguez & Enriquez (2018) underline the environmental advantages of robotic systems, aligning closely with TrashyBot’s objectives. However, challenges like improper waste disposal behaviors remain, as noted by Raphela, Manqele, & Erasmus (2024). TrashyBot aims to bridge gaps by combining classification, and detection promoting both technological and behavioral advancements in waste management. The literature validates TrashyBot's innovation in integrating AI, robotics, and intelligent technologies for comprehensive, real-time waste management solutions. The system represents a scalable and efficient approach to modern waste challenges, promoting environmental sustainability and reducing manual dependency.

Statement of the Problem

This study aims to develop of an "intelligent robot" called "TrashyBot," designed to collect and correctly categorize waste. The problems of the study aims seeks to answer the following questions:

1. What factors enable image processing to accurately classify waste into biodegradable, nonbiodegradable, hazardous, and recyclable categories, and what challenges or limitations hinder its effectiveness in achieving precise classification?
2. How can "TrashyBot" be integrated into existing waste management systems to maximize its effectiveness?
3. How can automation and robotics be evaluated in terms of their effectiveness in improving waste collection and segregation?
4. How the TRASYHBOT be assessed against ISO25010 software and hardware, the functional suitability, performance efficiency, usability, portability, reliability and compatibility?

Significance of the Study

The study is beneficial to the following:

To the Resident. TrashyBot improves waste management effectiveness through automated garbage collection and segregation, considerably lessening waste. This ensures effective segregation of wastes so that workers of the people in San Nicolas can concentrate on maintaining safe environment while ensuring sustainable waste disposal.

To the Community. TrashyBot greatly contributes to urban and residential societies by increasing waste management effectiveness and keeping public spaces clean through automated waste collection and sorting. Through the reduction of litter and enforcement of proper waste segregation, the system encourages environmental sustainability and enhances overall public hygiene and sanitation in populous areas.

To the Researchers. This study widens the knowledge and understanding of the researchers throughout the research.

To the Future Researchers: This study can be used by the future researchers as their reference for their future understandings.

Scope and Delimitation

This study focuses on the design, development, and implementation of "TrashyBot: An Intelligent Trash-Picking Robot with Waste Classification Features." The primary goal of the study is to create a functional robot that addresses waste management challenges through automation and technology. The scope of the study includes:

Scope

Waste Classification: "TrashyBot" is capable of identifying, collecting, and classifying waste into four categories: biodegradable, non-biodegradable, hazardous waste and recyclable. It is capable of holding waste weighing up to 2kg, with a height of 10 inches and a length of 6 inches. Equipped with **"**USB Camera for Raspberry Pi" product in combination with image processing technology based on TensorFlow for deep learning-based waste classification**.**

Waste Collection: The robot includes a built-in compartment to store collected trash, enabling efficient waste operation.

Compartment Capacity: TRASHYBOT handling during is about 10 inches tall and has a diameter of 6 inches for its trash can. The trash compartment can hold approximately 10kg of waste before requiring disposal.

Testing and Evaluation: "TrashyBot" will be tested in selected public areas, such as schools and other public areas, to evaluate its ability to detect, collect, and segregate waste.

Delimitation

Type of Waste: "TrashyBot" focuses on common solid waste such as plastic bottles, paper, and other lightweight materials.

Environment: The robot will be tested in accessible environments, such as parks, sidewalks, and indoor public spaces. It may not perform optimally in rough terrains, crowded areas, or locations with excessive debris.

Operational Range: The robot's performance is restricted by its battery life and trash compartment capacity, limiting its operational time and the amount of trash it can collect in a single run. TRASHYBOT's waste collection capacity is limited **to** 5kg per compartment, requiring periodic disposal.

Weather Conditions: "TrashyBot" is designed to function in dry conditions. It may not be tested for use in rainy or extreme weather conditions, as moisture can affect its sensors and electronics.

Conceptual Framework

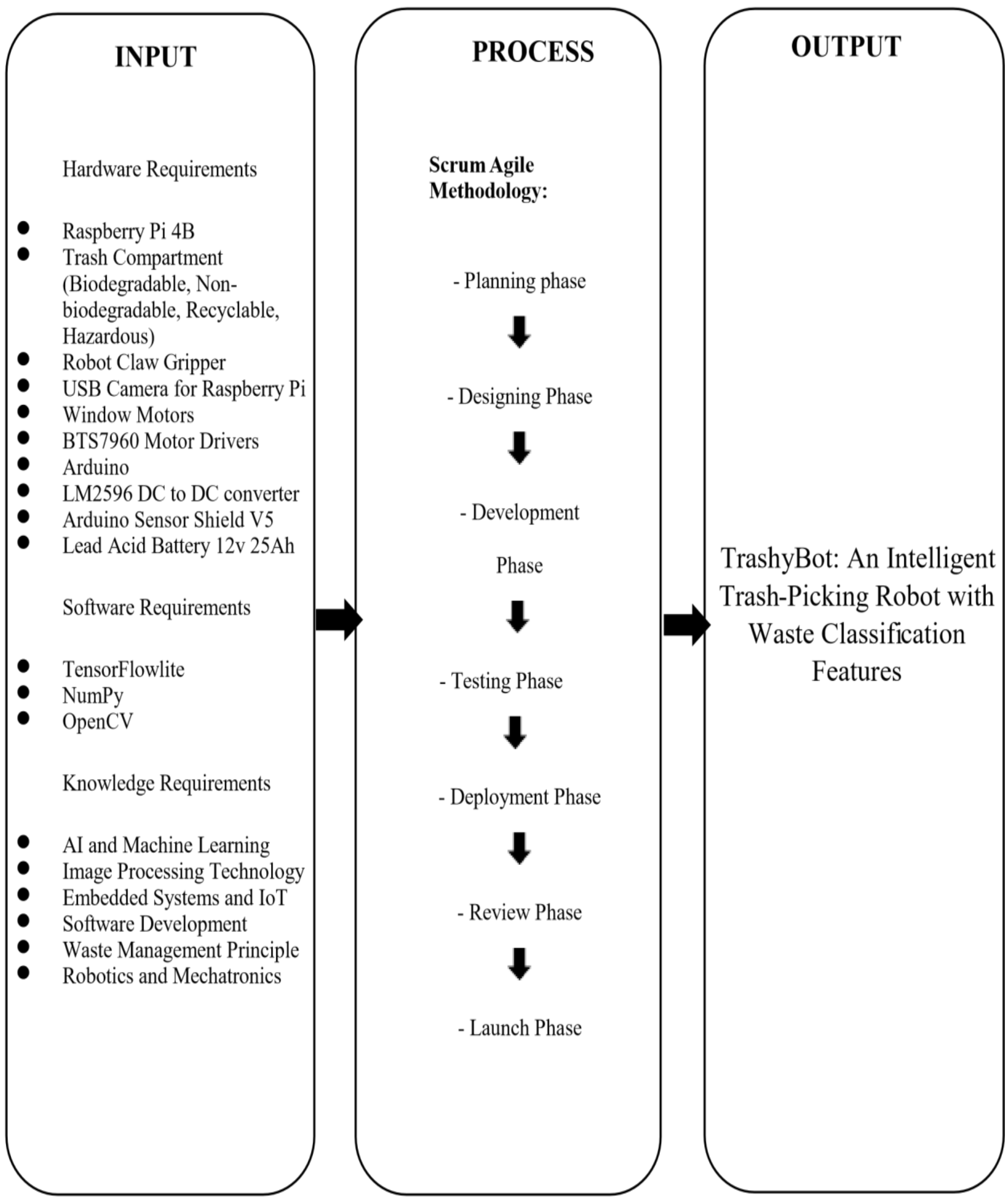

Figure 1: IPO Model of TrashyBot

The study on "TrashyBot: An Intelligent Trash-Picking Robot with Waste Classification Features" uses the IPO model to demonstrate its flow and development.The input stage of the conceptual framework for TrashyBot entails collecting necessary components, tools, and information needed to design the system. The stage sets the stage for the project by specifying the required hardware, software, and initial data gathering approaches.

Among the key elements in this stage is the determination of waste classification groups. Correct groupings are key to ensuring proper identification and sorting of biodegradable, nonbiodegradable, and recyclable items. This process enables TrashyBot to operate well in identifying various types of wastes and disposing them accordingly. Hardware needs wise, the project involves different modules that allow TrashyBot to function optimally. A Raspberry Pi acts as the main processor, processing data from camera and running AI models. The wastebasket gives space for allotted portions of organized trash, and proper disposal takes place. There is a physical pickup and segregation of trash components using a robot claw gripper and an imaging camera taking a snapshot of materials as waste in real-time processing via AI-powered algorithms. The software specifications are important for facilitating the smart capability of TrashyBot. TensorFlow, which is a machine learning library, is used in AI-powered image recognition and garbage classification. The NumPy numerical computing library is necessary for the processing of image data. These software facilities altogether improve waste classification and separation accuracy and speed.

In addition, surveys and interviews are carried out to gain input from major stakeholders, such as students, custodial staff, and school administrators. These data gathering processes assist in learning about waste disposal behaviors, determining system needs, and perfecting the design and operation of TrashyBot. The input received helps ensure that the project is compatible with the needs of the users and increases its applicability in real life.

