Circuit Breakers

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Litter Bot

Member's Contribution (assignments):

Each member contributed equally to every assignment for this report.

Christian Zamudio - Background, Marketing Requirements, Engineering Requirements, Design Alternatives, Design Alternative Evaluation Criteria, User Manual, Contribution of Work, Lessons Learned.

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Edwyn Arrezola - Background, Objective tree, Design Alternatives, Design Alternative Evaluation Criteria, Preliminary Design, User Manual, Final Design, Contribution of Work, Lessons Learned.

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II. Table of Content

III. Abstract

A rising problem that affects the environment and takes away from the quality of life in communities is littering in public areas. An autonomous robot called Litter Bot was created to address this issue by picking up litter in places like parks, sidewalks, and grassy areas. Litter Bot uses a quadrupedal locomotion system (4 legs that enable it to move) for effortless movement over slopes, mud, and grass, in contrast to standard machines that have trouble on uneven surfaces.

Litter Bot is a remote controlled robotic dog attached with a robotic arm that uses an autonomous system to locate litter. Using a protocol called pick and place where it locates an item, picks it up and moves it to be properly disposed of.

The design of the robot was selected following extensive research and evaluation of several concepts. A user survey was conducted in order to see how users felt about the idea of the project based on questions asked regarding garbage in their communities. From our data, collected in our user survey, see Appendix A, we began concentrating our efforts around the common concerns and implementation of the robot in communities. This led our group to concentrate on making it affordable, reliable, and user-friendly while making sure it satisfies safety and environmental regulations. Additionally, it runs silently to avoid disturbing those around it.

Litter Bot is a step toward a cleaner, greener future, not just a cleaning device. This robot contributes to a better environment for all by reducing litter and easing cleanup.

IV. Overview

Project Goals

Litter Bot will be a semi-autonomous garbage-cleaning robot designed to collect trash found on the sidewalks and grass terrains. It will be capable of picking up various types of litter, ranging from paper to bottles. With its advanced mobility and programming, the robot will be able to detect, target, collect, and dispose of a full garbage bag's worth of trash across both even and uneven surfaces, including sidewalks and grassy areas on a include/decline slope.

Needs Statement

Based on the City of Chicago Waste Strategy report, material generation increased over 17 percent from 1.25 million tons in 2010 to 1.46 million tons in 2020 [6]. The need being addressed is for an efficient and autonomous method to clean up garbage that is being left in public areas like parks, residential areas, highways, etc. Manually picking up this trash is time consuming and labor intensive.

According to the EPA (United States Environmental Protection Agency), escaped trash is trash that is littered where it then ends up on uneven surfaces like grassy areas. This issue of trash is costing an estimated $11 billion dollars per year [5].

Current limitations of waste cleanup do not include uneven surfaces such as in parks and public spaces. These traditional machines are not able to maneuver in these areas due to their size which leaves any cleanup of trash in uneven surfaces up to human labor and not widely implemented solutions.

Objective Statement

The objective of our project is to design and implement a semi-autonomous robot that will help minimize the issue of garbage, making our communities cleaner. The robot will have an autonomously equipped depth camera for trash detection, and a robotic arm to pick up garbage from the ground and into a disposable location. We will have a user control the robot to places where garbage needs to be collected.

Research Survey Analysis

Our project, Litter Bot, will be a semi-autonomous garbage collection robot. Will collect the garbage with a robotic arm. Functioning on the streets of the city, as well as on dirt and grass, to ensure most areas are clean and free of litter. Equipped with advanced mobility and programming, the robot will be able to detect, target, and collect garbage. As of today, various similar concepts have been developed in relation to this project.

With any project idea and creation, there is the chance of similarities between it and current systems. Take a Roomba, an autonomous vacuum that navigates around clutter and cleans the floors. While the concept is like our project, their purpose is different. Our project focuses on cleaning litter outside in the streets or alleyways, while a Roomba is generally used indoors. Another system, while it focuses on collecting trash like our project. The area of cleaning is not the streets or any areas on land but focuses on cleaning the waters. A floating garbage-removing robot, Aquatic Iguana [4]. Overall, there are other systems that ar2we similar and different to our project when it comes to functionality and overall purpose.

Apart from there being similar concepts and current systems, we also have existing patents that are relevant to the design of our project. Taking the patent of localization and mapping of pedestrians into consideration [1], while our project might not follow this method completely, we are still using some sort of detection for the garbage collection. This patent is somewhat relevant to our project design. There are other components of our project that we must consider that have relevant patents too. Such as a patent for a visual guiding and positioning method for compound robots [10]. Where distance, position, angle and, like our project, uneven ground [10] are taken into consideration when providing the robot with relative information for performing autonomous tasks. For our project, we would also have to consider some sort of security and monitoring system for it. A patent for monitoring method and device for mobile target is currently published [9]. Where monitoring of moving and immobile targets is captured and stored for identification. This system is implemented on a mobile robot, a component of our project. We would have to consider possible infringement of their patent when we design our monitoring, sensor, system for our project. The possibility of infringement would also have to be considered with other patents that cover smaller components of our project.

There are limitations to current designs for waste cleanup. One being the ability to clean on uneven surfaces, like areas in a park or some public spaces with uneven grass fields or concrete areas. This is due to the size of the machines and their capabilities of picking up certain garbage. This leaves it up to human labor, where someone must go and pick up the garbage left behind. One way to attack this problem is with the use of a quadrupedal locomotion system, this mode of movement allows for the robot to adapt to the level of the ground helping the center mass to stay perpendicular to the ground as much as possible.

One possible competitor that we have is MARBLE, Mobile Autonomous RoBot for Litter Emptying. An autonomous mobile robot with an arm developed for opening and emptying litter bins [7]. This robot can pick up litter, but it cannot operate well in other terrain. Due to its size, it finds it difficult to navigate properly, we plan to fix this by making our robot smaller and yet be able to go beyond flat terrains. There is also another competitor, Yarbo, a modular yard robot for automated outdoor equipment for tedious yard tasks and overall lawn care [11]. This robot differs from our project in that it has a specific location for performing its automated task, the yard. While our robot would be an all-terrain robot focusing on collecting litter. From grass to sidewalks and the streets. Also, our project will function with a robotic arm, while Yarbo focuses on using blowers and vacuums.

User Survey Analysis

https://docs.google.com/spreadsheets/d/15rMBHiOxBQUSZMnhYJJvS6GvjA_FsvbIrDX5CfubS8Q/edit?usp=sharing

Marketing Requirements

Based on our background research and survey results, we have created a list of what our system requirements should include and user needs.

1. Product should be able to move over uneven surfaces.
2. Product needs to be safe around other people and property.
3. Product needs to be durable, not malfunctioning.
4. Product should not invade the privacy of the public.
5. Product needs to hold a charge, not lose battery quickly.
6. Product marketing should address public concerns about environmental impact and ethical considerations.
7. Product should have theft protection features.
8. Product should have minimal noise output.
9. Products should be competitively priced to enhance marketability and accessibility. Also, to compete against companies with similar devices.
10. Product should align with consumer expectations and trends to ensure market relevance.
11. Product should be appealing to target audiences such as homeowners.
12. Product should be marketed as a new way to keep the city clean.

