# AI Camera-Integrated Waste Collection and Segregation System Using Raspberry Pi

A Design Project Presented to the Faculty of the

College of Engineering, Architecture, and Fine Arts

Department of Computer Engineering

University of Santo Tomas – Legazpi

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science in Computer Engineering

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February 2025

**ACKNOWLEDGEMENT**

The researchers would like to extend their deepest gratitude to the following people who inspired, supported, and gave assistance and information needed for them to make this project possible. It is, therefore, worth remembering the efforts of the following persons:

**Engr. Javier R. Vicera, MBA**, the Dean of the College of Engineering, Architecture, and Fine Arts, for the advice and support;

**Engr. Joshua L. Andrada, UBWS**, the adviser of this design project, for the endless support, encouragement, and words of wisdom giving necessary advice or suggestions to improve the research;

**Engr. Darwin B. Darca, MIT, Engr. John Richard A. Musni, Engr. Jolina May Damo, UBWS**, **and** the panelists, for their comments, suggestions, and recommendations for the improvement of the research;

**Jasper Jade Uvero**, a trustworthy friend, for the encouragement and every advice he gave to the researchers;

**To the researcher's families, friends, and loved ones**, for always believing in the researchers' abilities;

And above all, this would not be possible without the presence, help, and guidance of the **Almighty Father**, for giving the researchers the acquaintance and persistence for them to accomplish the study.

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## ABSTRACT

Waste management and segregation is a problem that happens daily in organizations like schools and offices which necessitates the development of innovative solutions for collecting and segregating. This study developed an AI Camera-Integrated Waste Collection and Segregation System using a Raspberry Pi, made to classify wastes into recyclable, biodegradable, and non-biodegradable categories. The system used the Object Detection Model called YOLOv5 to train custom datasets suited for garbage detection. The robotic arm, controlled by Servo Motors via Raspberry Pi, collects and sorts waste based on real-time detection results. The study used two datasets loaded together to ensure a higher accuracy and broader support of waste classification. This study contributes to sustainable waste management by integrating AI and robotics into smart waste collection systems.

# INTRODUCTION

## Project Context

In today's society, people are often too busy with their work or their academics to clean their households. Instead of spending time doing household chores, they spend it finishing their workload, their academic assignments, and their activities.

In line with this, the researchers produced a device that is programmed to detect and collect waste. The device is created using a combination of wooden chassis with servo motors, and ultrasonic sensors, then integrating that device with a software system and features that when the waste is collected, the device will automatically segregate them according to their respective type of waste (Biodegradable, Non-Biodegradable, or Recyclable).

The researchers came up with a garbage collecting system that is specially designed for places like offices or other organizational buildings, thus the researchers created: a device that is designed to assist janitors in collecting garbage inside the classrooms and offices while also segregating them off based on what type of garbage are they through the integration of AI cameras. By leveraging advanced technologies, this autonomous device will efficiently identify and collect garbage that can be seen in the targeted venues. Additionally, it was equipped with a segregation system to further reduce the work of the janitors from trying to segregate those collected garbage based on their respective categories.

This project was developed & experimented within the classrooms & offices of the University. Those places are the target venues the researchers chose because these are the places where littered garbage is commonly seen. These may pile up which can take the janitor a lot of time to clean the room and have a hard time segregating the garbage by their type correctly.

The researchers chose this project to find out if technology can be of help in improving cleaning. The second reason is for the researchers to experiment and attempt to successfully implement different systems in the project that help the cleaning process more effectively such as automatic segregation, to make an innovative floor cleaning. Lastly, the researchers want to assist the people responsible for maintaining the cleanliness of the university by creating a device that is intended to aid them in their jobs.

**Statement of the Problem**

The rising demand for maintaining cleanliness in our society coupled with the need for efficient waste management shows a challenge for us. Traditional manual cleaning processes are often time-consuming, labor-intensive tasks, and prone to human error, particularly in waste segregation.

The researchers studied (1) the feasibility of developing an AI-supported garbage collecting and segregating device that is capable of autonomously navigating inside a room while detecting waste, and (2) the overall efficiency of the proposed system in waste detection, and segregation accuracy, in comparison to traditional manual cleaning tasks.

### Objectives

There are two major objectives that this study wants to achieve. These objectives are (1) to develop and Integrate an AI-based garbage collector with Raspberry Pi. Additionally, (2) automatically clean and segregate garbage by the collected garbage type.

The device's performance and effectiveness will be assessed based on the amount of garbage it has collected compared to manual cleaning and how accurately it categorizes the different types of garbage. This project can be made possible due to the accessible and affordable components such as the Chassis, Wheels, Raspberry Pi, and the use of AI cameras that are needed for the creation of the device, which also means that the project wouldn't take a long time to finish since the core components needed for the project are few and are easily accessible.

### Scope and Limitations

This research study is aimed at the experience and opinions of the personnel who are responsible for cleaning the classrooms inside the university and how frequently garbage occurs inside the classrooms of the university.

The study may limit its capability in collecting garbage that is located inside an obscured area inside a room such as waste located in the corner of a room. Additionally, the proposed system can have some trouble collecting a clean flat sheet of paper, this is because they are difficult to collect using the researchers' device's planned components. Lastly, there will be a low chance that the researchers' system can collect it, but that mentioned object could either be an important document to the students or the personnel.

**Significance of the Study**

This project's beneficiaries are the janitors who are responsible for cleaning classrooms and offices in the university by helping them collect garbage that is commonly seen in classrooms and offices. Students and personnel will also be able to benefit from this by providing them with a clean workplace/classroom. Implementing this automated garbage collector, not only increases and improves the efficiency of garbage collection, but it promotes and maintains a clean and healthy environment within the University. Additionally, the researchers will be using the Raspberry Pi microcomputer for the proposed project to highlight that technology could be a solution for waste management. The implementation of an automated device that is customized to address the university's methods of maintaining & promoting cleanliness, can help in solving the demand for better cleaning performance and the development of cleaning robots, which are a similar study for the researchers' topic. As stated by Rizuwana Parween et al. in the study "Autonomous Self-Reconfigurable Floor Cleaning Robot": "The cleaning robots are going through some significant development in recent years, driven by the greater market penetration and the demand for better cleaning performance" (Parween et al., 2020).

**Review of Related Literature & Past Studies**

The development of automated systems for garbage collection and segregation has gained significant traction in recent years. With the rise of Artificial Intelligence and computer vision technologies, researchers and engineers have been able to create innovative solutions for more efficient waste management. This literature review aims to integrate and synthesize recent research findings related to AI-based computer vision systems, automated waste segregation, and object detection technologies and how the researchers can integrate these research findings into a floor-cleaning robot.

The concept of floor-cleaning robots or machines was traced back in the 1990's, they were introduced for the sake of the betterment of humankind. (N. Das et al., 2019) Several companies tried experimenting with the idea of an automated floor cleaner. However, "The early variations of these devices had the early prototypes as basic and have limited functionality." (Teendow: The evolutionary of cleaning robots, 2023). Because of the rapid advancements of technology in our current era, floor cleaning robots were one of the devices that are affected positively by the introduction of new & better components, opening a path of experimenting with different approaches to improvise this said device.

The project stated above is all about the early release of floor-cleaning robots. They were first introduced back in the 1990s and their main purpose is to aid humankind. Several companies had been experimenting with floor-cleaning robots that had limited capabilities and functionalities. The project introduced the same aim in line with the current researchers: to enhance the capabilities and features of the current existing project which can be of help in our environment to maintain its cleanliness and help to aid people in a certain way. The cited project introduced has limited functionality, allowing the researchers to produce features that can enhance its functionality and purpose.

"Cleanliness is an inseparable part of human life, and it can't only be seen in one place, for example, there's cleanliness in the place of work, office, school" (Irawan Yuda, et al., 2021) However, manual cleaning can cause problems to our health, and the most common example of this is inhaling certain particles which can lead to problems in our respiratory system (Nabamita Ramkrishna Das, et al, 2019). Additionally, to address this issue, humans developed automated floor cleaners. These machines not only reduce health risks associated with manual cleaning but also free up time for people, allowing them to focus more on more important tasks instead of spending excessive time cleaning. The problem this study aims to address is the development of an autonomous floor-cleaning device that is designed to assist people in cleaning rooms, thereby reducing their workload, and minimizing the risk of respiratory problems associated with manual cleaning.