Agile is an adaptive and iterative software and hardware development methodology that guarantees constant improvement and adjustment. TRASHYBOT's development adheres to the Agile Methodology, more precisely using the Scrum methodology to effectively develop and improve the system. Below is a summary of how agile phases are relevant to TRASHYBOT:

The **Planning Phase** involves gathering requirements and identifying the robot's key functionalities, such as waste detection, sorting, and collection, while setting project objectives. In the **Designing Phase**, the system architecture, hardware, and software design are developed. This includes creating the robotic structure, selecting appropriate sensors for trash detection, and defining the AI-powered image processing system. During the **Development Phase**, hardware components are manufactured and assembled, and the software is built. The AI-driven waste classification system are programmed and integrated into TRASHYBOT to enable real-time automation. In the **Testing Phase**, TRASHYBOT undergoes thorough functionality tests. Key features like sensors, AI-powered waste sorting, and autonomous navigation are evaluated for accuracy, efficiency, and reliability under real-world conditions, such as those in a school campus. The **Deployment Phase** follows, where the robot is implemented in designated areas for practical use. Finally, in the **Review Phase**, performance data is collected, and user feedback is analyzed. Enhancements are made to address issues such as waste sorting accuracy, battery performance, and mobility, ensuring continuous improvement through iterative updates.

The output is a fully functional TrashyBot that can address improper waste disposal. The robot is designed to detect and collect trash from various environments, accurately classify waste into biodegradable, non-biodegradable, and recyclable categories, and store it in its built-in compartment. This innovative solution aims to improve waste management practices and contribute to environmental sustainability.

Synthesis

Various studies have emphasized the role of robotics, artificial intelligence (AI), and sensor-based technology in streamlining the efficiency of waste management. The use of advanced sensors and AI in waste collection operations allows for effective identification and collection of litter in open spaces, which enhances the operations of waste disposal. Furthermore, the use of sensor-based intelligent trash cans optimizes waste handling through real-time waste monitoring and automation of collection. Such studies suggest increasing relevance of automation in modern trash disposal to suit TrashyBot's mission in the form of real-time detection and AI-separated waste collection to ensure proper management of wastes. Also aiding the employment of robotics in the management of trash, robot collection systems of waste not only streamline operations but reduce human interaction with toxic elements as well. Independent trash-gathering robots maximize efficiency and reduce employee costs. Waste segregation can also be improved by robot systems that sort waste into biodegradable, recyclable, and non-recyclable material. This information is directly related to the objective of TrashyBot, which also employs AI- based image processing for accurate classification of waste with minimal reliance on manual sorting.

Several studies have also examined the effect of automation on waste sorting and recycling. Automated waste sorting technologies can enhance recycling rates, particularly in urban regions. Robotic technology supports efficient waste sorting and landfill reduction in urbanized regions. The use of robotic waste management systems can enhance the efficiency of the system while minimizing the environmental effects of urban waste disposal. Such studies resoundingly support TrashyBot's gap, with current city waste management remaining inefficient in the real-time watching and automatic segregation that TrashyBot intends to offer through AIdriven waste sorting.

In addition, robotic garbage management and value for sustainability have also been subject to various research studies. Robot systems are especially important in helping to prevent the contamination of garbage and promoting value for sustainability. The potential for robotic integration in urban waste collection provides greater efficiency. Automation and robotic technologies in smart waste management can efficiently increase urban waste collection and sorting. Automated waste management systems help in keeping cities cleaner and in more efficient waste management policies. These researches affirm the need for automated waste collection systems, which TrashyBot directly answers through the automation of waste detection, collection, and sorting.

However, despite the creation of automated waste disposal, poor waste disposal remains an environmental problem of concern. Poor waste disposal still causes pollution, environmental contamination, and health risks. While other research is focused primarily on automation and robotics of waste collection and sorting, TrashyBot pioneers one step further by bridging the gap from classification and detection of waste. Besides streamlining waste collection, this is accomplished while actually engaging users in proper waste disposal practices, thus addressing both the technological and behavioral aspects of waste management. In short, the current literature has extensively explored the use of AI, robotics, and smart technologies in waste management. Nevertheless, there are gaps in fully integrated , real-time, and interactive waste disposal systems. TrashyBot expands this literature by offering a full solution that combines AI-driven waste sensing, real-time sorting, autonomous mobility, and smart notifications, which renders it an extremely adaptable and scalable system for modern waste management issues.

Definition of Terms

Automation - It refers to the TrashyBot's ability to autonomously detect, classify, and collect trash without requiring constant manual control.

Artificial Intelligence (AI) - It is utilized for image processing and waste classification of TrashyBot, enabling the system to identify and categorize waste as biodegradable, nonbiodegradable, or recyclable.

Image Processing - It is used to detect and identify different types of waste using a built-in camera on TRASHYBOT using TensorFlow.

Sensor Technology - Devices that detect and measure physical properties such as motion, weight, and proximity, used in this study to identify waste and guide the autonomous robot.

CHAPTER II

METHODOLOGY

Research Design

This study adopts a quantitative research method to examine the perceptions of Barangay San Nicolas Sta Ana Pampanga regarding waste management. Using of the quantitative research approach is appropriate for this research because it entails data analysis through numbers and hence is most suitable for the attainment of the research objectives. This research is based on the need for the respondents to provide accurate and adequate information to enable the provision of accuracy and reliability of the research findings.

As stated by Bhandari (2020), quantitative research involves the process of collecting and analyzing numerical data. This method can be utilized to identify patterns and averages, make predictions, test causal relationships, and generalize findings to broader populations. By leveraging this approach, the study aims to produce precise and meaningful results that contribute to a better understanding of waste management practices at San Nicolas Sta Ana Pampanga.

Respondent

The study will utilize a probability sampling method to collect responses from the Barangay San Nicolas Sta Ana Pampanga. Probability sampling ensures that every individual in the population has an equal chance of being selected, which enhances the representativeness and reliability of the findings. Within this methodological framework, the simple random sampling technique will be employed. This approach involves selecting 15 participants randomly from the target population, which includes the current Sk chairperson and 14 residents, ensuring that every individual has an equal probability of inclusion, as described by (Alshaikh & Abdelfatah, 2024). By adopting this method, the study seeks to ensure a thorough and accurate evaluation of the TRASYBOT's functional suitability, performance efficiency, usability, portability, reliability and compatibility.

Instrument

The survey questionnaires will be designed as an instrument to gather responses from the study participants, thereby enhancing the efficiency and accuracy of data collection. To assess the utilization of various quality attributes namely functional suitability, performance efficiency, usability, portability, reliability and compatibility. The researchers will adopted the product Quality, model and quality in use model outlined in ISO 25010. This approach ensures a robust framework for evaluating these attributes comprehensively. The questionnaire will offer a thorough assessment of the application's features and will be carefully designed according to ISO 25010 requirements. Each element of the questionnaire will focus on a different aspect of the platform's functionality and user experience. This will make it possible to analyze its overall performance and user satisfaction in great detail. This will guarantee that the application offers the intended user experience and complies with the established quality requirements.

A physical questionnaire created to represent these evaluation criteria will be used to collect input from San Nicolas Sta Ana Pampanga respondents. All survey instruments will be paper-based. The ISO 25010 software and hardware product quality standard, which serves as the foundation for the assessment procedure, is depicted in the following diagram.

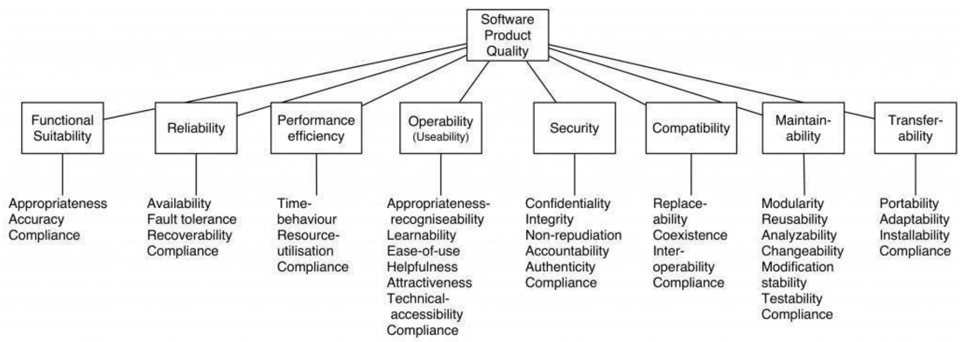

Figure 2: ISO 25010 – Software Product Quality

Data Gathering

The researchers prepared an approval letter and sought permission from barangay San Nicolas Sta Ana Pampanga to conduct a research study as part of the researcher's data collection process for the assessment of TRASHYBOT overall quality standards. The survey was designed to systematically gather quantitative data from San Nicolas Sta Ana Pampanga. In collaboration with software and hardware development, the TRASHYBOT was evaluated using the ISO 25010 framework to assess critical quality characteristics, including functional suitability, performance efficiency, usability, portability, reliability and compatibility. This comprehensive evaluation aimed to ensure that the TRASHYBOT meets the needs and expectations of its users.

Ethical considerations were carefully prioritized throughout the research process, ensuring compliance with the provisions of the Data Privacy Act of 2012 (R.A. 10173) to safeguard respondents' confidentiality and anonymity. Subsequently, the researchers distributed the survey questionnaires to the selected respondents. Upon completion, the responses were collected and analyzed, providing valuable insights and significant contributions to the research study.