13. Product should emphasize its high-level capabilities/features like AI

Objective Tree

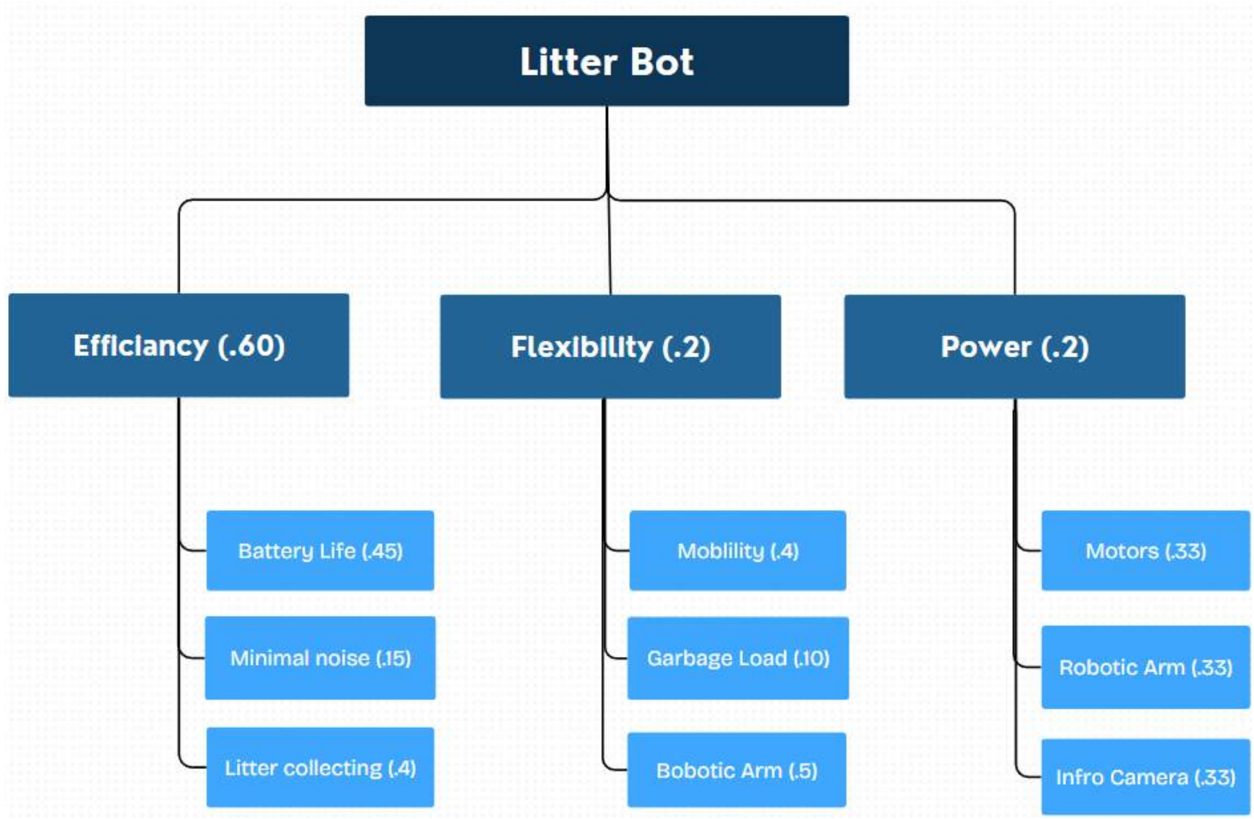

Figure 1: Objective Tree

V. Engineering Requirements / Technical Specifications

In this section we will translate the marketing requirements previously mentioned above, into engineering requirements. The first column indicates which marketing requirements we are discussing, the second column is the engineering requirement translated, and the third column is the justification. The third column, for justification, also states the applicable IEEE standards for the respective engineering requirements.

Table I: Engineering Requirements

Marketing Requirements	Engineering Requirements	Justification
1	Robot can navigate through hills, grass, dirt and uneven terrains	Allows access to all areas to ensure most garbage is collected.
2	Should accurately detect and avoid any pedestrian with a minimum of 90% success rate.	Allows for the device to locate people to avoid collating with them. Avoids an accident (IEEE 802.3-2005).
2, 4, 6	The robot should be able to detect and avoid any collision and trespassing of private and public property with a minimum of 90% success rate.	Allows the robot to stay within the public property and avoid invading the privacy of residents in their houses. While at the same time, make sure it causes no damage (IEEE 802.3-2005).
3	Robotic should be appropriately built for the public to get their hands on and use in their communities.	The robot must be affordable yet also have expected performance for people to use to help reduce the problem.
5	Robotic should be able to run for about 2-3 hours without any charge.	The robot can be used at its full potential and use all its features for a long period of time without interruptions (IEEE 1625-2008, IEEE 1491).
7	The system should be able to	The user should be alerted of

	accurately alert the user when damage or tampering is occurring.	the situation that the robot is facing to be able to access the situation and act according
8	The robot will produce minimal to no noise when performing its tasks.	Having a loud robot could cause a disturbance to the people around, making the robot less desirable to have.
9	The cost of developing the prototype should not exceed \$250, therefore the product can be priced at a lower cost.	This is the allocated budget for the project. With a lower production cost comes a lower price tag for the robot.
10, 11, 12	Robot should be able to clean up to 90% of the area, with minimal to no trash left. Along with some minimal human involvement to collect remaining garbage not collected.	Ensures effective garbage collections with high cleaning performance. As well as making sure there are still some human interactions, workers for example.
13	Robot will be able to perform autonomously. While using machine learning models to identify waste types with an accuracy of at least 90%.	Using AI, we can make the robot autonomous and be able to determine what is garbage and what is not garbage (IEEE 7009-2024).

Engineering Requirements Updated

This section is an update of the previous set Engineering Requirements for Litter Bot. These changes were done due to limitations and changes done to Litter Bot in the construction phase.

Table II: Engineering Requirements

Marketing Requirements	Engineering Requirements	Justification
1	Robot can navigate through hills, grass, dirt and uneven terrain.	Allows access to all areas to ensure most garbage is collected.
2	Users should be able to accurately detect and avoid	Allows for the device to avoid colliding with people.

	any pedestrian with a minimum of 90% success rate.	Avoids an accident (IEEE 802.3-2005).
2, 4, 6	Users should be able to detect and avoid any collision and trespassing of private and public property with a minimum of 90% success rate.	Allows the robot to stay within the public property and avoid invading the privacy of residents in their houses. While at the same time, make sure it causes no damage (IEEE 802.3-2005).
3	Robot should be appropriately built for the public to get their hands on and use in their communities.	The robot must be affordable yet also have expected performance for people to use to help reduce the problem.
5	Robot should be able to run for about 1-2 hours without any charge.	The robot can be used at its full potential and use all its features for a long period of time without interruptions (IEEE 1625-2008, IEEE 1491).
7	Users should be able to accurately troubleshoot damages or tampering occurring.	The user should be alerted of the situation that the robot is facing to be able to access the situation and act accordingly.
8	The robot will produce minimal to no noise when performing its tasks.	Having a loud robot could cause a disturbance to the people around, making the robot less desirable to have.
9	The cost of developing the prototype should not exceed $300, therefore the product can be priced at a lower cost.	This is the allocated budget for the project. With a lower production cost comes a lower price tag for the robot.
10, 11, 12	Robot should be able to clean up to 90% of the area, with minimal to no trash left. Along with some minimal human involvement. .	Ensures effective garbage collections with high cleaning performance. As well as making sure there are still some human interactions,

		workers for example.
13	Robot will be able to perform sime-autonomously. While using machine learning models to identify waste types with an accuracy of at least 90%.	Using machine learning, we can make the robot autonomous and be able to determine what is garbage and what is not garbage (IEEE 7009-2024).

Engineering Requirements Final Notes

This section shows how our engineering requirements were either met or not in relation to the final prototype.

Table III: Engineering Requirements Protoy

Marketing Requirements	Engineering Requirements	Final Prototype
1	Robot can navigate through hills, grass, dirt and uneven terrain.	The A1 is designed to move on uneven terrain when switching to sports mode.
2	Users should be able to accurately detect and avoid any pedestrian with a minimum of 90% success rate.	The A1 robot dog allowed for easy use with the given controller. During testing can be lined up with objects to be picked up.
2, 4, 6	Users should be able to detect and avoid any collision and trespassing of private and public property with a minimum of 90% success rate.	The prototype was not able to accomplish this autonomously but can be done with the user controlling A1.
3	Robot should be appropriately built for the public to get their hands on and use in their communities.	Currently the prototype allows for the public to implement into communities.

5	Robot should be able to run for about 1-2 hours without any charge.	The A1 robot can run stand alone for close to 2 hours but with everything attached to A1, the power consumption lasts around 1 hour.
7	Users should be able to accurately troubleshoot damages or tampering occurring.	Logs are currently implemented into the system but the current prototype does not allow easy access to these logs unless the prototype is connected with an HDMI cable to monitor.
8	The robot will produce minimal to no noise when performing its tasks.	The A1 robot does produce noise at levels researched at 65 decibels which should be okay for outdoor use without interrupting people. For reference, a lawn mower produces about 85 decibels of noise. The robot arm has minimal noise while performing tasks.
9	The cost of developing the prototype should not exceed $300, therefore the product can be priced at a lower cost.	The final prototype with what we purchased (A1 and robot arm not included) was $400. We did have some setbacks and purchased items that we didn’t end up using. What cost the most money was the Raspberry Pi 5 and Intel Realsense depth camera.
10, 11, 12	Robot should be able to clean up to 90% of the area, with minimal to no trash left. Along with some minimal human involvement. .	During testing of the robot, the robot was able to pick up the objects we tested while running the pick and place code. 90% of the time, items were correctly picked and placed.
13	Robot will be able to perform sime-autonomously. While using machine learning models to identify waste	The object detection of the depth camera does allow for 90% accuracy of items when close up and items are not

	types with an accuracy of at least 90%.	obscured. This does not affect the pick and place though, the bounding box would still be created for an item with a lower accuracy and be able to pick up that item.