The project is all about the importance and benefits of a clean environment, especially in the place of work, office, and school. It is mentioned that manual cleaning can cause problems for our health especially when inhaling dust particles that can lead to respiratory problems. The project introduced the same concept in line with the current proposed study: to aid and help people to lessen their workload and to prevent health risks that can be accumulated by manual cleaning.

The concept of autonomous floor-cleaning devices dates back to the 2000s. “These technological devices were built to assist humans and are programmed in such a way that they perform their tasks in a timely and precise manner. Floor cleaners have evolved over the years which started from vacuum cleaners to being fully automatic while having advanced features” (Murdan, Ramkisson, 2020). One of the early pioneering products was the Roomba robotic vacuum cleaner introduced by iRobot in 2002. It used sensors and navigation algorithms to clean floors autonomously. Over time, robotic floor cleaners incorporated additional capabilities like mopping along vacuuming. Modern robotic floor cleaners can map their surroundings, plan efficient cleaning paths, avoid obstacles, and even schedule cleanings autonomously. The incorporation of technologies like machine learning, computer vision, and simultaneous localization and mapping (SLAM) has further enhanced the intelligence and efficacy of these cleaning robots.

The project’s concept of autonomous floor cleaning devices was based on the early devices back in the early 2000s. Those technological devices were produced to assist human beings, and they were programmed in such a way as to perform their specific tasks with precise manners. The mentioned project can be of help to the researchers' study as it relates accurately to it, which is enhancing the existing project and by the help of this study, the researchers can enhance the project as it is cited that floor cleaners have evolved over the years.

Floor-cleaning robots leverage a combination of hardware and software technologies to achieve their autonomous cleaning capabilities. The core technological framework typically comprises microcontroller units, such as Arduino & Raspberry Pi boards, for low-level control and integration of various components. Drive mechanisms like omni wheels arranged in specific configurations enable multi-directional mobility. Cleaning mechanisms including vacuum motors for suction and rotating brushes/pads are used for scrubbing and mopping. Sensor arrays, such as ultrasonic, infrared, and LiDAR sensors, facilitate obstacle detection and environment mapping. Wireless communication modules like Bluetooth, Wi-Fi, and 5G enable remote control, data transfer, and cloud connectivity. Rechargeable battery packs and advanced energy management systems power the robot's operations. The software components play an equally crucial role, with embedded software and algorithms for sensor data processing, navigation, path planning, and cleaning actions. Innovative approaches like machine learning and computer vision are being integrated for intelligent object recognition, adaptive cleaning, and efficient path planning. Novel technologies such as simultaneous localization and mapping (SLAM), sensor fusion, and advanced navigation algorithms enable robots to create and update high-precision 3D environment maps for efficient navigation and coverage. User interfaces, mobile applications, and voice assistants provide manual control, scheduling capabilities, and intuitive human-robot interaction for cleaning routines.

The project highlights the main components that are used: ultrasonic sensors and Arduino are the main components of the project, it is similar to the researchers' project as, ultrasonic sensors are the choice of sensor and instead of using Arduino as the main microcontroller, the researchers are going to use Raspberry Pi as microcontroller of choice.

As highlighted in the study by Yatmono, et al. 2019, the integration of these hardware and software elements forms the technological backbone of floor-cleaning robots. The microcontrollers serve as the central processing units, coordinating the functioning of various subsystems. Sensors and algorithms enable autonomous navigation, obstacle avoidance, and efficient path-cleaning planning. The cleaning mechanisms, combined with the mobility system, allow the robots to effectively clean and maneuver through different environments.

The project is all about integrating both hardware and software components to produce a system that can benefit human beings to aid humans in cleaning households. The project aligns with the researchers' study because it utilizes hardware components and software to develop a system that can aid humans in cleaning inside our households.

The AIoT-based smart garbage bin proposed by Sung et al., (2022) demonstrated the feasibility of a self-navigating waste monitoring system that could request collection autonomously. However, it could not physically collect and segregate the waste. On the other hand, the intelligent floor-cleaning robot developed by Yatmono et al. could autonomously vacuum and polish floors using ultrasonic sensors and Omni wheels for navigation but did not incorporate any waste segregation capabilities.

The project is relevant to the researchers' study as, the project stated is a smart garbage bin based on AIoT, in the study the researchers are going to use the concept of it and integrate it into the system. Instead of the garbage bins mentioned in the project which will segregate the waste, the researchers' study, will separate its concept, as the researchers will create a system that can segregate wastes and proceed them to the proper garbage bin.

Several studies have focused on the development and implementation of AI-based device-vision systems. Shriram et al. (2021) presented a deep learning-based AI virtual mouse system using computer vision technology, which displays the potential of AIs in real-time image processing tasks. Furthermore, Teboulbi et al. (2021) have proposed a real-time implementation of an AI-based face mask detection system, highlighting the real-world applications of AI Cameras in public health and safety.

The project stated above is relevant to the researchers' study as; the project's concept is similar to the researchers' study. The project mentioned shows the evolution and real-life applications of AI cameras for improvement. In the project it is all about image processing a person's hand scanning for covid viruses, in the researchers' study it is similar as it will be using the process of image processing and scanning for different kinds of wastes.

The work by Donati et al. (2020) displays energy-saving road sweepers that use deep vision for garbage detection, illustrating the potential for AI and computer vision in waste management and environmental sustainability. Additionally, Yu (2020) developed a computer vision-based system for trash bin identification by classifying garbage, which further emphasizes the role of AI in waste segregation processes.

As indicated in the previous paragraph, the study cited above is all about garbage detection. The stated project mentioned can be of help to the researchers' study as the study includes garbage detection and has the feature of segregating the collected garbage.

The Al City Challenge conferences (Naphade et al., 2022; Naphade et al., 2023) provided insights into innovative AI technologies for vision-based systems. These studies highlighted the advancements in object detection, image recognition, and AI-powered surveillance systems. Their proposed system relies on AI Cameras for vision and trash identification. This research offers valuable insights into the state of AI technologies in computer vision.

The study mentioned is inclined with the researchers' study as object detection is mentioned in the project. Object detection is also a part of the researchers' system, the researchers will be using AI cameras to scan the detected waste and identify it on what type of waste it is. The project is all about object detection, in the mentioned project it is all about using AI cameras used for vision and trash identification. It is relevant to the researchers' study because AI cameras will be used for trash identification.

Despite their impact on household cleaning routines, floor cleaning robots are not without the challenges and limitations that they are facing. From issues related to navigation in complex environments to concerns regarding cleaning effectiveness, maintenance requirements, and privacy considerations, understanding these challenges is essential for both consumers and researchers, aiming to optimize the functionality and adoption of floor cleaning robots. In the study of Adithya et al., the researchers noticed that their floor cleaning robot's effectiveness needs some improvement on how they adapt to different rooms because in their paper, it's stated that in fully automatic mode, the robot can only cover around 90-92% of the garbage from the floor and the remaining 8-10% can be cleaned manually the researchers want to attempt to at least make their version of floor cleaning robot covers up at least 95% of the garbages. Additionally, the researchers want to try integrating AI Cameras instead of the ultrasonic sensors in the study of Yatmono et al for improved garbage elimination and segregation.

The project is relevant to the researchers' study as the project is all about enhancing existing projects and integrating them with the AI cameras, which are adapting to Artificial Intelligence. It is also relevant to the researchers' study as; the project is all about enhancing the effectiveness of the project to adapt to certain rooms which is similar to the researchers' study's choice of environment for the project.