Statistical Treatment

The researchers will employ the Likert scale to interpret and analyze the responses collected from the study's respondents. The Likert scale will consist of a numerical range from 1 to 5, with the following corresponding:

Scale	Mean	Descriptive Rating
5	4.51 – 5.0	Strongly Agree
4	3.51 – 4.50	Agree
3	2.51 – 3.50	Neutral
2	1.51 – 2.50	Disagree
1	1.0 – 1.50	Strongly Disagree

Table 1: Likert Scale Table

This scale will help measure respondents' feedback on various aspects of the TRASHYBOT, such as its functionality, usability, and overall effectiveness in San Nicolas Sta Ana Pampanga. The data gathered will be statistically analyzed to determine trends and insights, which will guide the further development and improvement of the application. By analyzing the frequency distribution of responses, the researchers will identify the proportion, or percentage, of respondents who selected each option on the Likert scale. This analysis will provide insights into the overall satisfaction and agreement levels regarding the TRASHYBOT, specifically in terms of its ability to engage users with the San Nicolas Sta Ana Pampanga. The results will help determine how well the TRASHYBOT meetsusers expectation.

Formula:

$$\% = \frac{f}{N} \times 100$$

Where:
% = Percentage
f = Frequency or number of responses
N = Total number of Responses

Sample Mean

$$\overline{X} = \frac{\sum_{i=1}^{n} x_i}{n}$$

n = number of items in the sample

Figure 3: Statistical Treatment Formula

The researchers will use frequency and percentage to perform the statistical treatment of the data, identifying the proportion of responses for each option. Additionally, the weighted mean and standard deviation will be employed to analyze the data points, providing a deeper understanding of the respondents' overall feedback and the variability in their responses. This approach ensures a comprehensive analysis of the data gathered.

Development Phases:

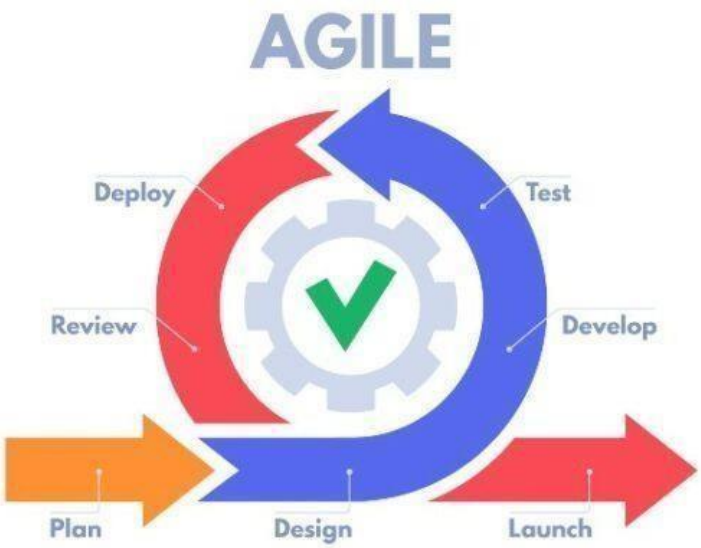

Figure 4: Scrum of Agile SDLC

The development of the Software Development Life Cycle (SDLC) in the context of a project called "TRASHYBOT" follows a structured process used for requirements/planning, designing, developing, testing, and maintaining software applications, with the integration of the Scrum framework from Agile SDLC to facilitate iterative development, continuous feedback, and incremental delivery of features.

The diagram outlines six key phases of SDLC in a circular workflow:

1. Planning Phase

In this phase, the focus is on identifying the key needs of the school community related to waste management, gathering information, and setting clear goals for the project. Project

Scope Definition: Define the robot's functions, such as waste detection, waste sorting (degradable, non-degradable, recyclable), autonomous movement, and waste collection.

- Student Engagement: Engage students in brainstorming sessions or surveys to understand their knowledge of environmental issues, attitudes toward waste management, and interest in using technology to address these problems.
- Resource Planning: Technology - Camera, motors, AI-based classification software, waste management systems. Team Members: Computer Engineering, AI specialists, environmental experts, and testers.
- Timeline Development: Define a clear timeline, marking the major milestones of a prototype completion, testing phases, user feedback, and project rollout.

2. Designing Phase

To develop the conceptual and technical designs of TrashyBot. This involves planning the physical structure and the software systems required for its operations.

- **Conceptual & System Architecture Design**: Determines TrashyBot's function, features, and hardware-software interaction.
- **Sensor & AI Integration**: Employs sensors for trash detection, path finding, and collision avoidance along with AI-based image processing for trash identification.
- **Technology & Power System**: Utilizes AI, robotics, and battery capacity to promote efficiency and sustainability.
- **Prototype & Structural Design**: Creates a compact and robust model, iteratively testing it for waste collection efficiency.

- **Mobility & Navigation**: Designs movement mechanisms with AI-driven autonomous navigation and obstacle avoidance.
- **Waste Collection Mechanism**: Incorporates robotic arms or vacuum systems to collect and shift waste effectively.
- **Compartmentalization**: Features individual waste bins for biodegradable, nonbiodegradable, and recyclable wastes.
- **Sustainability Features**: Preserves environmentally sustainable materials, low energy consumption, and low impact on the environment.
- **Testing & Deployment**: Performs performance analysis in actual-world settings, using feedback and analysis of data to improve design.

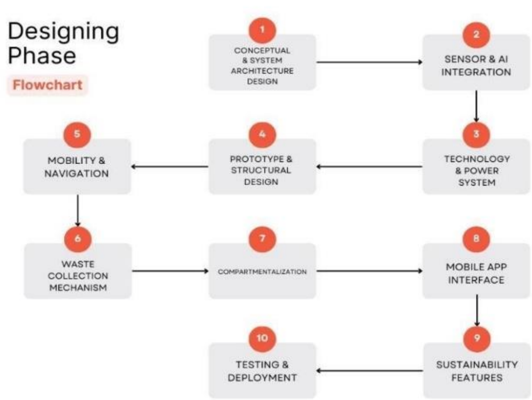

Figure 5: Designing Phase Flowchart

3. Development Phase

In the development phase, the prototype of TrashyBot is built by integrating hardware components and developing the software system for waste detection, collection, and classification.

- Hardware Development: Construct TrashyBot's physical frame, with approximate 10 inches tall and has a diameter of 6 inches for its trash can. The trash compartment can hold approximately 5kg of waste before requiring disposal, ensuring the inclusion of robust waste storage compartments, wheels for movement, and sensor mounts. Integrate proximity sensors for navigation and waste detection, along with waste collection mechanisms.
- Software Development: Create algorithms that process the sensor data and sort waste into three categories: recyclable, degradable, and non-degradable. This can be done using machine learning or image recognition techniques. Program TrashyBot's control system for autonomous navigation and waste collection. The robot should be able to move toward trash, pick it up, and classify it without human intervention.
- Integration of Components: Once both the hardware and software components are ready, assemble them into a fully functional robot. This step involves ensuring that the classification system, and movement control all work seamlessly together.

4. Testing Phase

The testing phase evaluates the prototype's functionality, identifying any issues in its design and performance to ensure it meets the project's goals.

- Initial Testing (Lab/Controlled Environment): Test TrashyBot's ability to detect and classify different types of waste in a controlled environment (e.g., a testing area with waste items). Ensure the waste sorting algorithm works accurately, and TrashyBot can correctly navigate its environment without collisions or errors.
- Field Testing (Pilot Testing): Deploy TrashyBot in a real-world setting, such as a school, park, or urban street, to test its performance. Monitor how well it detects and sort trash, its navigation around obstacles, and how it interacts with people. Gather feedback from the users in these environments, such as community members, school staff, or waste management personnel, on how effective TrashyBot is in maintaining cleanliness.
- Debugging and Optimization: Based on the testing results, debug and refine TrashyBot. This may involve tweaking the robot's waste classification software, adjusting sensor sensitivity, and improving its movement mechanics.

5. Deployment Phase

Once testing is complete, the TrashyBot is ready for deployment in the school setting. This phase involves setting up the robot for regular use and ensuring proper infrastructure is in place for its operation.

- Full-Scale Deployment: Deploy the TrashyBot in Holy Cross College, ensuring that it is easily accessible for janitor and maintenance staff. Set up charging stations around the school for easy recharging.

- Monitoring and Maintenance: Assign a maintenance schedule for regular checks of the TrashyBot to ensure its functionality (e.g., sensor cleaning, battery replacement, troubleshooting). Ensure the robot's waste compartment is emptied regularly.
- Educational Integration: Organize school events or workshops to teach students about waste management and how the TrashyBot works. Use the robot as an educational tool in science, technology, and environmental classes.

6. Feedback and Review Phase

To assess TrashyBot's overall success and its effectiveness in real-world applications, as well as gather insights for possible improvements.

- Performance Evaluation: Review data on how efficiently TrashyBot collected and sorted waste during the testing phase. Analyze its effectiveness in different environments and its operational efficiency (e.g., speed of collection, battery life).
- User Feedback Collection: Gather qualitative and quantitative feedback from people who interacted with TrashyBot. This could include students, staff, or community members who observed the robot in action. Will use surveys or interviews to understand user satisfaction and potential areas for improvement.
- Cost-Benefit Analysis: Analyze the costs involved in manufacturing, maintaining, and operating TrashyBot, and compare these costs to traditional waste management methods. Determine if the robot offers a significant advantage in terms of sustainability, efficiency, and long-term savings.

- Final Report and Recommendations: Compile the results from the testing and evaluation phases into a final report. Make recommendations for future development, including enhancements in software algorithms, improvements to the robot's hardware, or expanding its use to other environments. Based on the findings, decide if the robot should be deployed on a larger scale or if additional iterations are required for refinement.