List of Categories Used to Aid in Formulating Engineering Requirements:

- Functionality
- Performance
- Economics
- Energy/Power
- Environmental
- Health & Safety
- Legal
- Maintainability
- Manufacturability
- Operational
- Reliability and Availability
- Social and Cultural
- Usability (including user interface)
- Categories That Do Not Apply:
- Political

Justification on Why Above Topics Do Not Apply:

Political constraints often involve obtaining government approvals, addressing trade regulations, or ensuring system acceptance in unionized environments. However, this project is focused on the technical development of a litter robot for public use, which does not require navigating governmental or union related processes. Since it is not impacted by political approvals or trade barriers, political considerations are not relevant to the design of this system.

VI. Engineering Design Alternatives

The design alternative section uses the engineering requirements and objective tree from above to create three different design alternatives shown below. Each design alternative consists of a level 0 schematic and a table that describes the input and outputs, along with the functionality of the design. This section also consists of the similarities and differences between each design alternative.

See Appendix D for concept maps of each design alternative.

Similarity & Differences Between Designs

Each design aims to achieve a similar goal to the litter collection but differs in the power source, garbage collection mechanism and also specific functionality.

Similarities

The similarities between each alternate design is that all these designs use a litter bot module aimed at picking up litter. All designs include sensors as a part of the input mechanism to detect garbage. Each design lists movement as one of the outputs, suggesting that the robot approaches litter. Their designs are centered on detecting and responding by attempting to collect it. Each design's output indicates a method for physically interacting with trash for either picking up, sweeping or vacuuming. Indicating that the designs share a primary functional purpose of removing debris from the environment, regardless of the exact mechanism used.

Differences

Some differences that each alternate design has include the use of different mobility and method of picking up litter. Our mobility alternatives are organized from the easiest to construct to the more complex, in our first design consists of using a quadrupedal locomotion system that is adaptable to Multiple surface areas and provides stability of the bot. The next alternative consists of ordinary wheels, these are good as a standard point, but it develops issues when it's presented in off road terrain. The last movement method is using legs, this concept is only reserved for the robotic dog approach, the legs allow for precise movement, but it is the more complex of the 3.

Another variable that varies in each design alternative is the methods to pick up garbage, these consist of design 1 using a robotic arm armed with object recognition making a powerful tool to accurately locate and pick up garbage. Design 2 consists of a sweeper in front of the robot picking everything up in one single pass. This is good for fast pickup, but it creates conflict with bigger debris, overall, it's a solid choice for design 2. Design 3 consists of a vacuum, like the sweeper, it provides fast pick up of garbage, but it does create the potential of the vacuum seal getting clogged.

A key alternative that is worth mentioning is that each device has a different power source for each of the designs. Design 1 has an external Lithium Polymer Battery as its power source. This provides for the device to have multiple backup batteries when one battery depliages allowing for the robot to operate for longer periods of time and finish the job that it is tasked with. Design 2 has solar panels as its power source this allows the bot to charge at the same time its operating, this allows the robot to go further time without human intervention and it is still able to perform well, the problem arises when sunlight is not available and the robot is low on power, therefore it has to wait until its light outside to charge. Design 3 contains a charger as its power source, this method allows the robot to be hooked up to a power station to charge it inter battery to run over a certain amount of time, the only drawbacks is that when the battery dies it cannot operate again until the bot gets plugged.

Design Alternative I

Table IV: Input/Output Table for Design 1

Level 0	
Module	Litter Robot
Input	• External Battery • Sensors
Output	• Movement • Robotic Arm
Functionality	Recognizes litter via the input (sensors) signals. The output response by approaching the litter and then picking it up.

Figure 2: Level 0 Schematic for Design 1

Table V: Input/Output Table for Design 2

Level 0	
Module	Litter Robot
Input	• Solar Panels • Sensors
Output	• Movement • Sweep Pick Up
Functionality	Robot is able to detect debris via sensors. The output response with our sweeper brush sweeping the debris.

Figure 3: Level 0 Schematic for Design 2

Table VI: Input/Output Table for Design 3

Level 0	
Module	Litter Robot
Input	• Charger • Sensors
Output	• Movement • Vacuum
Functionality	The robot receives input from the sensors of debris in the immediate area. The output responds with the device approaching the debris and using the vacuum to suck it in.

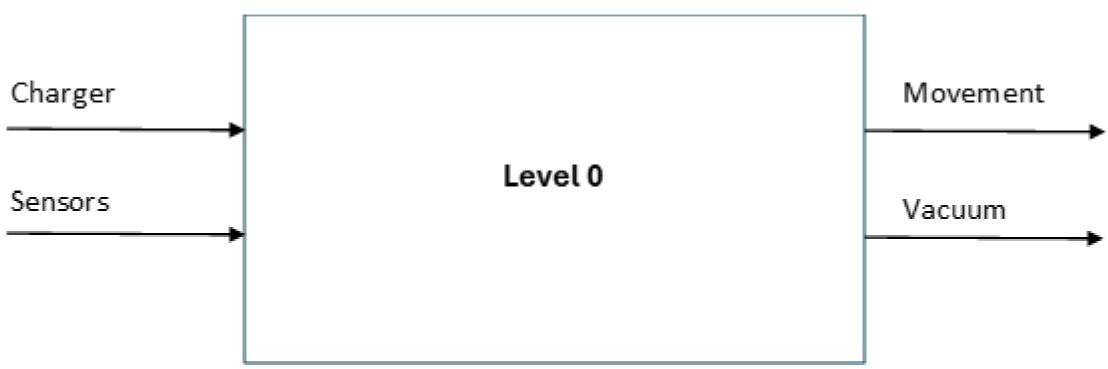

Figure 4: Level 0 Schematic for Design 3

VII. Design Alternative Evaluation Criteria

Cost to Consumer/Development Cost

Having a project budget limit of $300, affects the development of the project prototype. In what can be used to develop the prototype that will ensure that cost does not exceed $300. The cost to charge a consumer will be affected by the budget of $300, where we want to be able to cover development costs and make some profit from sales to consumers.

Group's Technical Knowledge about the Design Alternative

The design alternative that is chosen should not require knowledge that is above what any member is capable of. While there should be some challenge to show growth and understanding, we also have to be realistic and understand that there is limited time to develop the chosen design alternative. Therefore, the knowledge we have as of now, without having to learn new information, is more important due to the limited time we have.

Time Needed to Complete Design and Development

Having a limited time to complete the design and development of the project, make this an important criteria to keep in mind. We have to take into consideration the availability of each team member and the time we believe it will take to complete development of the project, to have completed the project to present for the EXPO.

Suitability for Demo During EXPO

Our project design alternative has to be able to be demonstrated at the Senior Design EXPO. Meaning that the project design alternative that is picked should have the ability to be made into a prototype. Any project design alternative that is not will not make a suitable working prototype is not recommended, since there will be nothing to be demonstrated at the EXPO.

VIII. Selection of Design Alternative and Justification

Decision Matrices

Together our group decided on the criteria we will use to rate the design alternatives. Each individual group member completed a pairwise comparison table related to the evaluation criteria we have chosen in the previous section. Together we have rated each design alternatives relative to criteria. Then, using the average weight of all group members pairwise comparison along with the rating of each design alternatives. We constructed our final decision matrix, with the final scores for each alternative.

See Appendix E for individual pairwise comparisons and the decision matrix.