The proposed device's capability to collect garbage and automatically segregate it as accurately as possible presents an opportunity for further research and development. The integration of advanced object detection algorithms and AI models could enhance the accuracy and efficiency of the garbage segregation process. Additionally, exploring the potential integration of IoT and AIoT as demonstrated by Gokarn et al. (2023), and Sung et al. respectively, could optimize the proposed system's performance in the targeted real-world environment. This literature review highlights the critical role of AI-based computer vision systems in garbage management and segregation. This review offers a comprehensive understanding of current technologies and possible future research directions in the context of the proposed floor-cleaning robot.

The project stated above is relevant to the researchers' study as the project is all about detection algorithms and AI. The stated project mentioned can be of help to the researchers' study as it includes the detection of garbage and separates them into the three classified types of waste (biodegradable, non-biodegradable, and recyclable).

Gunaseelan et al. (2023) present a design and implementation using a deep-learning algorithm for garbage segregation. Even though the specific details of their research were not provided, their study underscored the interest in deep-learning algorithms for waste segregation, which aligns with the focus of the current related literature review.

It explores the algorithms that can be used for garbage segregation. The study also highlights the increasing applications of AIs in waste management. It also underscores the importance of the researchers' proposed project, which aims to integrate AI Cameras programmed to detect garbage and segregate it.

Faiza et al. (2019) discuss a comprehensive study of the navigation techniques for robots. The study emphasizes the importance of hybridization of algorithms for achieving the best performance in complex environments.  Additionally, the study highlights the challenges and benefits of using these hybrid methods in robot path planning by addressing issues like computational complexity, and unclear data.

This study showcases the significance of combining different algorithms for optimized performance, response times, accuracy, and error handling of an autonomous system, which is relevant to enhancing the proposed topic’s navigation performance and adaptability.

Dai et al. (2019) highlight the significance of simultaneous localization and mapping (SLAM) and the fundamental role it plays in indoor navigation for an autonomous robot and devices. Their study emphasizes its role in mapping and localization. This finding is further supported by Wahab et al (2020). Which discussed the enhancement of the accuracy of the robot in mapping and localization through research point cloud registration, visual feature matching, and inertia navigation.

In the context of floor-cleaning robots, SLAM techniques are important for creating accurate maps of indoor spaces. These maps enable the robot to plan optimal cleaning paths, avoid obstacles, and efficiently cover the entire floor area.

**Synthesis of the study**

The summary of the related literature given is that the main purpose of which is to help us human beings to lessen our workload in doing household chores by aiding us in using the device or technology to clean the floors in our household. Another purpose of this is, for us not to inhale certain particles, the dust, which can be bad for our health and can lead to problems in our respiratory system.

The given related literature focuses on conceptualizing an automated floor-cleaning robot, device, or technology that can aid us human beings in cleaning floors, picking up unnecessary waste, and not spending most of our time cleaning them. Floor cleaning robots were developed not just to assist us with cleaning, but also to reduce health risks, such as those caused by inhaling dust.

The majority of the given related literature focuses on creating innovative solutions for more efficient waste management in the environment. Developing innovative solutions benefits humans by assisting with everyday tasks such as cleaning, washing clothes, cooking, and managing schedules, allowing them to focus on more important tasks. Every single one of the given related literature can benefit individuals, especially individuals who are handicapped, have disabilities, and the individual that suffer from severe illness.

**Gap to be Bridged**

Similarly to the related literature that was provided, the researchers developed a prototype that not only can collect waste, but also segregate them. The previous studies are all about a floor-cleaning device. One of them was a floor-cleaning robot that could only collect paper and plastic waste and did not segregate them according to their respective category. The researchers' study is an enhanced or modified version of previous existing studies by making use of their different ideas and features and putting it all on a single prototype which is the researchers' proposed project.

The floor cleaning robot can be enhanced by integrating AI cameras within the AIoT framework of Sung et al. that is programmed with the influence from the studies of Donati et al., Yu, and Naphade et al. The embedded computer vision models in the AI cameras would allow detection, localization, and classification of different waste types like plastic, metal, paper, and organic matter. As demonstrated in the smart garbage bin. This visual perception can guide the robot's autonomous navigation from the study of Yatmono et al. to efficiently collect the identified waste into separate compartments based on material category. The AI cameras can also monitor bin levels, akin to the smart garbage bin of Sung et al, and request collection when full. Furthermore, the collected waste will be analyzed by the AI that will be programmed into the software of the device for insights into waste patterns and optimizing collection routes over time.

**Operational Terms**

**Automated floor cleaner** – This will serve as a guide for the researchers as their study's concept is similar to it. A robotic floor cleaning system that integrates sensors, mapping technologies, and cleaning tools to autonomously navigate and clean floor surfaces, adapting to different surface types and cleaning requirements.

**Webcam** – Its main purpose is to scan what kind of waste it detects, and after detecting the waste it then sends the data back to the microcontroller to proceed with the waste segregation. It scans first the waste it detects and determines where it should proceed after detecting it..

**Raspberry Pi** – This will serve as the core of the system which is responsible for executing all of the codes and designated outputs of the system. It is the researchers' chosen microcontroller used for taking and executing the codes and uploading them to the different systems of the prototype.

**Chassis** – The base of the proposed system which will be used for the assembling of other components such as motors, Raspberry Pi, and robotic arm. The researchers will create them by hand to make sure the chassis's sizing is appropriate for accommodating all of the system's parts.

**Ultrasonic Sensors** – It is used in the way that it acts as the vision and object detection of the machine in navigating inside the classrooms of the University. It detects nearby objects or obstacles and performs countermeasures that are programmed to it when it detects an object or obstacle.

**Robotic Arm** – The component that is responsible for collecting the detected waste.

# METHODOLOGY

## Research Design

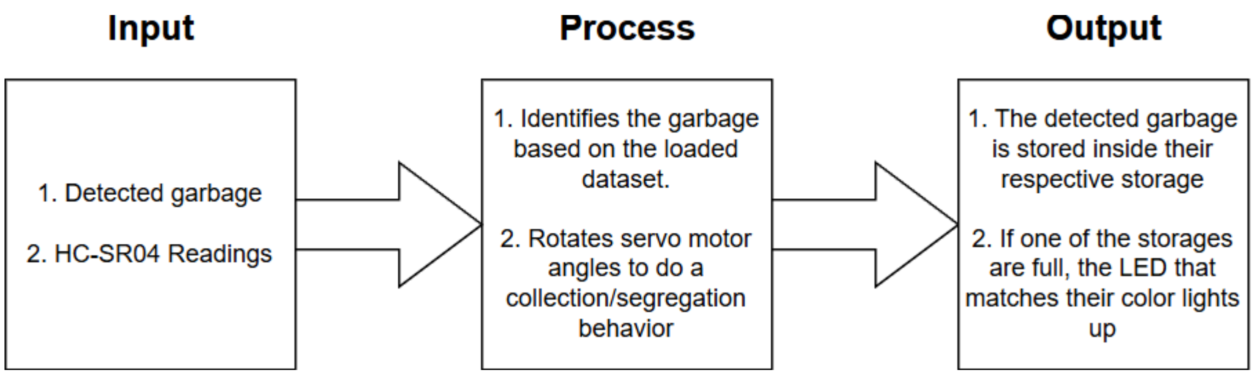


***Figure 1. Conceptual Framework***

Figure 1 shows the Conceptual Framework of the system. This shows that the system would start by scanning the garbage waste that it will detect, after which the main processes occur; identification of the type of waste and determining where the identified waste corresponds to the garbage bins. The flow ends after an LED turns on depicting that the garbage bin is full.