7. Launch Phase

The Launch Phase marks TrashyBot's transition from development to real-world use, focusing on creating awareness, fostering excitement, and engaging stakeholders to showcase its functionality and benefits in waste management.

- Official Unveiling: Host an event to formally introduce TrashyBot to students, staff, and the community.
- Demonstrations: Showcase TrashyBot's capabilities through live demonstrations of waste detection, sorting, and collection.
- Community Engagement: Conduct interactive workshops and presentations to raise awareness about environmental issues and the role of technology in sustainable practices. This Scrum of Agile SDLC model ensures a systematic and efficient approach to software development, reducing risks and improving product quality.

CHAPTER III

RESULTS AND DISCUSSION

In this chapter present the analysis and interpretation of the study data. For clarity integration in the discussion, the data are provided in the proper sequence and order of the questions.

Development and Testing

After the researchers developed the TRASHYBOT: An Intelligent Trash-Picking Robot with Waste Classification, the researchers conducted the test of the system and selected respondents who have time. Also the researchers he explain the Data Privacy Act of 2012 (R.A. 10173) to safeguard respondents' confidentiality and anonymity. So that the testing and development will go perfectly. Then he explain that the TRASHYBOT are not fully functional but we provide video on how work the TRASHYBOT.

Implementation Plan/Result

After the evaluation, by using the fivepoint likert scale the researchers computed the weighted mean of the data gathered from the respondents to interpret the results of this study. Using this approach the researchers will know if the respondents found the system an acceptable to daily use, helpful in this environment, and recommend for others. Based on the research instrument adopted from ISO25010, the results of the system evaluation are presented in this section.

EVALUATION OF TRASHYBOT SYSTEM SOFTWARE QUALITY USING ISO25010 (1 IT EXPERT)

Table 1. Mean Score and Verbal Interpretation of the Assessment of Functional Suitability.

Indicators	Weighted Mean	Standard Deviation	Descriptive Rating
Functional Completeness: Degree to which the set of functions covers all the specified tasks and intended users' objectives.	**3.00**	**0.00**	**Neutral**
Functional Correctness: Degree to which a product or system provides accurate results when used by intended users.	**2.00**	**0.00**	**Disagree**
Functional Appropriateness: Degree to which the functions facilitate the accomplishment of specified tasks and objectives.	**3.00**	**0.00**	**Neutral**
Grand Mean	**2.67**	**0.47**	**Neutral**

Legend: 1.00 – 1.50: Strongly Disagree, 1.51 – 2.50: Disagree, 2.51 – 3.50: Neutral, 3.51 – 4.50: Agree, 4.51 – 5.00: Strongly Agree

Table 1 shows the perception of the respondent to the functional suitability of TRASHYBOT, an overall weighted mean of 2.67, which is marked as “neutral”. Moreover, “Functional Correctness: to which a product or system provides accurate results when used by intended users." obtained the lowest mean of 2.00, and "Functional Correctness: Degree to which a product or system provides accurate results when used by intended users.". Also Functional Appropriateness: Degree to which the functions facilitate the accomplishment of specified tasks and objectives. they both obtained the highest mean of 3.00. In general, the respondent expressed the Functional Suitability.

Table 2. Mean Score and Verbal Interpretation of the Assessment of Performance Efficiency.

Indicators	Weighted Mean	Standard Deviation	Descriptive Rating
Time Behavior: Degree to which the response time and throughput rates of a product or system, when performing its functions, meet requirements.	**2.00**	**0.00**	**Disagree**
Resource Utilization: Degree to which the amounts and types of resources used by a product or system, when performing its functions meet requirements.	**3.00**	**0.00**	**Neutral**
Capacity: Degree to which the maximum limits of a product or System parameter meet requirements.	**3.00**	**0.00**	**Neutral**

Grand Mean	2.67	0.47	Neutral

Legend: 1.00 – 1.50: Strongly Disagree, 1.51 – 2.50: Disagree, 2.51 – 3.50: Neutral, 3.51 – 4.50: Agree, 4.51 – 5.00: Strongly Agree

According to the information presented in Table 2, the Performance Efficiency received an average weighted mean score of 2.67 and a descriptive interpretation of "Neutral." Moreover, "Capacity: Degree to which the maximum limits of a product or system parameter meet requirements", obtained the lowest mean of 3.00 while both Time Behavior and Resource Utilization received 3.00. This suggests that the respondent viewed the capacity is not capable in this study, because the system not done and not consistent performing.

Table 3. Mean Score and Verbal Interpretation of the Assessment of Usability

Indicators	**Weighted Mean**	**Standard Deviation**	**Descriptive Rating**
Appropriateness recognizability - Degree to which users can recognize whether a system is appropriate for their needs.	**4.00**	**0.00**	**Agree**
Operability: Degree to which a product or system has attributes that make it easy to operate and control.	**2.00**	**0.00**	**Disagree**

User Error Degree to which a system prevents users against operation errors.	**2.00**	**0.00**	**Disagree**
Grand Mean	**2.67**	**0.94**	**Neutral**

Legend: 1.00 – 1.50: Strongly Disagree, 1.51 – 2.50: Disagree, 2.51 – 3.50: Neutral, 3.51 – 4.50: Agree, 4.51 – 5.00: Strongly Agree

Based on the data shown in Table 3, the Usability criterion attained a weighted mean score of 2.67, which corresponds to a descriptive interpretation of "Neutral." This indicates that the respondents find the system nether usable and not easy to interact with, so that the system reaching the neutral satisfaction level.

Table 4. Mean Score and Verbal Interpretation of the Assessment of Portability

Indicators	Weighted Mean	Standard Deviation	Descriptive Rating

Adaptability - Degree to which a product or system can effectively and effectively be adapted for different or evolving hardware, software or other operational or usage environments.	**3.00**	**0.00**	**Neutral**
Installability - Degree of effectiveness and efficiency with which a product or system can be successfully installed and/ or uninstalled in a specified environment.	**2.00**	**0.00**	**Disagree**
Grand Mean	**2.50**	**0.50**	**Disagree**

Legend: 1.00 – 1.50: Strongly Disagree, 1.51 – 2.50: Disagree, 2.51 – 3.50: Neutral, 3.51 – 4.50: Agree, 4.51 – 5.00: Strongly Agree

According on the data shown in Table 4, the Portability criterion attained a weighted mean score of 2.50, which corresponds to a descriptive interpretation of "Disagree." This indicates that the respondents find the system needs successfully installed and need to be in adapted for different or evolving hardware, software or other operational or usage environments.

Table 5. Mean Score and Verbal Interpretation of the Assessment of Reliability

Indicators	Weighted Mean	Standard Deviation	Descriptive Rating
Maturity - Degree to which a system or component meets needs for reliability under normal operation.	**2.00**	**0.00**	**Disagree**
Availability - Degree to which a system or component is operational and accessible when required for use.	**2.00**	**0.00**	**Disagree**
Grand Mean	**2.00**	**0.00**	**Disagree**

Legend: 1.00 – 1.50: Strongly Disagree, 1.51 – 2.50: Disagree, 2.51 – 3.50: Neutral, 3.51 – 4.50: Agree, 4.51 – 5.00: Strongly Agree

Based on the data shown in Table 5, the Reliability criterion attained a weighted mean score of 2.00, which corresponds to a descriptive interpretation of "Disagree." This indicates that the respondents find the system not meet the usable and not easy to interact, so that the system reaching the disagree satisfaction level.

Table 6. Mean Score and Verbal Interpretation of the Assessment of Compatibility

Indicators	Weighted Mean	Standard Deviation	Descriptive Rating
Co-Existence - Degree to which a system can perform	**3.00**	**0.00**	**Neutral**

its required functions efficiently while sharing a common environment and resources with other products, without detrimental impact on any other product.			
Interoperability - Degree to which two or more systems, products or components can exchange information and use the information that has been exchanged.	**3.00**	**0.00**	**Neutral**
Grand Mean	**3.00**	**0.00**	**Neutral**

Legend: 1.00 – 1.50: Strongly Disagree, 1.51 – 2.50: Disagree, 2.51 – 3.50: Neutral, 3.51 – 4.50: Agree, 4.51 – 5.00: Strongly Agree

Table 6 shows the perception of the respondent to the Compatibility of TRASHYBOT, an overall weighted mean of 3.00, which is marked as "neutral". So that the compatibility is highest among the 6 ISO25010.

Table 7. Mean Score and Verbal Interpretation of the Summary of the System's Overall Evaluation based on ISO 25010

Indicators	**Weighted Mean**	**Standard Deviation**	**Descriptive Rating**
Functional Suitability	**2.67**	**0.47**	**Neutral**

Performance Efficiency	**2.67**	**0.47**	**Neutral**
Usability	**2.67**	**0.94**	**Neutral**
Portability	**2.50**	**0.50**	**Disagree**
Reliability	**2.00**	**0.00**	**Disagree**
Compatibility	**3.00**	**0.00**	**Neutral**
Grand Mean	**2.59**	**0.30**	**Neutral**

Legend: 1.00 – 1.50: Strongly Disagree, 1.51 – 2.50: Disagree, 2.51 – 3.50: Neutral, 3.51– 4.50: Agree, 4.51 – 5.00: Strongly Agree

Table 7 shows the summary of system evaluation results from the ISO25010 quality criteria. Among these items the Compatibility received the highest weighted mean of 3.00, while reliability had the lowest weighted mean of 2.00 and Portability also had the lowest weighted mean of 2.50 this means that there is slightly more room for improvement in these areas. Issues like minor system inconsistencies may had been observed so that this very significant enough to cause concerns. The overall weighted mean score of TRASHYBOT is 2.59 based on the ISO25010, which correspond to descriptive rating of "Neutral". The respondent neutral that the system needs improvement and the quality expectations, especially satisfactory across the assessed quality standards.