Final Decision

Based on the decision matrix provided, our team has chosen Design Alternative 1 as the most suitable option for our final design. Design Alternative 1 achieved the highest overall score of 3.64, compared to scores of 2.64 for Design Alternative 2 and 1.86 for Design Alternative 3. The primary factors that contributed to this decision were the high scores in categories with significant weight, particularly in "Your group's technical knowledge about the design alternative," where Design Alternative 1 received a perfect score of 5. This indicates that our team feels most confident in our ability to develop and implement this design, reducing risk and potential challenges during the project. Additionally, despite having a lower score in development cost, the suitability of this design for the EXPO demo and its moderate development time also contributed to its overall feasibility. Although design 1 has been chosen due to more familiarity with the hardware, design 2 can also be considered as a backup to our plan and additionally if anything needs to be changed as we further the design process.

While Design Alternative 2 and 3 had strengths in other areas, our evaluation criteria prioritized technical familiarity and overall suitability for demonstration, leading to the selection of Design Alternative 1 as our final choice.

Table VII: Decision Matrix

Criteria	**Weight**	Design Alternative 1	Design Alternative 2	Design Alternative 3
Cost to consumer/Development cost	**0.25**	1	3	3
Group's Technical	**0.31**	5	3	1
Time to complete Design/ Development	**0.26**	5	3	1
Suitability for demo during EXPO	**0.18**	3	1	3
	Total Score	**3.64**	**2.64**	**1.86**

IX. Preliminary Design

Level 1 Diagram

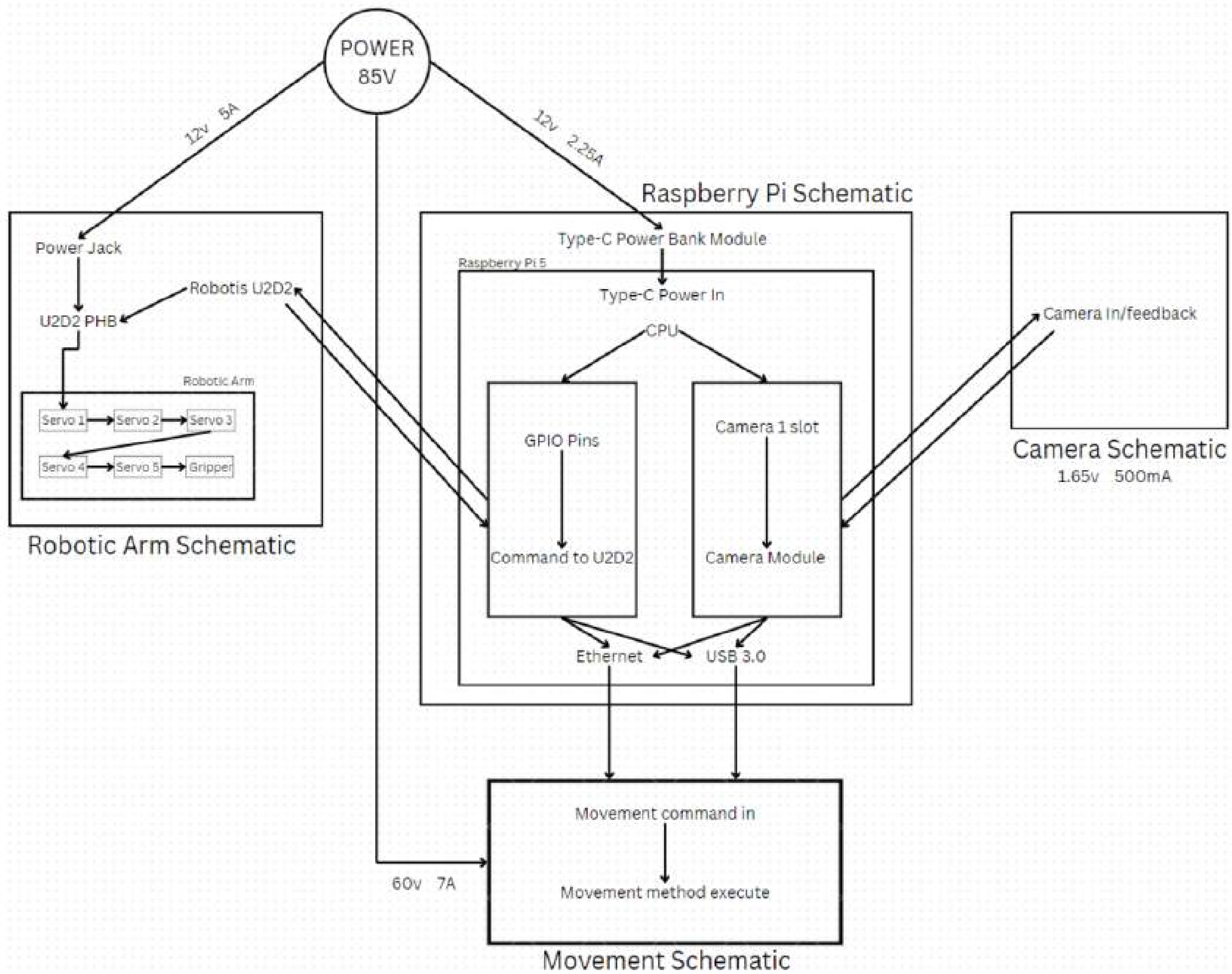

Figure 5: Level 1 Schematics

The schematic outlines a robotic system which is powered by an 85V source. The Raspberry Pi serves as the central controller which is connected to a robotic arm through U2D2 board and a camera module for vision. The power is distributed to the robot arm with 12V and 5A and Raspberry Pi with 12V and 2.25A. Movement Commands are processed through the Raspberry Pi and executed through USB or Ethernet connections. This system is integrating power, vision, control and movement for the robotic functionality.