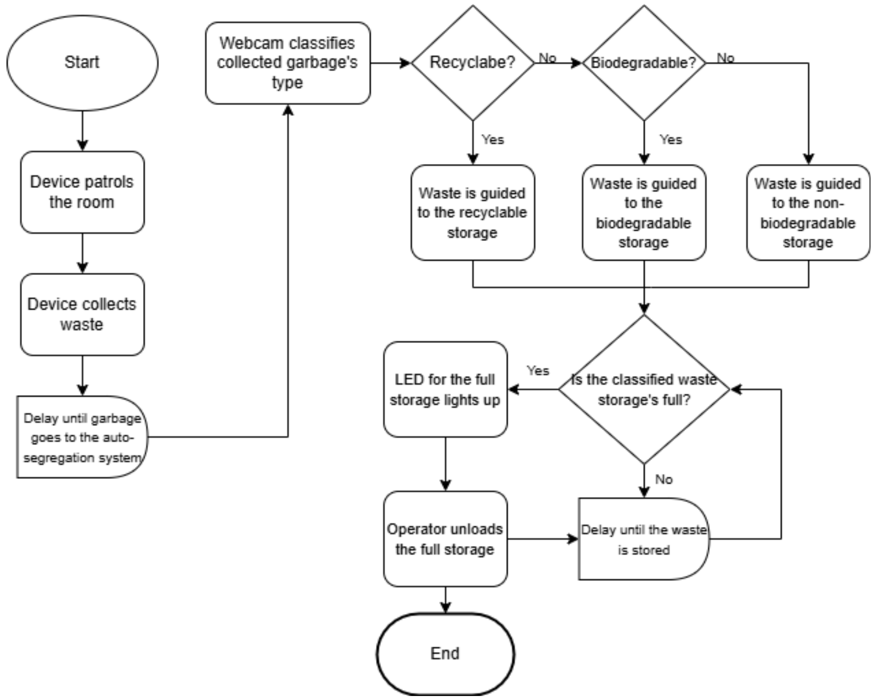


***Figure 2. Flowchart of the Project***

Figure 2 represents the Flowchart of the proposed device's sequence of processes. When the device is turned on, it automatically starts to patrol the area looking for garbage and when it locates one, it will collect it through the vacuum cleaner attached to its front and will be directly placed in the auto segregation system where the Camera Module will detect the type of the garbage that the device has collected through a database that contains the basic details of the trash and what category it is. When the detection is finished, it will be placed on that type of garbage storage based on what the Camera Module has detected for that trash. For the storage notification, the LED lights are at a LOW state each is also connected to the three storage which indicates they are not empty, and those LED lights corresponding to what type of storage will turn into a HIGH state if it is full. After this whole process, the device will continuously patrol around the room to check for more waste until the operator decides to boot the system off.

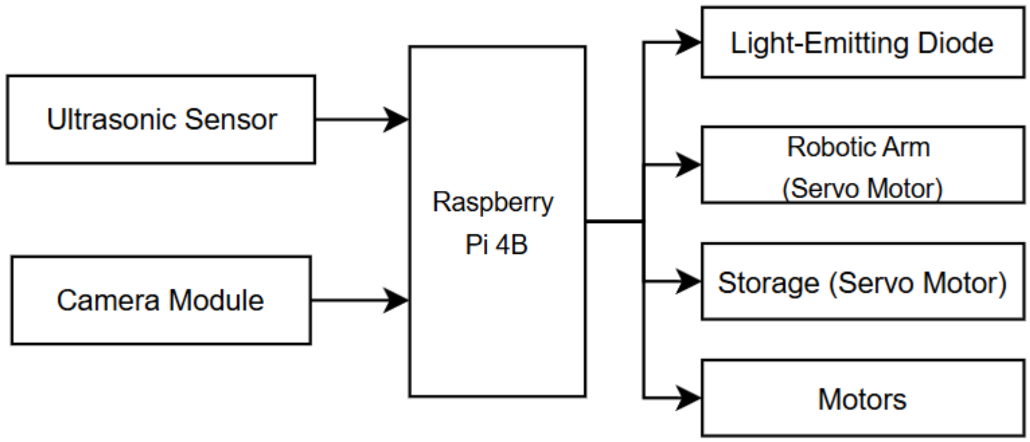


***Figure 3. Block Diagram***

Figure 3 depicts the Block diagram of the system. The block diagram shows how the components of the system will work successfully. Raspberry Pi acts as the core of the system because it is where all the main processes occur. This shows the system will function first after the ultrasonic sensor detects an object or obstacle. After the detection of the ultrasonic sensor, the camera module will then scan what type of waste the ultrasonic sensor has scanned. The data therefore is being sent back to the Raspberry Pi where the segregation system will occur. After the segregation part, the scanned waste will then proceed to the storage where there is an LED that will turn on if the storage is full.

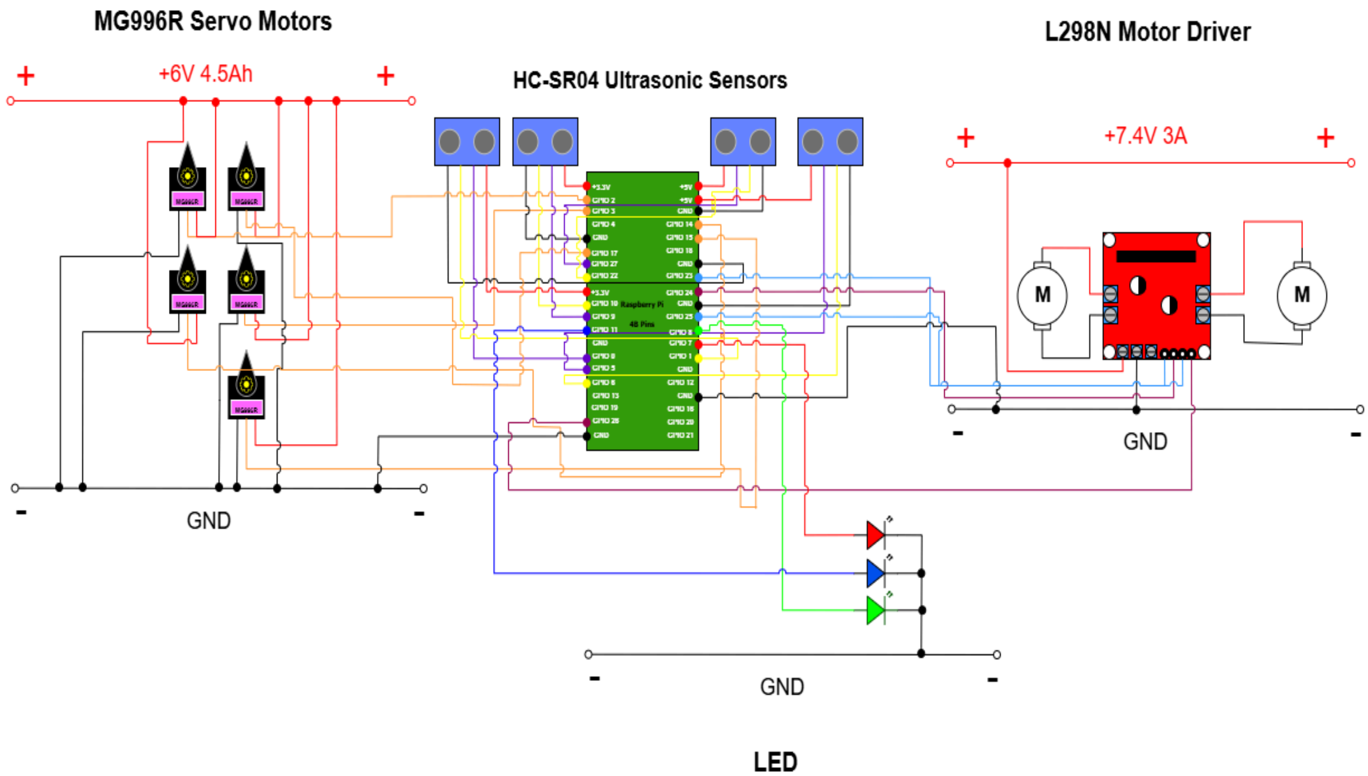


*Figure 4. Schematic Diagram of the Project*

Figure 4 shows the schematic diagram of the prototype. Each component used in the project is connected to the General-Purpose Input/Output (GPIO) pins of the Raspberry Pi to control the servo motors and the L298N motor driver while powering the LEDs and the HC-SR04 ultrasonic sensors, as well as activating their TRIG and ECHO pins. The servo motors and the motor driver are powered by an external power source consisting of a 6V 4.5Ah lead-acid battery and two 3.7V 1.5A batteries connected to a battery case. Each external power source is soldered to a PCB that shares a GND connection with one of the Raspberry Pi's GND pins to ensure smooth signal interpretation and prevent hardware damage.