EVALUATION OF TRASHYBOT SYSTEM SOFTWARE QUALITY (15 LOCAL IN BARANGAY SAN NICOLAS STA ANA PAMPANGA)

Table 8. Mean Score and Verbal Interpretation of the Assessment of Functional *Suitability.*

Indicators	Weighted Mean	Standard Deviation	Descriptive Rating
TrashyBot accurately identifies and classifies different types of waste.	**4.27**	**0.77**	**Agree**
TrashyBot effectively picks up trash and cleans the area without missing items.	**3.60**	**0.71**	**Agree**
Its functionality meets your expectations for waste management.	**4.67**	**0.47**	**Strongly Agree**
Grand Mean	**4.18**	**0.65**	**Agree**

Legend: 1.00 – 1.50: Strongly Disagree, 1.51 – 2.50: Disagree, 2.51 – 3.50: Neutral, 3.51 – 4.50: Agree, 4.51 – 5.00: Strongly Agree

Based on the data shown in Table 8, the Functional Suitability criterion attained a weighted mean score of 4.18, which corresponds to a descriptive interpretation of "Agree." This indicates that the respondents of the local of the barangay San Nicolas Sta Ana Pampanga find the system meet the usable and easy to interact, so that the system reaching the satisfaction level. . Among these items interaction the functionality meets your expectations for waste management received the highest weighted mean of 4.67.

Table 9. Mean Score and Verbal Interpretation of the Assessment of Performance Efficiency.

Indicators	Weighted Mean	Standard Deviation	Descriptive Rating
TrashyBot operates at a fast and efficient pace in waste collection.	**3.87**	**0.88**	**Agree**
It performs well under heavy waste conditions without compromising speed.	**2.47**	**0.50**	**Disagree**
Grand Mean	**3.17**	**0.19**	**Neutral**

Legend: 1.00 – 1.50: Strongly Disagree, 1.51 – 2.50: Disagree, 2.51 – 3.50: Neutral, 3.51 – 4.50: Agree, 4.51 – 5.00: Strongly Agree

According on the data shown in Table 9, the Performance Efficiency criterion attained a weighted mean score of 3.17, which corresponds to a descriptive interpretation of "Neutral." This indicates that the respondents of the local of the barangay San Nicolas Sta Ana Pampanga find the system needs more efficient.

Table 10. Mean Score and Verbal Interpretation of the Assessment of Usability

Indicators	Weighted Mean	Standard Deviation	Descriptive Rating
TrashyBot is easy to operate and understand for users.	**3.67**	**0.47**	**Agree**
The user interface, controls, or instructions are simple and intuitive.	**3.67**	**0.47**	**Agree**
It requires minimal effort to learn how to use TrashyBot effectively.	**4.67**	**0.47**	**Strongly Agree**
Grand Mean	**4.00**	**0.47**	**Agree**

Legend: 1.00 – 1.50: Strongly Disagree, 1.51 – 2.50: Disagree, 2.51 – 3.50: Neutral, 3.51 – 4.50: Agree, 4.51 – 5.00: Strongly Agree

Based on the data shown in Table 10, the Usability criterion attained a weighted mean score of 4.00, which corresponds to a descriptive interpretation of "Agree." This indicates that the respondents of the local of the barangay San Nicolas Sta Ana Pampanga find the system meet the usability us a usable and easy to interact with TRASHYBOT, so that the system reaching the satisfaction level of the respondents. Among these items interaction the it requires minimal effort to learn how to use TrashyBot effectively received the highest weighted mean of 4.67.

Table 11. Mean Score and Verbal Interpretation of the Assessment of Portability

Indicators	**Weighted Mean**	**Standard Deviation**	**Descriptive Rating**
TrashyBot can be easily transported and deployed in different locations.	**3.00**	**0.00**	**Neutral**
It adapts seamlessly to various environments (e.g., indoor).	**2.00**	**0.00**	**Disagree**
Grand Mean	**2.50**	**0.50**	**Disagree**

Legend: 1.00 – 1.50: Strongly Disagree, 1.51 – 2.50: Disagree, 2.51 – 3.50: Neutral, 3.51 – 4.50: Agree, 4.51 – 5.00: Strongly Agree

According on the data shown in Table 11, the Portability criterion attained a weighted mean score of 2.50, which corresponds to a descriptive interpretation of "Disagree." This indicates that the respondents of the local of the barangay San Nicolas Sta Ana Pampanga find the TrashyBot can’t not be easily transported and deployed in different locations. Also because the robot is not perfectly done.

Table 12. Mean Score and Verbal Interpretation of the Assessment of Reliability

Indicators	Weighted Mean	Standard Deviation	Descriptive Rating
TrashyBot works consistently and is available when needed.	2.33	0.47	Disagree
It handles errors or malfunctions efficiently, minimizing downtime.	2.33	0.47	Disagree
The robot performs its tasks without frequent interruptions or breakdowns.	3.87	0.88	Agree
Grand Mean	2.84	0.73	Neutral

Legend: 1.00 – 1.50: Strongly Disagree, 1.51 – 2.50: Disagree, 2.51 – 3.50: Neutral, 3.51 – 4.50: Agree, 4.51 – 5.00: Strongly Agree

Based on the data shown in Table 12, the Reliability criterion attained a weighted mean score of 2.84, which corresponds to a descriptive interpretation of "Neutral." This indicates that the respondents of the local of the barangay San Nicolas Sta AnaPampanga find the system not perfectly done.

Table 13. Mean Score and Verbal Interpretation of the Assessment of Compatibility

Indicators	Weighted Mean	Standard Deviation	Descriptive Rating
TrashyBot integrates well with existing waste management systems or tools.	**4.53**	**0.50**	**Strongly Agree**
It functions properly alongside other equipment without conflicts.	**2.87**	**0.72**	**Neutral**
Grand Mean	**3.70**	**0.61**	**Agree**

Legend: 1.00 – 1.50: Strongly Disagree, 1.51 – 2.50: Disagree, 2.51 – 3.50: Neutral, 3.51 – 4.50: Agree, 4.51 – 5.00: Strongly Agree

According on the data shown in Table 13, the Compatibility criterion attained a weighted mean score of 3.70, which corresponds to a descriptive interpretation of "Agree."

This indicates that the respondents of the local of the barangay San Nicolas Sta Ana Pampanga find the system is likely meet the criteria about waste management.

Table 14. Mean Score and Verbal Interpretation of the Assessment of Overall Impact Thoughts

Indicators	Weighted Mean	Standard Deviation	Descriptive Rating
The robot makes the area cleaner than before.	**2.60**	**0.71**	**Neutral**
The robot is helpful for keeping the area clean.	**2.53**	**0.62**	**Neutral**
I think this robot is a good idea.	**3.07**	**0.77**	**Neutral**
I would like to see more robots like this in other places.	**3.60**	**0.95**	**Agree**
Grand Mean	**2.95**	**0.43**	**Neutral**

Legend: 1.00 – 1.50: Strongly Disagree, 1.51 – 2.50: Disagree, 2.51 – 3.50: Neutral, 3.51 – 4.50: Agree, 4.51 – 5.00: Strongly Agree

Table 14 shows on how the TRASHYBOT will work the Overall Impact and Thoughts criterion attained a weighted mean score of 2.95, which corresponds to a descriptive interpretation of "Neutral." This indicates that the respondents of the local of the barangay San Nicolas Sta Ana Pampanga find the system not perfectly done. The TRASHYBOT is not entirely functional due to certain components being damaged or burned.

Table 15. Mean Score and Verbal Interpretation of the Summary of the System's Overall Evaluation

Indicators	Weighted Mean	Standard Deviation	Descriptive Rating
Functional Suitability	4.18	0.65	Agree
Performance Efficiency	3.17	0.19	Neutral
Usability	4.00	0.47	Agree
Portability	2.50	0.50	Disagree
Reliability	2.84	0.73	Neutral
Compatibility	3.70	0.61	Agree
Overall Impact and Thoughts	2.95	0.43	Neutral

Grand Mean	**3.33**	**0.59**	**Neutral**

Legend: 1.00 – 1.50: Strongly Disagree, 1.51 – 2.50: Disagree, 2.51 – 3.50: Neutral, 3.51 – 4.50: Agree, 4.51 – 5.00: Strongly Agree

Table 7 shows the summary of system evaluation results from the barangay San Nicolas Sta Ana Pampanga quality criteria. Among these items the Performance Efficiency received the highest weighted mean of 4.18, while reliability had the lowest weighted mean of 2.84 and Portability also had the lowest weighted mean of 2.50 this means that there is slightly more room for improvement in these areas. Issues like minor system inconsistencies may had been observed so that this very significant enough to cause concerns. The overall weighted mean score of TRASHYBOT is 3.33 based on the ISO25010, which correspond to descriptive rating of "Neutral". The respondent neutral that the system needs improvement and the quality expectations, especially satisfactory across the assessed quality standards.