Circuit Design

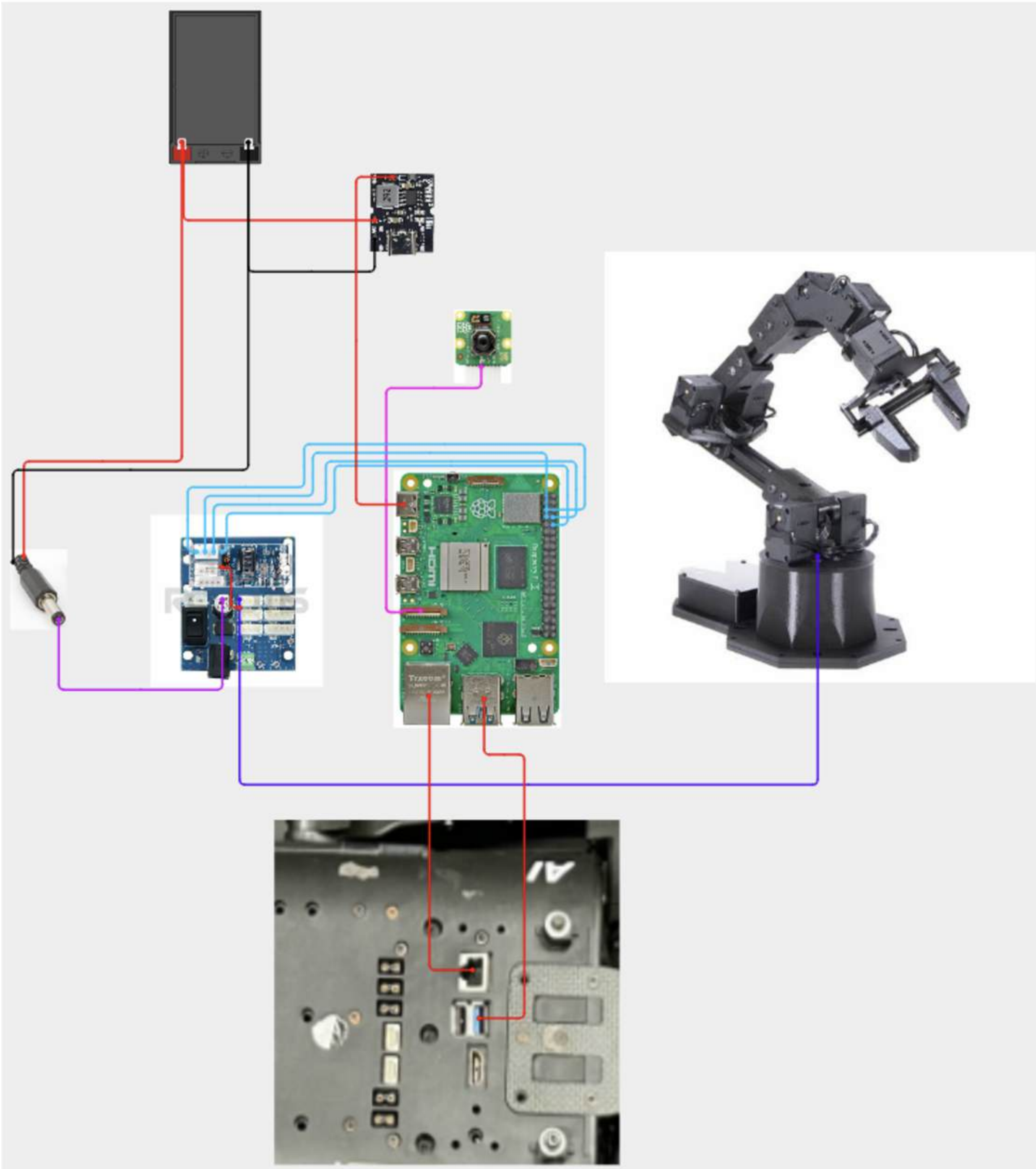

Figure 6: Raspberry Pi or Arduino Circuit Schematic

This circuit design integrates a Raspberry Pi 5 as the central controller for a robotic system. The power supply connects to the raspberry pi and other components, which includes a robotic arm, camera module and motor controller. The motor controller manages the mobility of the robot base whereas the robot arm is controlled through GPIO pins on the Raspberry Pi. The camera module adds the vision mobility and enables object tracking. This system combines vision, mobility and manipulation for efficient robotic functionality.

Software Design

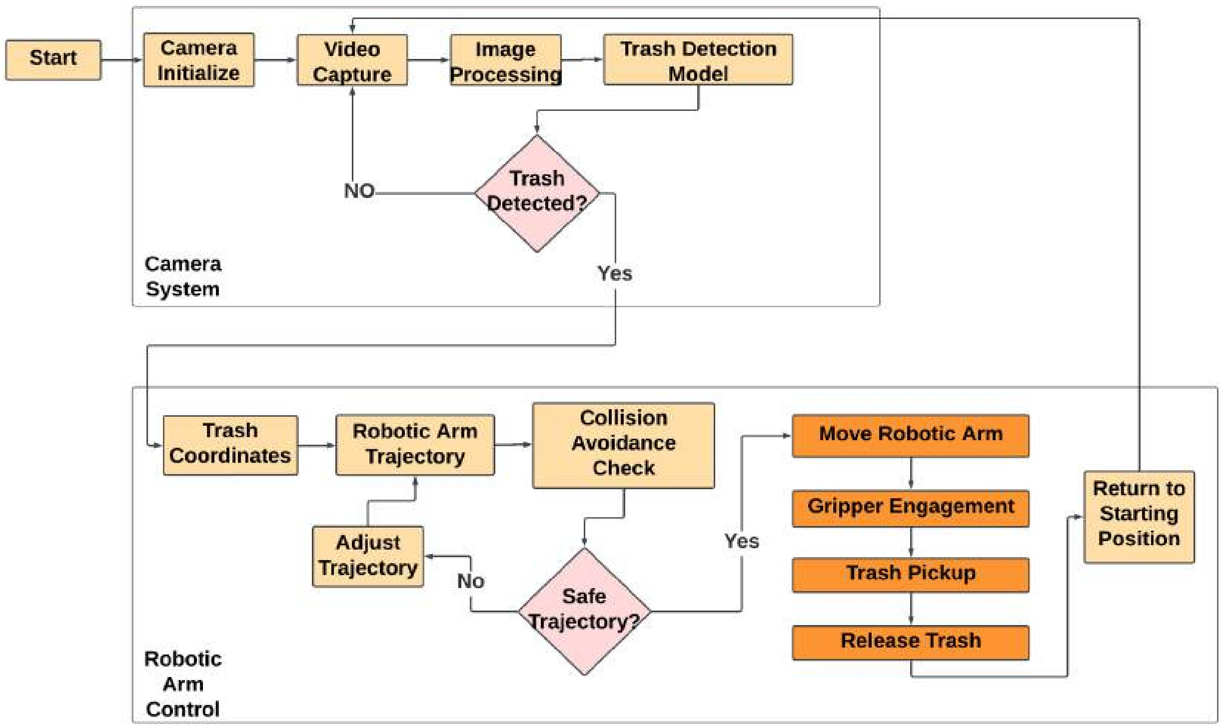

Figure 7: Software Architecture

The high-level flowchart shown in Figure 7 above, illustrates both our camera and robotic arm systems that will be used for litter detection and collection. Once we initialize the camera, it will function to detect for trash, if trash is detected then it would move on to controlling the robotic arm movement. If there is no trash detected then it would make the camera continue to detect any trash around. Once moved to controlling the robotic arm movement, we calculate the trajectory of the robotic arm movement. Which then we ask if it is safe to make the movement without collision, if it is not then we recalculate for a better trajectory. If it is safe to make a calculated trajectory, then the robot arm will initialize and start to operate. The robotic arm will operate its gripper and collect the detected trash. Once this is complete for the detected trash, we loop back to the camera trash detection and start looking for new trash to collect.

X. Testing

In this section we will touch on the testing conducted for Litter Bot. Object Gripped by Gripper Test was conducted by running the code from the beginning of each test run. For the small bottle the gripper was successful in gripping the bottle 10 outta 10 times. While the larger bottle was successful 7 outta 10 attempts.

Table VIII: Object Gripped by Gripper Test

Object Gripped	Results
Small Bottle (4 in.)	10 / 10
Large Bottle (4 in.)	7 / 10

This test was conducted to test battery life with every part of Litter Bot running. We conducted four different trials to see how long the battery lasted for each time. Overall, battery life lasted no more than 1 hour and 10 minutes, with the shortest time being 45 minutes. This supported our engineering requirement to an extent of having a battery life of 1 to 2 hours.

Table IX: Battery Life Test w/ Unitree A1 + Raspberry Pi5 + Intel RealSense Camera + OpenManipulator Arm Turned ON

Trail #	Results
1	45 minutes
2	60 minutes
3	58 minutes
4	70 minutes

While we did not conduct extensive testing on battery life with just having Unitree A1 stationary and having all other parts running. We did note it to prolong battery life up to 1 hour and 26 minutes, approximately.

Final testing conducted, Table X, was for the confidence of our object detection. As shown on the table there are results of 90%, or close to 90%. Demonstrating that our object detection has a high confidence, where we will be able to detect our object, bottle.

Table X: Object Detection Confidence

Class (Object Detected)	Confidence (Percent)
bottle	88.9
bottle	88.1
bottle	88.8
bottle	89.6
bottle	90.1
bottle	89.5
bottle	88.5
bottle	89.3

See Appendix I for the terminal figure of Object Detection Confidence.

XI. Final Design

The final design of Litter Bot, see figure 8, is implemented using Unitree A1 Robotic Dog for its quadrupedal locomotion system for effortless movement on uneven surfaces. With an OpenMANIPULATOR-X Arm for autonomous pick and place. Using the data from an Intel RealSense Depth D435 Camera for object detections and position coordinate determination.