***Figure 5. Prototype Blueprint of the Project***

Figure 6 shows the blueprint of the prototype to be done by the researchers. While it doesn't focus on the electrical component connections of the prototype, it instead shows the placements of each part of the prototype. The angles that are provided in the figure are top, back, and side views.

**Materials/Components**

***Figure 6. Raspberry Pi***

Raspberry Pi is a series of small single-board computers developed by the Raspberry Pi Foundation. It is used for various electronic projects that can be programmed by a computer or a laptop. This will serve as the core of the device as it will be responsible for controlling all the components that the proposed project will use such as turning the LED indicators for the storage into either HIGH or LOW depending on the syntax that was given to it.

***Figure 7. Ultrasonic Sensor***

Ultrasonic sensors are an electronic component that uses ultrasonic sound waves to measure distances between objects. It functions by sending out ultrasonic pulses and measuring the time it takes for the pulses to bounce back after hitting something. This is used for the calculation of the distance from the sensor to the object.

This is responsible for the obstacle detection in the project to prevent it from colliding with them and instead allows the model to rotate and lets them detect a path that does not have any obstacles for them to go onto as well as determining if one of the storages are full and letting the system know if the prototype is too far for the trash that is to be collected.

***Figure 8. Connecting Wires***

Connecting wires will be responsible for the connections of all the components to Raspberry Pi, allowing them to be powered up and controlled by the code run inside the Raspberry Pi itself.

***Figure 9. LED***

Light-emitting diodes (LED) are electrical components that emit light when connected to a power source and a ground reference. They are going to be used in the prototype to indicate that the storage is full by lighting up one of the three LEDs that match the color of the storage.


***Figure 10. 6V 4.5Ah Rechargeable Lead-Acid Battery***

One of the external power supplies used in the prototype. This battery is enough to safely power the MG996R servo motors as the operating voltage that they require ranges from 4.8V up to 7.2V, the battery also provides a high current (4.5A) which is over the stall current (2.5A) of the MG996R servo motors.


***Figure 11. Servo Motor (MG996R)***

The prototype will use the servo motor model MG996R, it is a dark-colored servo motor that has enough torque to carry heavier objects than the commonly used SG90 servo motor.

They are the perfect choice of a motor for the project because it is capable of doing a 180-degree rotation allowing the device to turn left or right to avoid the obstacles that it detects. Additionally, they will be installed on the collector of the device (Robotic arm) for collecting the detected wastes and managing the correct angle in storing those wastes to the storage.

***Figure 12. Webcam***

The project will use a Webcam to act as the machine’s vision. It will be programmed to capture in real-time as it will be the component responsible for detecting wastes.

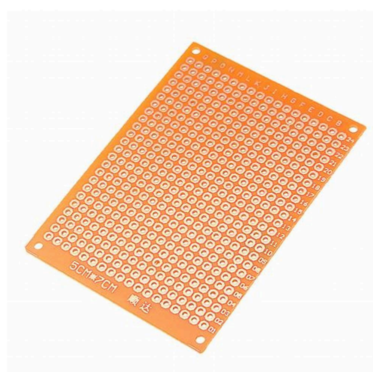

***Figure 13. Universal PCB***

The prototype will use Printed Circuit Boards (PCB) which will be soldered to connect the components like the MG996R servo that draws higher current to an external power source.

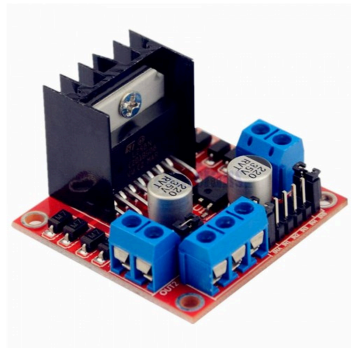

***Figure 14. L298N Motor Driver***

L298N motor drivers are responsible for controlling the DC motors of the prototype. They are programmable which allows them to change the direction of the motors to forward or backward. These components allow the prototype to move forward, backward, and turn left or right when it detects an obstacle.

***Figure 15. Plywood***

The prototype's model such as its main body layers, arms, and storage will be made out of plywood. The storage is shaped as a hexagon which will then be painted with red, green, & blue on each side equally. The body of the prototype is composed of two layers, with the first layer being the placement of the Raspberry Pi and the components' connections. The second layer is placed on top of the first layer and will have a hexagon-shaped plate screwed on top of an MG996R servo motor as the one that rotates the storage.


***Figure 16. 3.7V 1.5A Lithium-Ion Battery***

One of the external power supplies used in the prototype. This battery will be installed on a dual battery case to double their voltage and amperes (7.4V 3A), enough to power up the L298N Motor Drivers and DC Motors.

**Implementation Plan**

***Table 1. Implementation Plan***

| Strategy | Activities | Persons Involved | Duration | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Aug | Sept | Oct | Nov | Dec | Jan | Feb |
| Setting and preparing components | - Installing operating system on Raspberry Pi and preparing the components that will be used in the design | Researchers | | | | | | | |
| Building the device | - Programming the software of the system<br>- Connecting all the components needed by modifying the internal part of the RC Truck | Researchers | | | | | | | |
| Experimentation | - Implementing test runs on the device to check possible faulty actions or to see if it needs improvements | Researchers | | | | | | | |
| Simulation | - Performing simulations in classrooms to check the performance of the system.<br>- Make adjustments in the system if necessary | Researchers | | | | | | | |

Table 1 represents the implementation plan of the researcher used for the project. It consists of the strategies and activities that the researchers carefully planned that ensured the project to be a success. It also shows the duration of how much time the activities were consumed for the project.

**Data Gathering Tools**

For this study, the researchers employed two primary data-gathering tools which are (1) Internet Research and (2) Device Test Runs. These tools were enough to get the necessary data the researchers need by conducting online research including the latest developments in AI-powered waste systems, best practices in waste segregation, and existing studies or implementations of similar systems. Additionally, the researchers conducted multiple test runs of the device which made them aware of errors that were fixed while also assessing its performance in terms of its waste detection & segregation accuracy, and storage capacity.

**Ethical Considerations**

The project's primary ethical concern revolves around safeguarding the data from the images that the system will be obtaining. The cameras can raise privacy issues, particularly if the image they have captured contains people or sensitive areas around the room. The researchers will ensure that any data collected from these images is stored securely and should be used only for its intended purpose. Second, is the impact of the system on jobs. The device is not intended to completely replace the personnel who are responsible for cleaning the room completely but instead, its purpose is to assist them with their work to lessen their workload. Lastly, the human-AI interaction will be made user-friendly and not complex to operate for the users of the device.

## RESULTS & DISCUSSION

This section includes all the results that were taken according to testing the prototype, which are ultrasonic sensor detection values alongside the two datasets' loss values, precision, recall, and mean average precision (mAP) that will be loaded from the code of the system. Additionally, the researchers will discuss the effectiveness and accuracy of the prototype when detecting and collecting garbage.

### Presentation of Data

After the datasets were trained for waste detection, the researchers evaluated the datasets to assess their accuracy in identifying the classes or objects that they were trained to detect. Below are the tables of values that were taken from YOLOv5's dataset evaluation command which outputs a table containing the dataset's correct predictions which are represented by the letter 'P' that can be calculated as $P = \frac{True\ Positives}{(True\ Positives + False\ Positives)_{-}}$, recall that is represented as 'R' in the table which has the value of the dataset's ratio of true positives which can be calculated as $R = \frac{True\ Positives}{(True\ Positives + False\ Negatives)}$. Lastly, the values mAP50 & mAP50-95 combine Precision (P) & Recall (R) to measure the model's accuracy, considering object overlap thresholds from 50% (IoU=0.50) to 95% (IoU=0.95). In simpler terms, mAP tells us how well the model places a marking around a detected object.