CHAPTER IV

SUMMARY OF FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

This part shows the summary of findings and the drawn conclusions. The researchers adopted survey questionnaire which consists of five- point Likert Scale that fits the research. The researchers gave the questionnaires to 15 respondents to obtain the data needed. Mean and frequency were included in descriptive statistics.

Summary of Findings

The Modern society has increasingly struggled with a decline in individual discipline, evident in the rising disregard for elders, authority, and, most notably, the environment. Littering has emerged as a significant concern, with small waste items carelessly discarded in public spaces, waterways, and coastal areas, contributing to environmental deterioration. This escalating issue underscores the importance of effective waste management strategies to encourage environmental responsibility and support sustainable practices. The main objective of this study was to design and develop of a TRASHYBOT a system that allows users and offers a more user-friendly, time-saving, and accessible method of waste management especially was validated using the ISO25010 quality attributes of a expert in hardware and software. Among the attributes assessed, interaction capacity recorded the highest weighted mean, indicating that the system can fulfill its functional suitability, performance efficiency, usability they both receive the mean

“2.67”, then portability receive mean “2.50”, but the lowest is the reliability receive mean “2.00”, and the highest compatibility receive mean “3.00”.

Additionally, the system was evaluated by the local of barangay San Nicolas Sta Ana Pampanga using the functional suitability, performance efficiency, usability, portability, reliability, and compatibility. The system recorded the overall weighted mean score of TRASHYBOT is 3.33 all corresponding to a descriptive rating of "Neutral". These findings indicate that TRASHYBOT is highly effective in delivering functionality, convenience, and a positive experience, successfully addressing the inefficiencies found in waste management methods.

CONCLUSIONS

After the conduct of the study, the researcher concluded that:

1. TRASHYBOT operates minimal human intervention, reducing labor requirements and enhancing the waste management operations.
2. TRASHYBOT classifies waste into recyclable, hazardous, non-recyclable, and biodegradable categories using AI-powered image processing. The approach shows that image processing is a practical way to enhance waste management classification, even though there are certain accuracy restrictions because of lighting, item resemblance, or camera angles.

3. The researchers not successfully achieved the general objective of designing and developing "TrashyBot: An Intelligent Trash-Picking Robot with Waste Classification", because of the time and is not entirely functional due to certain components being damaged or burned.

RECOMMENTIONS

Based on the findings and conclusions of the study, the following recommendations are proposed:

1. It is recommended to redesign the machine with a more modern, attractive, and aesthetic appearance to appeal to a broader audience and create a more inviting user experience in public areas.

2. It is recommended to efficiency the image processing so that will work perfectly to see the trash.

3. Increase System Usability and User-Friendliness. The system's operability and ease of interaction should be improved by developing a simple user interface or mobile application that allows users to monitor and control the robot easily. Clear instructions and user feedback systems can also help reduce user errors and enhance the overall experience.

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APPENDICES

APPENDICES A
(BARANGAY LETTER)

HOLY CROSS COLLEGE
Sta. Lucia, Sta. Ana, Pampanga
RESEARCH AND DEVELOPMENT UNIT
School of Engineering, Computer and Library Studies
A.Y. 2024-2025

April 2025

John Paul Turla
SK-Chairperson
Barangay San Nicolas Sta Ana Pampanga

Dear Sir. Turla,

We, the undersigned students pursuing a Bachelor of Science in Computer Engineering, are currently engaged in a research project titled "TrashyBot: An Intelligent Trash-Picking Robot with Waste Classification." The primary objective of this research is to develop an autonomous robotic system that can efficiently identify, collect, and classify waste to improve waste management and promote environmental sustainability. We aim to design and implement a smart trash-picking robot capable of distinguishing between different types of waste, ensuring proper disposal, reducing manual labor, and assisting in maintaining cleanliness. This study will primarily focus on people of the barangay San Nicolas, evaluating how TrashyBot can enhance waste collection processes in public spaces, ease the workload of workers staff, and encourage proper waste segregation among people of San Nicolas. To support our research, we will conduct surveys among students and utility personnel to gather relevant data on current waste management practices, challenges faced, and potential areas of improvement. The survey will help us assess the effectiveness and acceptance of the TrashyBot system among its intended users.

In this regard, we respectfully seek your approval to conduct this study. We assure you that all gathered data will be treated with the utmost confidentiality, and we will strictly adhere to all protocols and privacy regulations. Your support in granting approval for this research is greatly appreciated.

Thank you.

Respectfully,

ADRIAN S. CANLAS

RONNEL O. DEANG

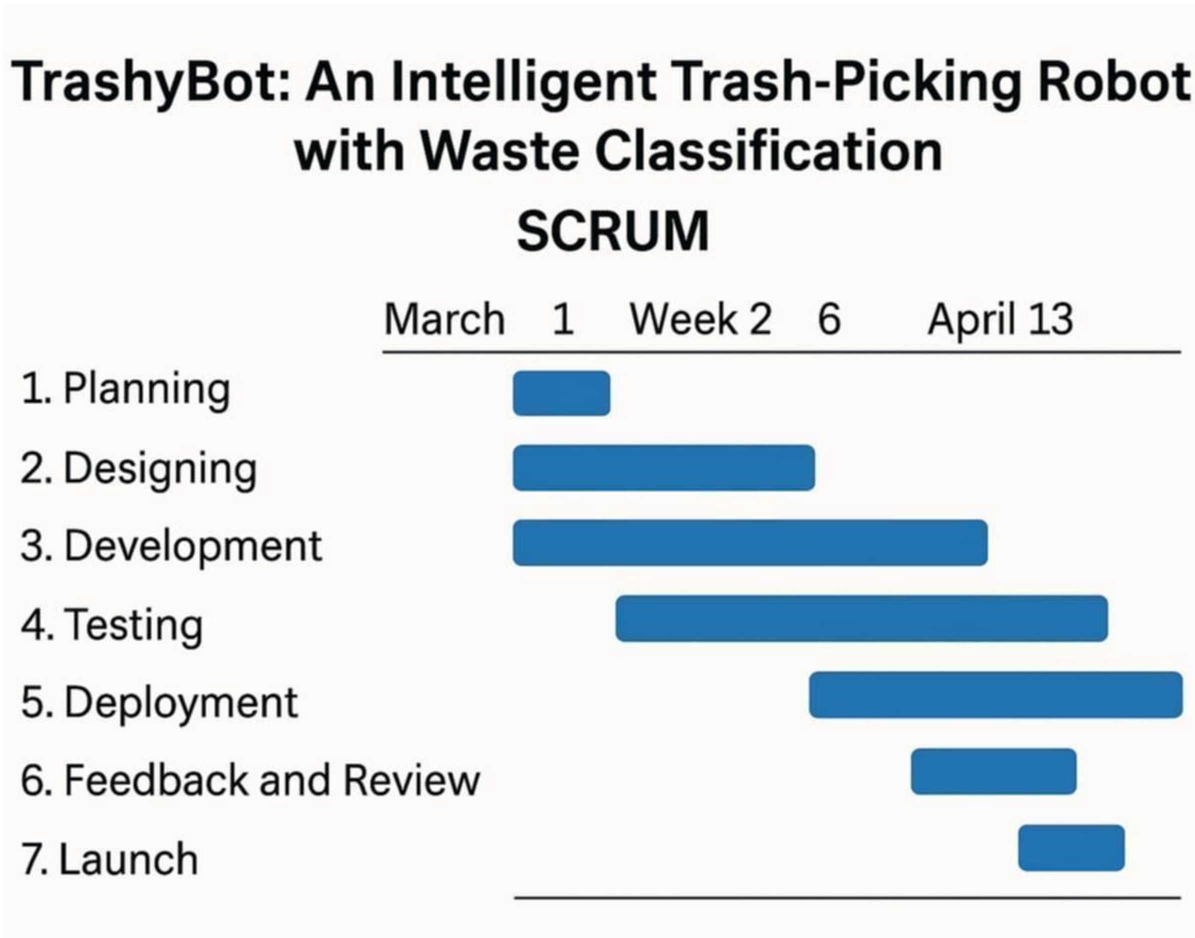
Researchers, BSCpE-III Students

Approved by:

John Paul Turla
SK-Chairperson

APPENDICES B

(GANTT CHART)



APPENDICES C
(COMPONENTS)

NAME	IMAGE	DESCRIPTION
Steel Plates		Steel plates are flat steel materials with a high width-tothickness ratio, widely used in construction and manufacturing.
Raspberry Pi 4B		The Raspberry Pi 4 Model B is a compact and versatile single-board computer designed for a wide range of applications.
XL4015		The XL4015 is a step-down (buck) DC-DC converter IC. It's designed to convert a higher input voltage to a lower, regulated output voltage.

Fans		Fans are used to draw cooler air into the case from the outside, expel warm air from inside and move air across a heat sink to cool a particular component.
Battery 12v **25Ah**		A 12V 25Ah battery is a rechargeable power source commonly used in various applications.
BTS7960 **Motor Driver**		The BTS7960 is a highcurrent Hbridge motor driver module designed for controlling DC motors.
		A USB webcam is a digital camera that connects to a computer or device via a USB

USB Webcam		port, enabling video and image capture.
Robotic Arm		A robotic arm is a programmable mechanical device designed to mimic the movements and functions of a human arm.
Widow Motor		A window motor, commonly used in automobiles, is a small electric motor that powers the mechanism responsible for moving car windows up and down.
Wheels		Wheels are circular components designed to rotate around an axle, enabling movement and reducing friction.