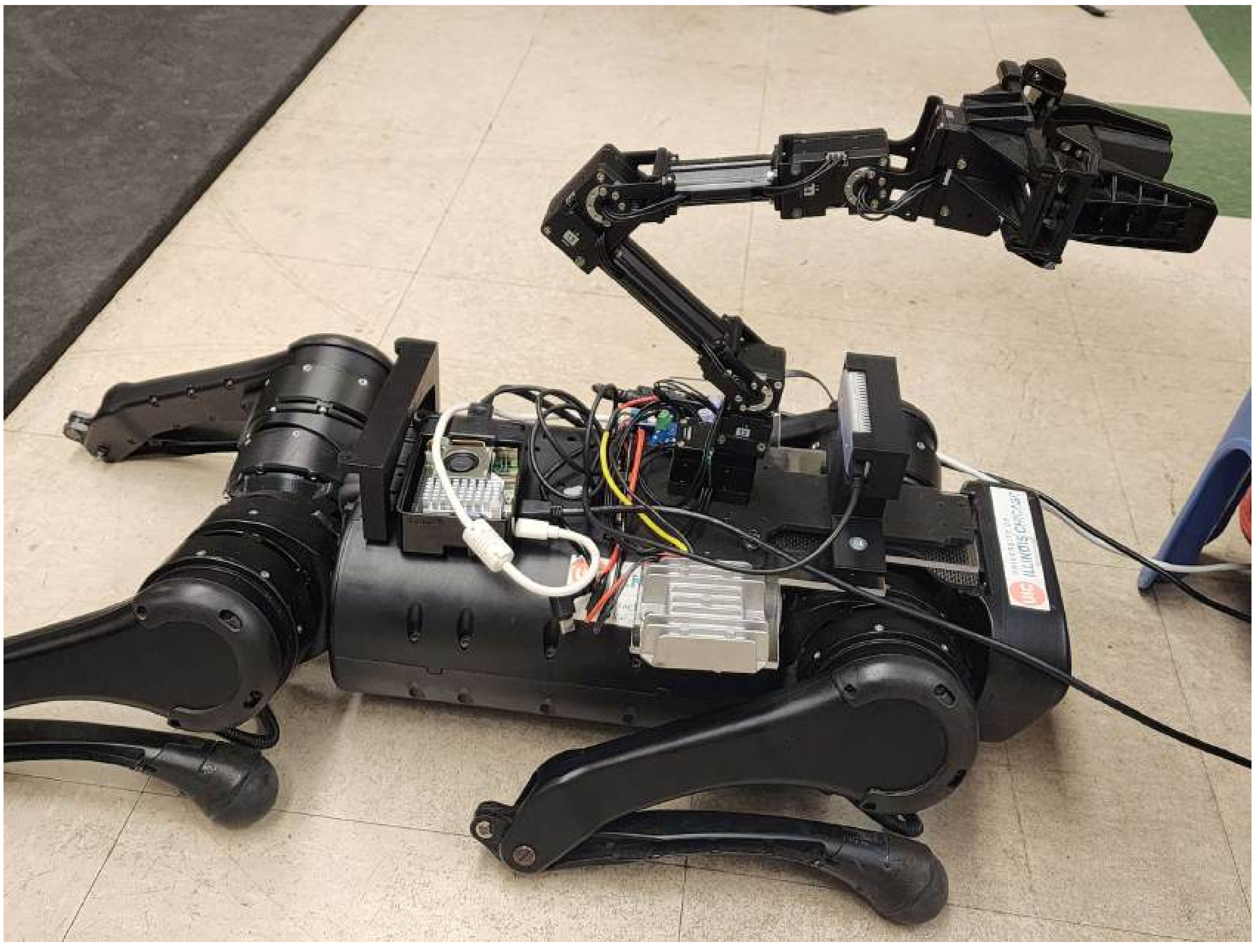

Figure 8: Final Prototype for Litter Bot

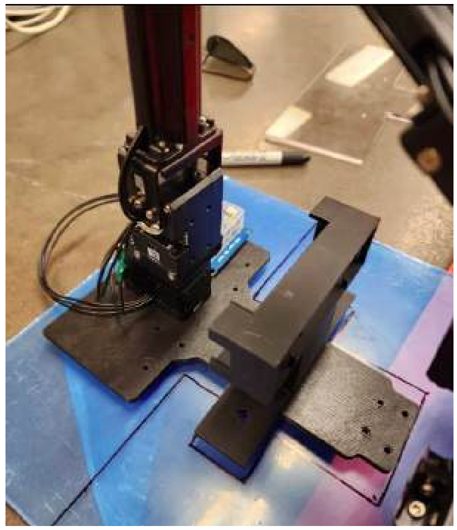

Figure 9: Robot arm and camera base

Image shows robot arm and the camera base in the T-shape acrylic platform base. Make sure it lines up with the A1 robot holes and it's not in the way of the robot's legs.

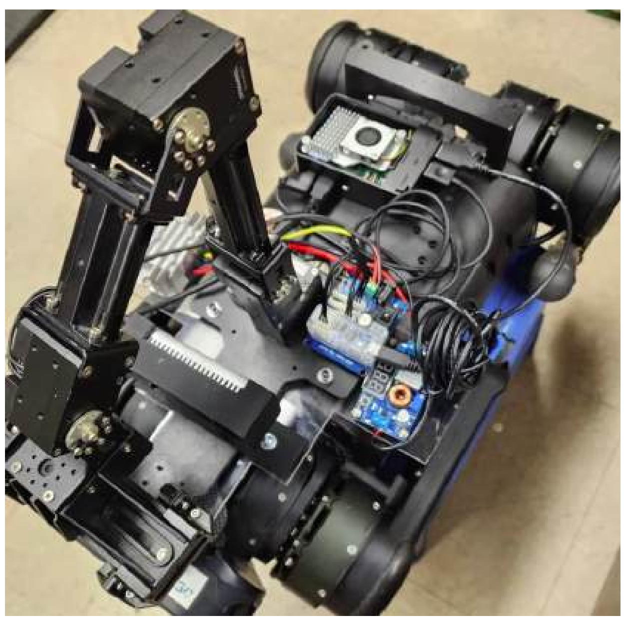

Figure 10: Connection

This image shows the placement of the components in the platform base. Buck converter (Pi converter) is located all the way to the right side of the T-shape base. Next to the converter is the U2D2 board and power distribution board. The robotic arm converter is located all the way at the left of the picture (metal case). Raspberry Pi is located at the back of the Unitree.

Bill of Materials

Table XI: Cost Analysis and Budget

Part Name	Quantity	Cost Per Quantity	Total
Ordered Using Budget			
Parts Not Used on Final Project			
Raspberry Pi AI Camera [14]	1	$69.99	$69.99
CSI FPC Flexible Cable For Raspberry Pi 5 [15]	2	$7.97	$15.94
Parts Used on Final Project			
Raspberry Pi Active Cooler (SC1148) [13]	1	$9.99	$9.99
M2 x 4mm Hex Socket Head Cap Screws [16]	1	$7.76	$7.76
		Total:	**$103.69**
Personal Purchases / Already Owned (Parts Used on Final Project)			
CanaKit Raspberry Pi 5 Started Kit Pro [17]	1	$159.99	$159.99
Unitree A1 [18]	1	$14,900	$14,900
OpenManipulator-X (RM-X52-TNM) [19]	1	$1,558.26	$1,558.26
Intel® RealSense™ Depth Camera D435 [20]*	1	$97.23	$97.23
Right Angle USB C to 2 Pin Bare Wire Open End Wire [21]	1	$8.99	$8.99
XT30U Plug Male Female Connector [22]	1	$16.99	$16.99

DC-DC Buck Converter [23]	1	$13.99	$13.99
		Total without Robotic Arm & Robot Dog:	**$297.19**
		Overall Total:	**$16,755.45**

*Note that this is the link to buy from Intel directly, however, we bought our part of Ebay for a lower price.

The table above shows the parts, and their respective cost, that were ordered from our budget and from our personal money. There are some items like the Raspberry Pi AI Camera and CSI FPC Flexible Cables, that were purchased with the budget but not used on the final design of the project. This is due to the fact that we went in a different direction for the camera used, which does not need the CSI FPC Flexible cables like the AI camera did.

Overall, the final parts used for Litter Bot design are:

- Unitree A1
- OpenManipulator-X
- Raspberry Pi 5
    - Active Cooler
- Intel RealSense Depth Camera D435
- Acrylic base/mount (this part was designed and cut to fit on top of Unitree A1)
- Buck Converter Step Down
- XT30U Plug Male Female Connector
- M2 Screws
- Right Angle USB C to 2 Pin Bare Wire

XII. Task Allocation and Timeline

In this section is the task allocation Breakdown for Spring 2025. See Appendix H for the task allocated for each team member and the timeline of the project.

XIII. Contribution of Work

Christian Zamudio

I contributed to creating an autonomous pick and place code that works with the Openmanipulator-X (robot arm) and Intel Realsense depth camera. This code is in a ROS2 Humble node that launches the YOLO object detection. Once the object detection node is up and running, there is a seperate code that calculates the cartesian path of the arm in order to pick up the object being detected. The cartesian path code is also ran as ROS2 node where the inputs from the object detection node is sent to this node and then executing the pick and place. I also began the installation process of the robot arm and depth cameras SDK. The SDK's were installed onto the Raspberry Pi 5 which allow for communication through the terminal. With that said, the only way to get around installing the SDK's was through a docker image of ROS2 Humble which is how we currently use to launch each node. After the completion of the pick and place code, I began working with the team to attach the robot arm onto the top of the Unitree A1 robot dog (A1). This included customizing an acrylic plate for the robot arm and depth camera to sit on top of. Once we marked the measurements for everything, we cut out the piece of acrylic and attached it onto A1.