***Table 2: Dataset A Metrics***

| Class | Images | Instances | P | R | mAP50 | mAP50-95 |
|---|---|---|---|---|---|---|
| All | 183 | 442 | 0.951 | 0.879 | 0.937 | 0.82 |
| Can | 183 | 143 | 0.976 | 0.951 | 0.982 | 0.898 |
| Food-Wrapper | 183 | 42 | 0.892 | 0.714 | 0.81 | 0.662 |
| Paper | 183 | 187 | 0.967 | 0.94 | 0.983 | 0.874 |
| Plastic Bottle | 183 | 70 | 0.97 | 0.909 | 0.975 | 0.845 |

***(Dataset "Thesis Computer Vision Project" by Ed Mikael Bobic)***

Table 2 contains the values of the first dataset that was loaded in the prototype's code. This dataset supports only four types of waste but has higher performance metrics to make up for it as seen in its overall precision (P) value of 0.951 (95.1%) and recall (R) value of 0.879 (87.9%).

***Table 3: Dataset B Metrics***

| Class | Images | Instances | P | R | mAP50 | mAP50-95 |
|---|---|---|---|---|---|---|
| All | 2098 | 18916 | 0.602 | 0.477 | 0.531 | 0.341 |
| Biodegradable | 2098 | 13637 | 0.799 | 0.508 | 0.631 | 0.343 |
| Cardboard | 2098 | 1292 | 0.747 | 0.437 | 0.577 | 0.390 |
| Glass | 2098 | 2380 | 0.883 | 0.679 | 0.811 | 0.560 |
| Metal | 2098 | 1360 | 0.743 | 0.609 | 0.677 | 0.427 |
| Paper | 2098 | 33 | 0.0803 | 0.121 | 0.0471 | 0.0348 |
| Plastic | 2098 | 214 | 0.387 | 0.472 | 0.42 | 0.262 |

***(Dataset "GARBAGE CLASSIFICATION 3" by Material Identification)***

Table 3 contains the values of the second dataset that were loaded in the prototype's code. This dataset supports a wider range of classes that it can detect but at the cost of lower performance metrics as seen from its precision (P) value of 0.602 (60.2%), and recall value of 0.477 (47.7%).

***Table 4: HC-SR04 Distance Values***

| **Detection Purpose** | **Detection Range** |
|---|---|
| Obstacle Detection | Below 25cm |
| Object Distance Detection | Between 35cm to 37.5cm |
| Storage Checking Detection | Below 8cm |

Table 4 presents the values that were used for the different detection purposes in the system that were measured using the HC-SR04 ultrasonic sensor. The detection purposes are categorized into three functions: obstacle detection, object distance detection, and storage checking detection.

- **Obstacle Detection:** This ensures that the system avoids collisions from any obstacles once the distance reading of the sensor is below 25cm.
- **Object Distance Detection:** This function is responsible for measuring the distance between the collector of the prototype and the waste to be collected.
- **Storage Checking Detection:** This checks the storage of the prototype to make sure that there is still room for the waste collected.

**Discussion**

Wastes have always been a common problem in offices and schools. This study can hopefully assist people in managing their wastes effectively. This prototype was developed based on the research's objectives which are to develop an AI waste classification prototype that collects and segregates automatically at the same time navigates itself automatically while having the ability to avoid obstacles. The prototype is equipped with servo motors for robotic arm control and storage rotation that rotate to specific angles specialized for storing the three types of wastes which are recyclable, biodegradable, and non-biodegradable. Additionally, ultrasonic sensors are also equipped as well for measuring the distances of the obstacle and waste that's to be collected.

During the development of the prototype, the researchers faced the problem of selecting the precise datasets to be used in the computer vision of the system, and due to the code needing a high amount of memory usage. Additionally, the researchers faced the critical problem of having the Raspberry Pi board itself completely stop working because of an unknown reason, while also facing the problem regarding the weights of the storage and arms that make the servo motors have a difficult time supporting their weight as they are too heavy for the servo motor to carry them.

Because of these challenges, the researchers realized the complexity of the study which also allowed them to think of different types of solutions to solve those challenges and successfully develop a working prototype that fulfills the objectives the researchers have set for their study.

**Findings**

After the researchers have completed the code and the hardware connections of the prototype, the researchers' findings are:

- The servo motor requires an external supply to function, hence the prototype had several plugs attached to a single extension. Five servo motors cannot be powered by a Raspberry Pi because the combined current consumption exceeds the Pi's capacity.
- The Raspberry Pi microcomputer which is used to control the whole prototype needs to be manually turned on to run the systems of the prototype.
- The prototype may only collect and segregate one item at a time making it less effective in rooms with a lot of wastes grouped.
- The prototype has a chance to not collect a clean, flat sheet of paper completely as the mechanism for it is not guaranteed to properly collect them as the mechanism is designed to collect various types of waste and not just for that specific item only.

After multiple simulations and testing of each of the prototype's systems, the researchers found out that the prototype works well when we simulate each of the 4 systems one at a time. When the researchers tried to combine all of the 4 systems into one system it resulted in the microcomputer Raspberry Pi 4B overloading the whole system and it automatically shuts down because of the multiple systems. Even though the microcomputer is loaded with 8 gigabytes of memory, it still couldn't handle the load that is loaded on it.

Even with all the objectives met, this project cannot guarantee an autonomous system. Just like any prototype, there are industries in which there are limitations on the use of this prototype and its system. First is the limited number of systems that the Raspberry Pi can process and execute. Due to the multiple systems that are loaded onto the microcomputer namely; The Obstacle avoidance system, Object detection system, Navigation system, and the Waste segregation system. Apart from those systems there are also two included datasets that contain all of the data needed for the object detection system which is AI integrated. The said datasets are loaded also to the Raspberry Pi making the microcomputer carry out heavy assigned tasks to execute, resulting in overloading and the microcomputer automatically shuts down because of it.

**Recommendations**

After testing the prototype, the researchers thought of improvements to further enhance its performance and its effectiveness in assisting people during the cleaning process. The recommendations of the researchers to improve the prototype's capabilities is to first, use a much better, faster, and more advanced microcomputer used in this prototype as it takes a while to process its detections. Next is to let the prototype handle wastes that are grouped to each other and segregate them correctly. Another recommendation is to use more powerful servo motors that are designed to handle heavy-duty tasks which allows the prototype to have a much larger storage capacity.

After executing multiple simulations and tests, the researchers recommend if financial constraints are not an issue, and one can easily afford and obtain these materials, the researchers would recommend using the latest microcomputer which is the Raspberry Pi 5 or any microcomputer that can withstand multiple systems. The use of the latest version of the Object detection model to process multiple images more efficiently. The use of a camera module that is compatible with the chosen microcomputer or microcontroller, to scan and identify wastes more efficiently. Slight adjustments in the codes wherein, after it detects a waste, it will automatically go towards the detected waste and not just avoid or bump into it.

**Conclusion**

The study developed an AI Camera-Integrated Waste Collection and Segregation System that has demonstrated the potential of combining hardware with software to enhance the waste management process. The software of the prototype is composed of two YOLOv5-trained custom data sets designed for detecting garbage wastes, OpenCV for computer vision, and Python as the programming language. The hardware of the prototype is made out of woods connected for the main body as well as storage whose each side is painted red, green, and blue to distinguish what type of garbage storage they are, and the arm of the collector as well, for the hand of the prototype, the researchers used curtain rod and a halved garbage bin designed for picking up wastes.

The prototype has several systems to achieve its collection and segregation features. One of those features is the collection mechanism, it's activated when both the camera detects the waste. After that, the collection mechanism is then activated controlling the servo motors controlling the arm of the prototype by rotating to 80 for both the left and right arm then rotating to 0 degrees for the left arm and 180 degrees for the right arm to put the detected waste to the storage. The segregation mechanism of the prototype is done by using a single MG996R servo motor to rotate the storage to three specific angles which are: 88 degrees for non-biodegradable, 100 degrees for biodegradable, and 180 degrees for recyclable.