Sprocket		A sprocket is a wheel with teeth designed to engage with a chain, track, or other perforated material. It plays a crucial role in transmitting rotary motion or converting it into linear motion.
Compartment Pail		A compartment pail is essentially a bucket or container that is divided into sections or compartments. These compartments allow for the separation of different items or materials.
Arduino Sensor Shield v5		The Arduino Sensor Shield v5 is a versatile expansion board designed to simplify the connection of sensors, servos, and other components to an Arduino board.

Arduino		Arduino is an opensource electronics platform designed for creating interactive projects. It combines hardware and software to make prototyping and programming accessible to beginners and experts
SSD		An SSD (Solid State Drive) is a type of storage device used in computers and other devices.

APPENDICES D (CODE)

```
import serial
import serial.tools.list_ports
import time
import cv2
import numpy as np
import threading
from queue import Queue
from tensorflow.lite.python.interpreter import Interpreter

# Initialize video capture and model
video = cv2.VideoCapture(0)
video.set(cv2.CAP_PROP_FRAME_WIDTH, 320) # Reduced width
video.set(cv2.CAP_PROP_FRAME_HEIGHT, 240) # Reduced height
imW = video.get(cv2.CAP_PROP_FRAME_WIDTH)
imH = video.get(cv2.CAP_PROP_FRAME_HEIGHT)
video.set(cv2.CAP_PROP_FPS, 15)

# Load TFLite model
model_url = "detect.tflite"
labels_url = "labelmap.txt"
interpreter = Interpreter(model_url)
interpreter.allocate_tensors()

# Load labels
with open(labels_url, 'r') as f:
    labels = [line.strip() for line in f.readlines()]
if labels[0] == '???':
    del(labels[0])

# Model input details
input_details = interpreter.get_input_details()
output_details = interpreter.get_output_details()
height = input_details[0]['shape'][1]
width = input_details[0]['shape'][2]
floating_model = (input_details[0]['dtype'] == np.float32)
input_mean, input_std = 127.5, 127.5
```

```
# Initialize serial communication with the robotic arm
def find_arduino_port():
    ports = serial.tools.list_ports.comports()
    for port in ports:
        if "ttyUSB" in port.device or "ttyACM" in port.device:
            print(f"[INFO] Found Arduino on {port.device}")
            return port.device
    raise Exception("[ERROR] Arduino not found. Please check your connections.")

# Auto-detect the Arduino serial port
try:
    arm_port = find_arduino_port()
    arm_arduino = serial.Serial(arm_port, 9600, timeout=1)
    print(f"[INFO] Connected to Arduino on {arm_port}")
    time.sleep(2)  # Wait for Arduino to be ready
except Exception as e:
    print(e)
    exit()

# Initialize serial communication for the wheels (another Arduino)
try:
    wheel_port = find_arduino_port()  # Use a different port for the wheels
    wheel_arduino = serial.Serial(wheel_port, 9600, timeout=1)
    print(f"[INFO] Connected to wheels Arduino on {wheel_port}")
    time.sleep(2)
except Exception as e:
    print(e)
    exit()

# Map detected objects to categories
category_map = {
    'plastic': 'RECYCLABLE',
    'metal': 'RECYCLABLE',
    'paper': 'RECYCLABLE',
    'banana': 'BIODEGRADABLE',
    'apple': 'BIODEGRADABLE',
    'food': 'BIODEGRADABLE',
    'glass': 'NON_BIODEGRADABLE',
    'styrofoam': 'NON_BIODEGRADABLE',
    'battery': 'HAZARDOUS',
```

```
    'spray_can': 'HAZARDOUS',
}

# Function to send wheel movement command (forward, backward, turn)
def move_wheels(command):
    wheel_arduino.write((command + "\n").encode())
    print(f"[INFO] Sent to wheels: {command}")
    time.sleep(3)

# Main loop for frame capture and processing
frame_queue = Queue(maxsize=1)
frame_skip = 5
frame_count = 0

while True:
    if not frame_queue.empty():
        frame = frame_queue.get()
        frame_count += 1

        if frame_count % frame_skip != 0:
            continue

        frame_rgb = cv2.cvtColor(frame, cv2.COLOR_BGR2RGB)
        frame_resized = cv2.resize(frame_rgb, (width, height))
        input_data = np.expand_dims(frame_resized, axis=0)

        if floating_model:
            input_data = (np.float32(input_data) - input_mean) / input_std

        interpreter.set_tensor(input_details[0]['index'], input_data)
        interpreter.invoke()

        boxes = interpreter.get_tensor(output_details[0]['index'])[0]
        classes = interpreter.get_tensor(output_details[1]['index'])[0]
        scores = interpreter.get_tensor(output_details[2]['index'])[0]

        detected_category = None

        for i in range(len(scores)):
            if 0.6 < scores[i] <= 1.0:
```

```
            ymin = int(max(1, boxes[i][0] * imH))
            xmin = int(max(1, boxes[i][1] * imW))
            ymax = int(min(imH, boxes[i][2] * imH))
            xmax = int(min(imW, boxes[i][3] * imW))

            object_name = labels[int(classes[i])]
            label = f'{object_name}: {int(scores[i] * 100)}%'

            cv2.rectangle(frame, (xmin, ymin), (xmax, ymax), (10, 255, 0), 4)
            label_ymin = max(ymin, 25)
            cv2.putText(frame, label, (xmin, label_ymin - 7),
                        cv2.FONT_HERSHEY_SIMPLEX, 0.7, (0, 0, 0), 2)

            x_center = int((xmax + xmin) / 2)
            y_center = int((ymax + ymin) / 2)
            cv2.circle(frame, (x_center, y_center), 10, (0, 0, 255), 1)

            if object_name in category_map:
                detected_category = category_map[object_name]
                print(f"[INFO] Detected: {object_name} => Category: {detected_category}")
                break

        if detected_category:
            # Send category command to the robotic arm
            arm_arduino.write((detected_category + "\n").encode())
            print(f"[INFO] Sent to Arduino: {detected_category}")

            # Command wheels to move based on the detected object category
            if detected_category == 'RECYC

#include <Servo.h>

// Define servo objects
Servo waistServo;
Servo shoulderServo;
Servo elbowServo;
Servo wristPitchServo;
Servo wristRollServo;
Servo gripperServo;
```

```
// Define initial (resting) positions
const int waistHome = 180;
const int shoulderHome = 180;
const int elbowHome = 120;
const int wristPitchHome = 120;
const int wristRollHome = 90;
const int gripperOpen = 90; // Gripper open at rest

void setup() {
 // Attach servos to their respective pins
 waistServo.attach(8);
 shoulderServo.attach(9);
 elbowServo.attach(10);
 wristPitchServo.attach(11);
 wristRollServo.attach(12);
 gripperServo.attach(13);

 Serial.begin(9600);

 // Move to initial resting position
 moveToInitialPosition();
}

void loop() {
 if (Serial.available() > 0) {
  String command = Serial.readStringUntil('\n');

  if (command == "RECYCLABLE") {
   moveToRecyclablePosition();
  }
  else if (command == "BIODEGRADABLE") {
   moveToBiodegradablePosition();
  }
  else if (command == "NON_BIODEGRADABLE") {
   moveToNonBiodegradablePosition();
  }
  else if (command == "HAZARDOUS") {
   moveToHazardousPosition();
  }
 }
```

```
}

// Function to move to initial resting position
void moveToInitialPosition() {
  waistServo.write(waistHome);
  shoulderServo.write(shoulderHome);
  elbowServo.write(elbowHome);
  wristPitchServo.write(wristPitchHome);
  wristRollServo.write(wristRollHome);
  gripperServo.write(gripperOpen);
}

// Function to return the arm to a position depending on the object's height
void moveToHeightAdjustedPosition(int waistPos, int shoulderPos, int elbowPos, int
wristPitchPos, int wristRollPos) {
  waistServo.write(waistPos);
  shoulderServo.write(shoulderPos);
  elbowServo.write(elbowPos);
  wristPitchServo.write(wristPitchPos);
  wristRollServo.write(wristRollPos);
}

// Sample functions to move the arm to different positions
void moveToRecyclablePosition() {
  // Define position depending on the object's height and distance
  int waistPos = 80;
  int shoulderPos = 100;
  int elbowPos = 120;
  int wristPitchPos = 90;
  int wristRollPos = 90;

  waistServo.write(waistPos);
  shoulderServo.write(shoulderPos);
  elbowServo.write(elbowPos);
  wristPitchServo.write(wristPitchPos);
  wristRollServo.write(wristRollPos);
  gripperServo.write(gripperOpen);  // Open gripper
  delay(1000); // Wait for arm to move
  gripperServo.write(30);  // Close gripper
  delay(500); // Grab item
```