Parin Pandit

My primary contribution to the project was working on the camera and object detection system. I was responsible for helping to obtain the X, Y and Z coordinates of the detected objects using depth data. Initially I started by collecting around 100 images for each of three types of trash bottles, cans and chip wrappers and attempted to create a custom image library. However due to time constraints and the complexity of annotation we decided to pivot to using the COCO library dataset which already contained annotated images of bottles. Additionally I was helping Edwyn with calibrating the robot dog ensuring that it could interact properly with the object detection system and navigate correctly. Also worked with the team to mount the robot arm and depth camera onto the A1, where we all started designing an acrylic plate to support both components. After carefully marking the measurements we cut the acrylic to shape and securely attached it to the top of the robot creating a stable platform for integration.

Edwyn Arrezola

The contributions that I made towards this project were the following. I helped Christian debug parts of the pick and place system software. I present to offer input and give suggestions to make the code work properly. I focused on the power distribution of the whole robot, diverting power from the robotic dog to the microprocessor via port 8 on the A1 unitree dog, and diverting power from the same source to the robotic arm via port 9. To make this possible, I tested converters to step down the voltage from the source so that the outputs being the microprocessor and the robotic arm didn't get fried or not to get enough power to operate. I calibrated the unitree A1 robot dog to be as stable as possible, and with help of our advisor, we were able to get a stable robot which was essential to mount the autonomous system into it. I was also the pilot for the test runs, I learned to control the robot to accurately get the system to move efficiently and to place the autonomous system to work properly. Another thing that I contributed was the creation of the mounted platform (acrylic base) that was later used to place all the components. With this platform I was able to perform cable management and organize everything so that it would be easy to plug and unplug everything at once.

Juan Estrada

My contribution to this project was implementing the object detection code for Litter Bot. I worked on the code to ensure only bottles were being detected by our D435 camera. I also worked on testing the code for the object detection with Pairing to ensure everything ran correctly, to then be used by Christain when implementing ROS2 Humble. I helped in testing the depth camera ensuring that it worked and was able to perform the tasks that it needed to complete. I helped set up the Raspberry Pi5 in previous attempts for starting the project before Christian figured out the best possible setup for implementing our project. I helped design the acrylic base used for our robotic arm on the Unitree A1 dog. Along with helping screw and position everything on top of the Unitree A1 correctly, ensuring nothing would fall or obstruct other parts of the robot.

XIV. Lessons Learned

Christian Zamudio

The lessons I learned throughout this project was how to use ROS2 to simulate robot movements as well as learning the entire coding process for the pick and place code. All the code was written in Python and I actually haven't previously used Python for any coding projects. This was a big challenge on top not previously using the A1 robot or robot arm. I learned that I should have put more research into seeing how compatible the robots were with the Raspberry Pi 5 as I kept having to figure out errors in the installation process of the SDK's. This led to me researching Docker in order to get everything running properly. After this, the entire project came down to the wire with me having to figure out the object detection and pick and place. I had a lot of fun learning about all these different topics and was really immersed in the process.

Parin Pandit

During this project I gained a much deeper understanding of how machine learning works in real world applications. I specifically learned how object detection models like YOLOv11n operate and how to use depth cameras to extract spatial information about detected objects. In addition to working with detection models and cameras, I overcame several challenges related to dataset creation. Initially I attempted to build a custom dataset by collecting and annotating images of different trash items but due to time constraints and the manual effort required for labeling we used the COCO library. This experience taught me the practical tradeoffs between custom model training and using pre-existing datasets. I also developed a better understanding of the challenges involved in building datasets, training models and also integrating them into the hardware systems. At first I had minimal understanding of how ROS 2 works but after working on this project I was able to get more knowledge on how to debug and launch files. Overall this experience improved my problem solving skills and gave me valuable hands-on experience in robotics.

Edwyn Arrezola

Some of the thing that I learned through the project include the following:
I gained experience on how to use the Linux software, there was a time where we had a backup system like the final prototype, everything that Christian has done on the microprocessor, I was

replicating it on another device as a safety plan, although it did not get the full application as the final product, the little bit I was able to replicate was done from scratch. Another thing that I learned was how ROS2 libraries work and operate. Like I said before, I was present when Christian was also learning ROS2, we both spent time analyzing this and finding ways to apply it onto the project. This process took a long time to crack, but finally it happened. I learned how to test and adjust converters to apply to our project, with the help of the senior design faculty (Ricardo Ramirez Madrigal) I was able to get the correct step down voltage configuration to make everything work properly. I learned how the A1 unitree robotic dog and the openMANIPULATOR X robotic arm works because throughout the testing phase, either the dog or the arm would glitch or breakdown, I came in to fix it and get it up and running as soon as possible. I spent time learning how to maneuver the unitree A1 robot in a simulator to avoid collisions with people or equipment, so that I would be ready to operate it during the testing phase.

Juan Estrada

Throughout the implementation of Litter Bot, there have been some ups and downs. Task that questioned our knowledge and understanding of what we were trying to construct. Through all this, I have learned many new skills and at the same time I was able to reinforce prior skills. When working on the YOLO object detection code, I was able to polish and improve my coding skills in python. While at the same time learn about object detection implemented with YOLOv11, and about the dataset used from COCO library that had images used for detection. I have also learned how to use a Raspberry Pi5 and work with Linux software on it to implement our code and nodes used for Littler Bot. Also, another big point that I have learned that has shaped how I will approach future projects. That being conducted extensive research on each component used for the project. Facing multiple compatibility issues throughout the project, taught me how to do proper research to ensure that implementation runs smoothly in the future.

XV. Conclusions

Overall, from the first semester that we took to conduct research and plan how to build Litter Bot. To the second semester used to implement our ideas, to construct and produce a prototype for Litter Bot. The final product is a semi-autonomous robot that uses Unitree A1 Dog, for its quadrupedal locomotion system for effortless movement on uneven surfaces. An OpenManupulator-X robotic arm for autonomous pick and place of trash detected. Along with an Intel RealSense Depth Camera D435 for object detection and determining object position.

For future improvements, we could look into increasing the battery life of Litter Bot. With currently having a battery life of 1 to 2 hours, we can possibly increase that to 3 to 4 hours with a larger capacity. We could also, in the future make Litter Bot completely autonomous, with minimal to no human involvement. This can be done by looking into a better microprocessor that can handle and run larger codes. Along with a better compatibility with every other component used on Litter Bot. Another improvement that can be implemented in the future is increasing the objects detected. This can be implemented by increasing the library used for object detection, and by using more specific images we can further improve the detection of trash objects. In the end, Litter Bot produces what we have set ourselves for, a prototype that uses autonomous pick and place code with object detection to collect litter.