By finishing the development of the prototype, the researchers concluded that waste collection robots have a bright future ahead of them with even more advanced features and various applications not just for floors, but in other areas of the room as well.

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# Appendix Programs

# A. Prototype's Code

**Final prototype code using the Python Language**

```
modelPathA = "A.pt"

modelPathB = "B.pt"

try:

    model_a = torch.hub.load('ultralytics/yolov5', 'custom',
    path=modelPathA)

    model_b = torch.hub.load('ultralytics/yolov5', 'custom',
    path=modelPathB)

except Exception as e:

    print(f"Error loading YOLOv5 models: {e}")

    exit(-1)

# Segregation of Items

class_to_message_a = {

'can': "Segregate to Recyclable",

'food-wrapper': "Segregate to Non-Biodegradable",

'paper': "Segregate to Biodegradable",

'plastic bottle': "Segregate to Recyclable"

}

class_to_message_b = {

'BIODEGRADABLE': "Segregate to Biodegradable",

'CARDBOARD': "Segregate to Recyclable",

'GLASS': "Segregate to Non-Biodegradable",

'METAL': "Segregate to Recyclable",

'PAPER': "Segregate to Biodegradable",
```

```
'PLASTIC': "Segregate to Non-Biodegradable",
}
# Confidence threshold
threshold = 0.5
# Start Camera
cam = cv2.VideoCapture(0)
width = 480
height = 320
cam.set(cv2.CAP_PROP_FRAME_WIDTH, width)
cam.set(cv2.CAP_PROP_FRAME_HEIGHT, height)
if not cam.isOpened():
     print("Error: Could not open webcam.")
     GPIO.cleanup()
exit(-1)
time.sleep(1)
# OpenCV Window
cv2.namedWindow("Preview Window", cv2.WINDOW_NORMAL)
cv2.resizeWindow("Preview Window", 480, 320)
# Collecting Status
collecting = False
# Main Loop
try:
 while True:
     # Ultrasonic Sensor readings
```

```
distance_to_object = measuringUltra()
redFull = redUltra()
grnFull = grnUltra()
bluFull = bluUltra()
# Storage Checking
if bluFull <= 8:
GPIO.output(bluLED, GPIO.HIGH)
else:
GPIO.output(bluLED, GPIO.LOW)
if grnFull <= 8:
GPIO.output(grnLED, GPIO.HIGH)
else:
GPIO.output(grnLED, GPIO.LOW)
if redFull <= 8:
GPIO.output(redLED, GPIO.HIGH)
else:
GPIO.output(redLED, GPIO.LOW)
# Capture frame
ret, frame = cam.read()
if not ret or frame is None:
print("Error: Failed to capture from webcam")
continue
frame_rgb = cv2.cvtColor(frame, cv2.COLOR_BGR2RGB)
# Detect objects with both models
```

```
results_a = model_a(frame_rgb)

results_b = model_b(frame_rgb)

# Process detections from Model A

detections_a = results_a.xyxy[0].cpu().numpy() if
results_a.xyxy[0].shape[0] > 0 else []

for *box, confidence, classId in detections_a:

if confidence < threshold:

continue

x1, y1, x2, y2 = map(int, box)

class_name = model_a.names[int(classId)]

label = f"{class_name} {confidence:.2f}"

cv2.rectangle(frame_rgb, (x1, y1), (x2, y2), (0, 255, 0), 2) #
Green for Model A

cv2.putText(frame_rgb, label, (x1, y1 - 10),
cv2.FONT_HERSHEY_SIMPLEX, 0.6, (0, 255, 0), 2)

# Print segregation message for Model A

if class_name in class_to_message_a:

     collecting = True

     stop_motors()

     category = class_to_message_a[class_name]

     print(category)

     if 35 < distance_to_object <= 37.5:

     if "Non-Biodegradable" in category:

     segregation_servo(88)

     time.sleep(3)
```

```
    collectGarbage()

    obstacleAvoidance()

    elif "Biodegradable" in category:

    segregation_servo(180)

    time.sleep(3)

    collectGarbage()

    obstacleAvoidance()

    elif "Recyclable" in category:

    segregation_servo(0)

    time.sleep(3)

    collectGarbage()

    obstacleAvoidance()

    elif distance_to_object < 25:

    move_backward()

    elif distance_to_object > 45:

    move_forward()

    collecting = False

# Process detections from Model B

detections_b = results_b.xyxy[0].cpu().numpy() if
results_b.xyxy[0].shape[0] > 0 else []

for *box, confidence, classId in detections_b:

if confidence < threshold:

continue

x1, y1, x2, y2 = map(int, box)
```

```
class_name = model_b.names[int(classId)]

# Skip "PAPER" and "PLASTIC" detections from Model B

if class_name == "PAPER" or class_name == "PLASTIC":

print(f"Skipping {class_name} detection.")

continue

label = f"{class_name} {confidence:.2f}"

cv2.rectangle(frame_rgb, (x1, y1), (x2, y2), (255, 0, 0), 2) #
Blue for Model B

cv2.putText(frame_rgb, label, (x1, y1 - 10),
cv2.FONT_HERSHEY_SIMPLEX, 0.6, (255, 0, 0), 2)

# Print segregation message for Model B

if class_name in class_to_message_b:

    collecting = True

    stop_motors()

    category = class_to_message_b[class_name]

    print(category)

    if 35 < distance_to_object <= 37.5:

    if "Non-Biodegradable" in category:

    segregation_servo(88)

    time.sleep(3)

    collectGarbage()

    obstacleAvoidance()

    elif "Biodegradable" in category:

    segregation_servo(180)

    time.sleep(3)
```

```
            collectGarbage()
            obstacleAvoidance()
            elif "Recyclable" in category:
            segregation_servo(0)
            time.sleep(3)
            collectGarbage()
            obstacleAvoidance()
            elif distance_to_object < 34:
            move_backward()
            elif distance_to_object > 38:
            move_forward()
            collecting = False
        # Start Navigating
        obstacleAvoidance(distance_to_object)
        cv2.imshow("Preview Window", frame_rgb)
        if cv2.waitKey(1) & 0xFF == ord('q'):
        break
# Emergency Shutdown (Ctrl+C)
except KeyboardInterrupt:
        print("Program cancelled....")
finally:
        print("Exiting and cleaning up resources.")
        cam.release()
        cv2.destroyAllWindows()
```

```
resetAngle()

segregation_servo(88)

GPIO.cleanup()

exit(0)
```

# B. Cost of Materials

**Table 5: Cost of Materials**

| Component | Price |
|---|---|
| Raspberry Pi 4 Model B (8GB RAM) | ₱5,989 |
| Raspberry Pi Heat Sink | ₱173 |
| SD Card (64GB) | ₱450 |
| Raspberry Pi Case | ₱200 |
| Ultrasonic Sensor (HC-SR04) × 4 | ₱200 |
| Servo Motor (MG996R) × 5 | ₱1610 |
| Plywood | ₱520 |
| Paint (Red, Green, Blue, White) | ₱450 |
| Wallpaper | ₱160 |
| Jumper Wires, Male-Female, Female-Female | ₱240 |
| Lead-Acid Battery (6V 4.5Ah) | ₱352 |
| LED (Red, Green, Blue) | ₱45 |
| | **Total: ₱10,479** |