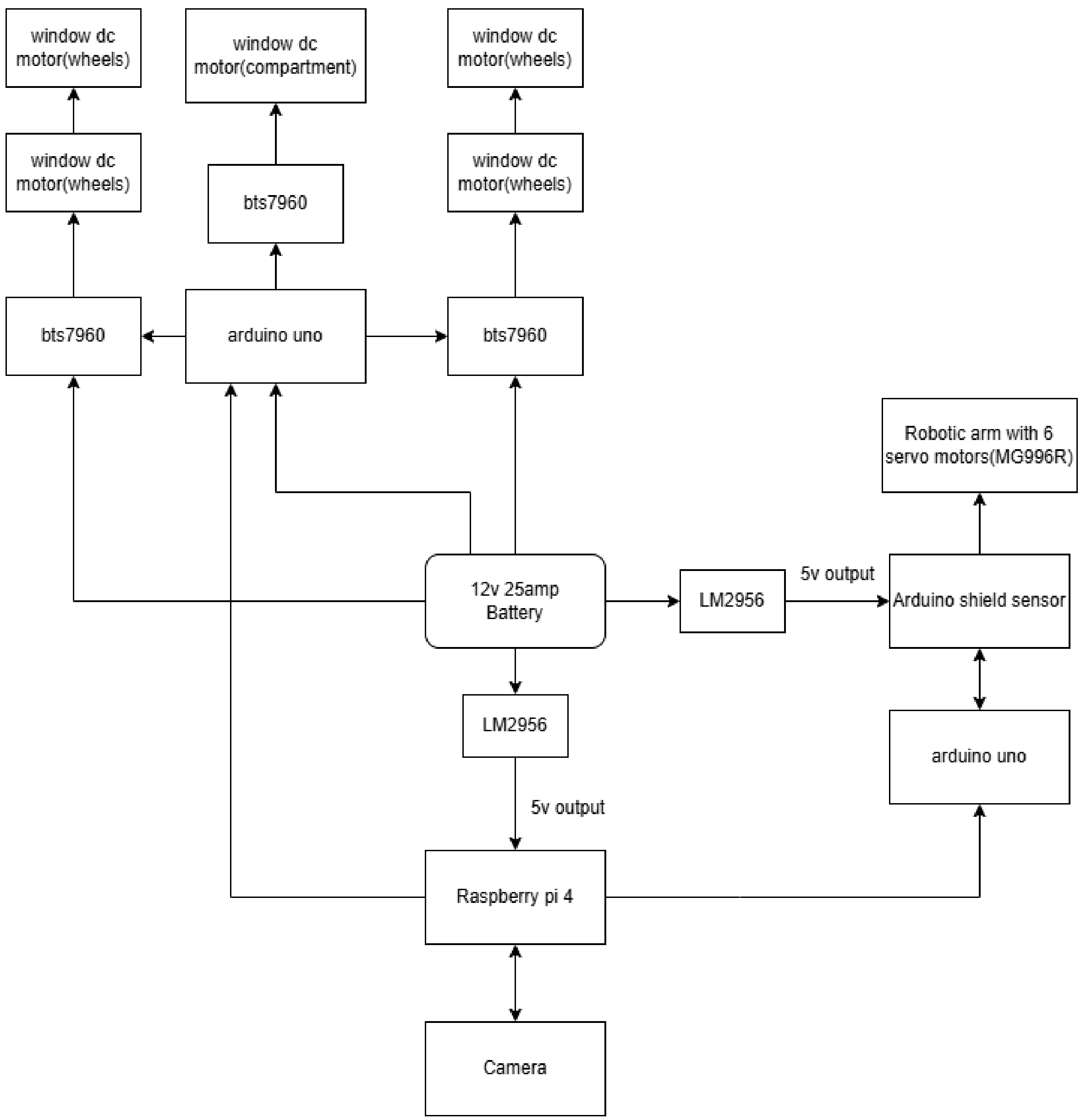
```
  // Adjust resting position based on object height (use dynamic positions here)
  moveToHeightAdjustedPosition(waistPos, shoulderPos, elbowPos, wristPitchPos,
wristRollPos);
}

void moveToBiodegradablePosition() {
  // Define position based on height/distance
  int waistPos = 100;
  int shoulderPos = 80;
  int elbowPos = 110;
  int wristPitchPos = 100;
  int wristRollPos = 90;

  waistServo.write(waistPos);
  shoulderServo.write(shoulderPos);
  elbowServo.write(elbowPos);
  wristPitchServo.write(wristPitchPos);
  wristRollServo.write(wristRollPos);
  gripperServo.write(gripperOpen);
  delay(1000);
  gripperServo.write(180);
  delay(500);

  // Return to adjusted position after grabbing
  moveToHeightAdjustedPosition(waistPos, shoulderPos, elbowPos, wristPitchPos,
wristRollPos);
}

void moveToNonBiodegradablePosition() {
  // Define position based on height/distance
  int waistPos = 70;
  int shoulderPos = 120;
  int elbowPos = 100;
  int wristPitchPos = 80;
  int wristRollPos = 90;

  waistServo.write(waistPos);
  shoulderServo.write(shoulderPos);
  elbowServo.write(elbowPos);
```

```
  wristPitchServo.write(wristPitchPos);
  wristRollServo.write(wristRollPos);
  gripperServo.write(gripperOpen);
  delay(1000);
  gripperServo.write(180);
  delay(500);

  // Adjust resting position after grabbing
  moveToHeightAdjustedPosition(waistPos, shoulderPos, elbowPos, wristPitchPos,
wristRollPos);
}

void moveToHazardousPosition() {
  // Define position based on height/distance
  int waistPos = 110;
  int shoulderPos = 110;
  int elbowPos = 90;
  int wristPitchPos = 85;
  int wristRollPos = 90;

  waistServo.write(waistPos);
  shoulderServo.write(shoulderPos);
  elbowServo.write(elbowPos);
  wristPitchServo.write(wristPitchPos);
  wristRollServo.write(wristRollPos);
  gripperServo.write(gripperOpen);
  delay(1000);
  gripperServo.write(180);
  delay(500);

  // Adjust resting position based on the object picked
  moveToHeightAdjustedPosition(waistPos, shoulderPos, elbowPos, wristPitchPos,
wristRollPos);
}

int motorPin1 = 3; // Motor A
int motorPin2 = 4; // Motor B
int motorPin3 = 5; // Motor C
int motorPin4 = 6; // Motor D
```

```
void setup() {
 Serial.begin(9600);
 pinMode(motorPin1, OUTPUT);
 pinMode(motorPin2, OUTPUT);
 pinMode(motorPin3, OUTPUT);
 pinMode(motorPin4, OUTPUT);
}

void loop() {
 if (Serial.available() > 0) {
  String command = Serial.readStringUntil('\n');

  if (command == "FORWARD") {
   moveForward();
  }
  else if (command == "BACKWARD") {
   moveBackward();
  }
  else if (command == "TURN_LEFT") {
   turnLeft();
  }
  else if (command == "TURN_RIGHT") {
   turnRight();
  }
 }
}

void moveForward() {
 digitalWrite(motorPin1, HIGH);
 digitalWrite(motorPin2, LOW);
 digitalWrite(motorPin3, HIGH);
 digitalWrite(motorPin4, LOW);
}

void moveBackward() {
 digitalWrite(motorPin1, LOW);
 digitalWrite(motorPin2, HIGH);
 digitalWrite(motorPin3, LOW);
 digitalWrite(motorPin4, HIGH);
}
```

```
void turnLeft() {
  digitalWrite(motorPin1, LOW);
  digitalWrite(motorPin2, HIGH);
  digitalWrite(motorPin3, HIGH);
  digitalWrite(motorPin4, LOW);
}

void turnRight() {
  digitalWrite(motorPin1, HIGH);
  digitalWrite(motorPin2, LOW);
  digitalWrite(motorPin3, LOW);
  digitalWrite(motorPin4, HIGH);
}
```

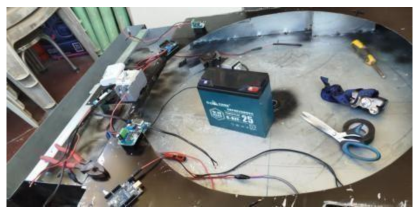
APPENDICES E
(CIRCUIT DIAGRAM OF TRASHYBOT)

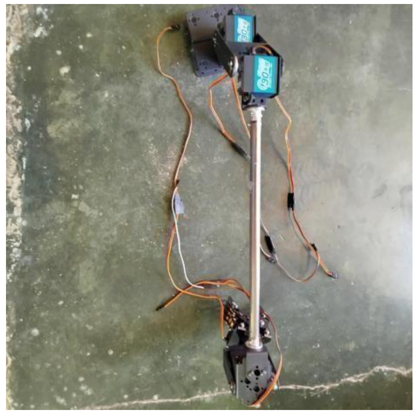


APPENDICES F

(DOCUMENTATION)

NAME	IMAGE	DESCRIPTION
Steel Plates		Creating the body of the trashyBot.
Compartment		Designing the compartment, so that the waste will maximize it.

Shaping		Shaping of the compartment
Testing		Testing of the components, if working.
Trash		Collecting of trash for image processing.

Robotic Arm		This arm will catch the trash and will segregate it.
IMAGE PROCESSING		Classifying waste detection. You can see in the picture the type of waste example is metal and plastic.

APPENDICES G (RESEARCHERS PROFILE)

ADRIAN S. CANLAS

POSITION

Technical support, Testing Assistant and lead Author of Paper, Hardware

EDUCATION

Year
3rd year student
Bachelor Of Science in Computer Engineering
Holy Cross College

SKILLS

- Writer
- Active listening
- Communication skills
- Problem solving
- Hardware
- Software

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CONTRIBUTION

- Coordinated in the team and the project.
- Studied user feedback for more improvements.

RONNEL O. DEANG

POSITION

Maintenance, Software and Hardware

EDUCATION

Year
3rd year student
Bachelor Of Science in Computer Engineering
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SKILLS

- Problem solving
- Hardware
- Software

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- Coordinated in the team and the project.
- Studied user feedback for more improvements.