# C. Documentation

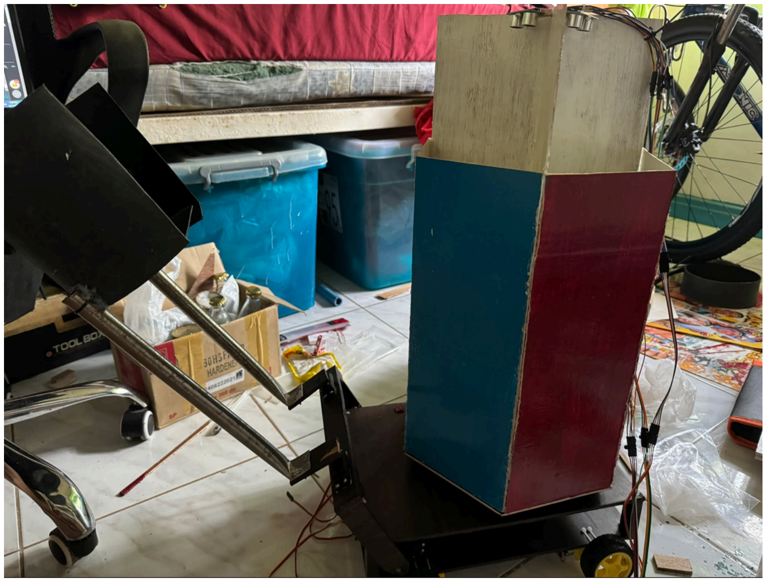

***Figure C.1: Prototype Model (Original)***

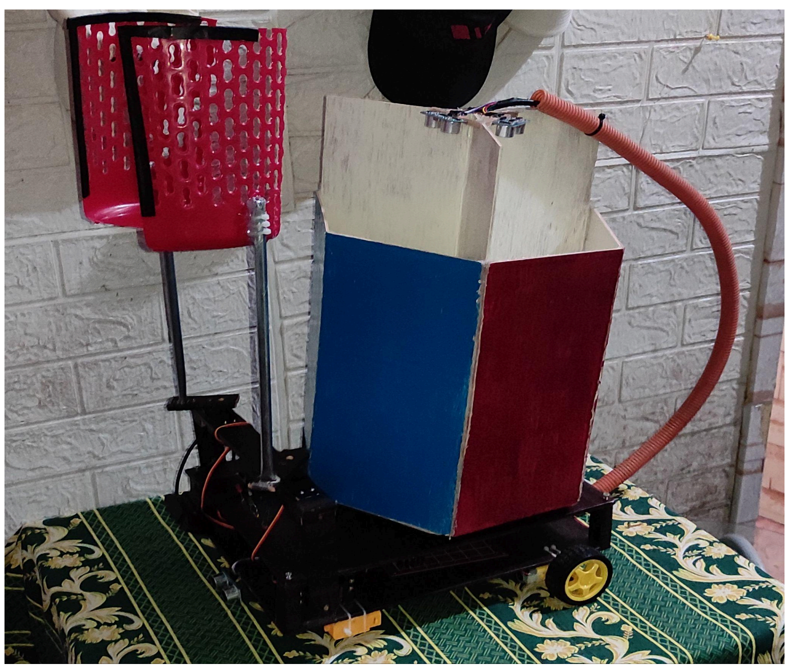

***Figure C.2: Prototype Model***


***Figure C.3: Dataset Training & Testing***

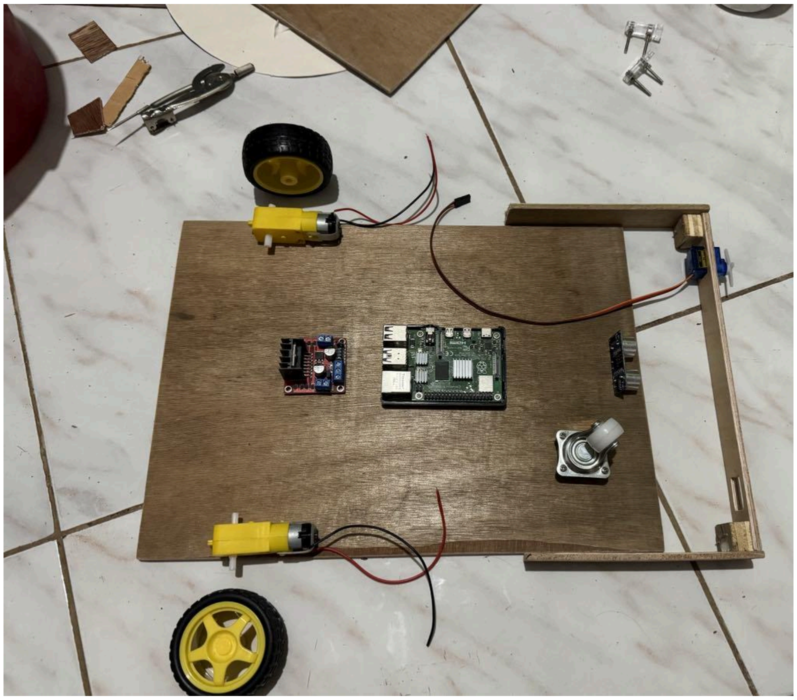

***Figure C.4: Components Dry Fitting***

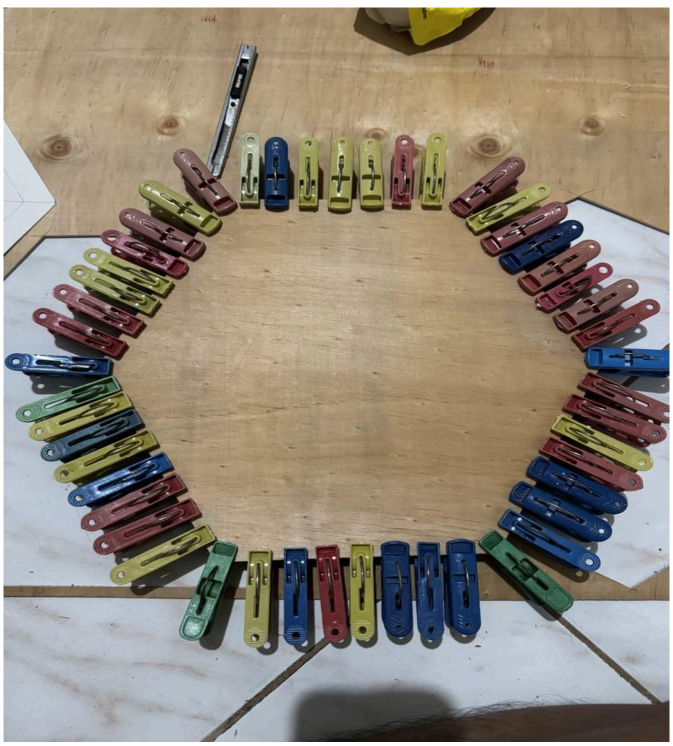

***Figure C.5: Storage Base***

***Figure C.6: Painting of divider of the Storage***

***Figure C.7: Prototype Model Development***

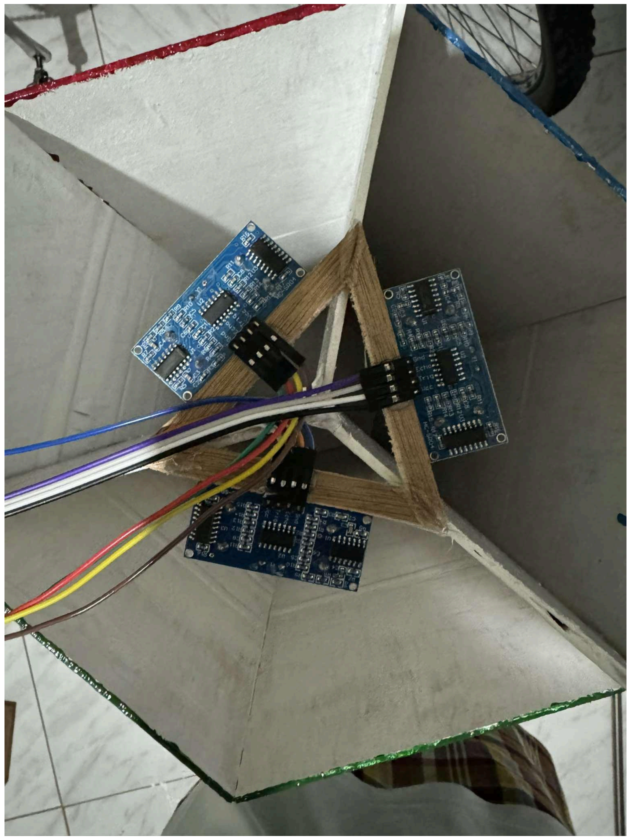

***Figure C.8: Storage HC-SR04 placement***

***Figure C. 9: Building and testing the prototype***