XVI. References

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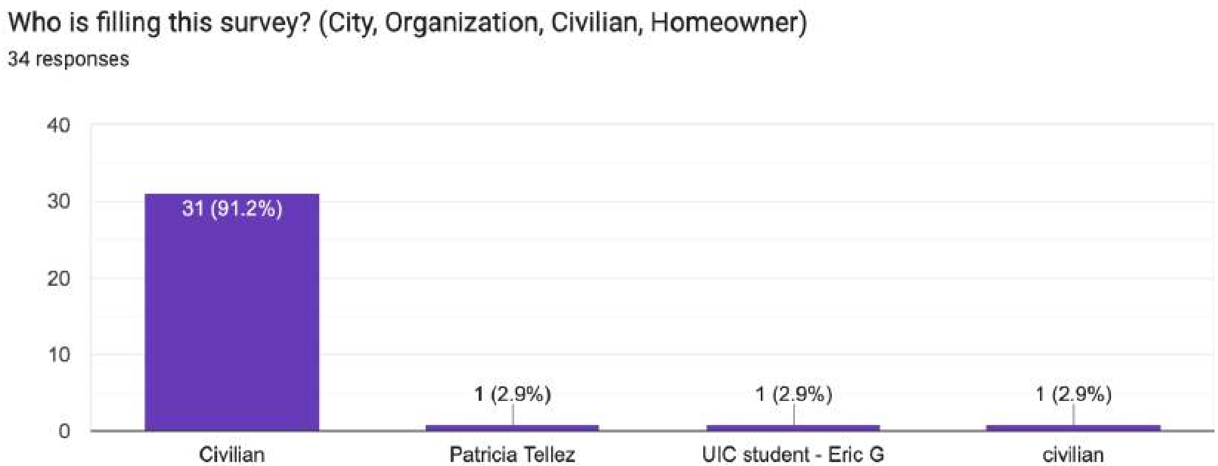
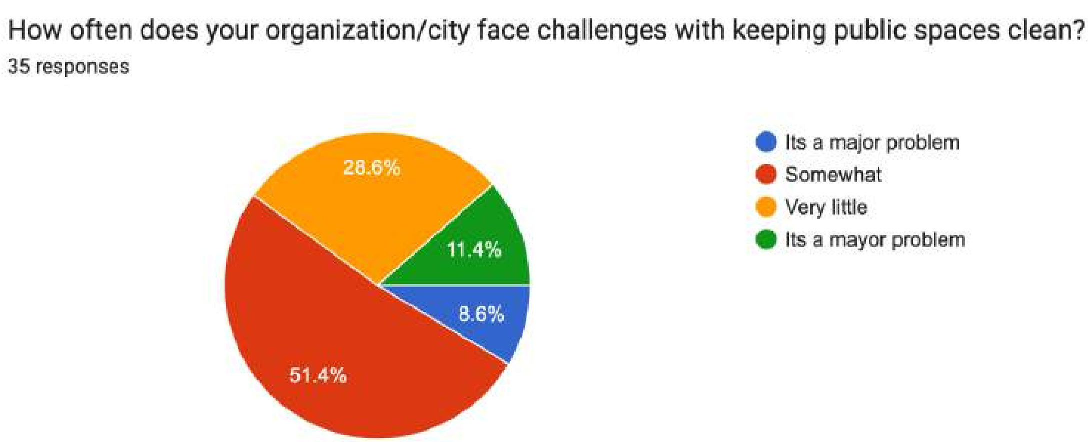
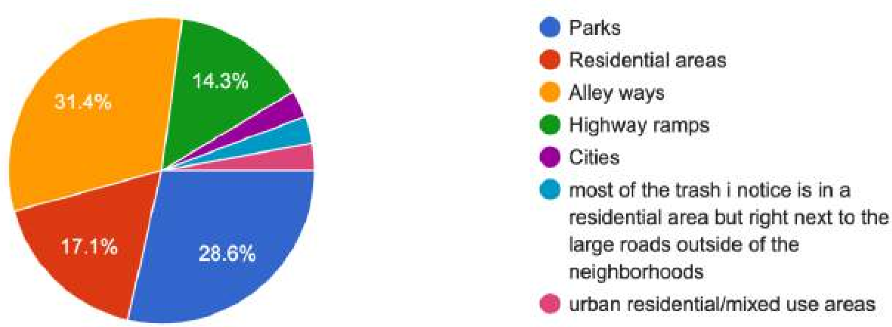
XVII. Appendices

Appendix A: User Survey Questions and Raw Data





What types of locations do you believe need the most attention for garbage collection?
35 responses



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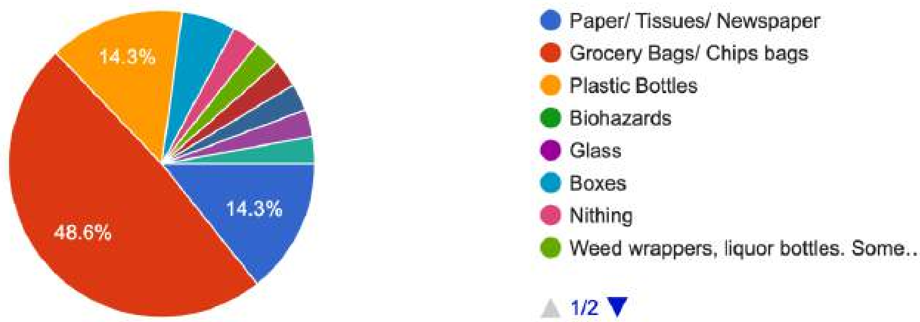
What methods or technologies are currently being used for garbage collection in your area?
35 responses

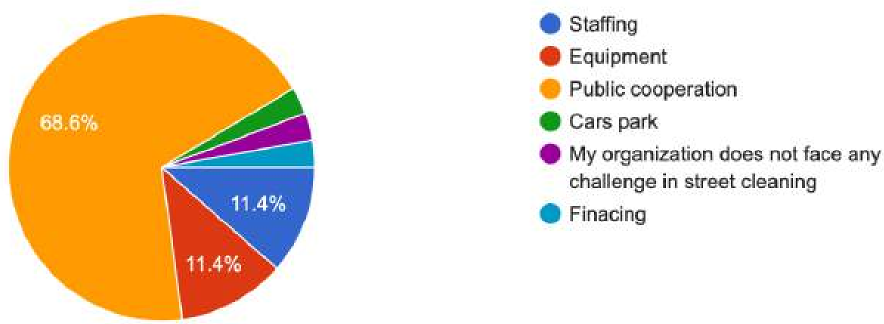
What type of garbage to you see frequently in your neighborhood?

35 responses



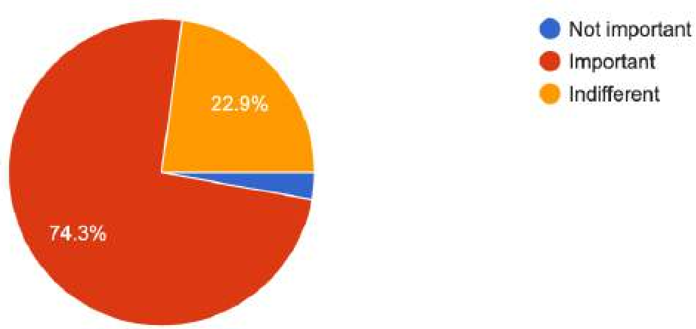
What are the biggest obstacles your organization faces when it comes to street cleanliness?

35 responses

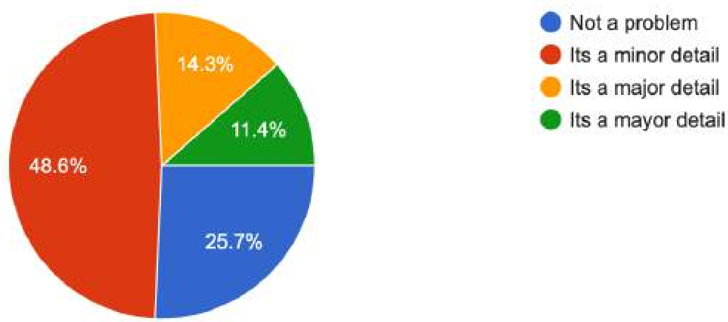


How important is sustainability in your organization's waste management initiatives?

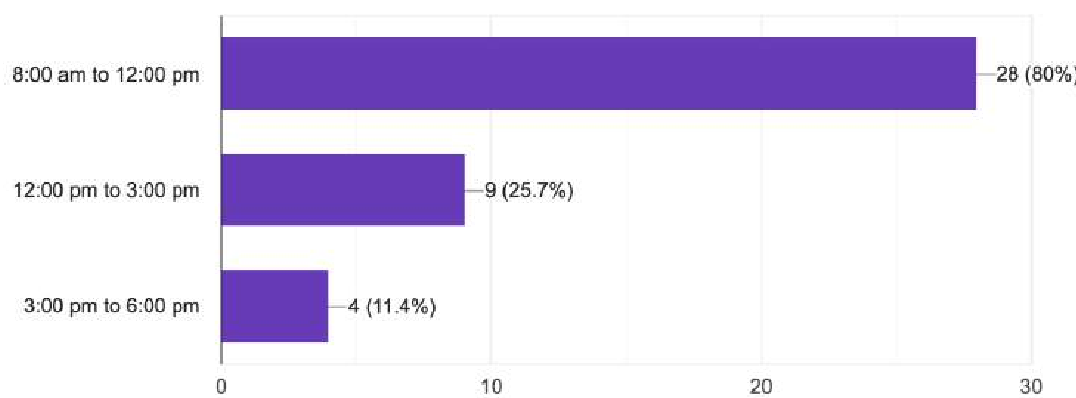
35 responses

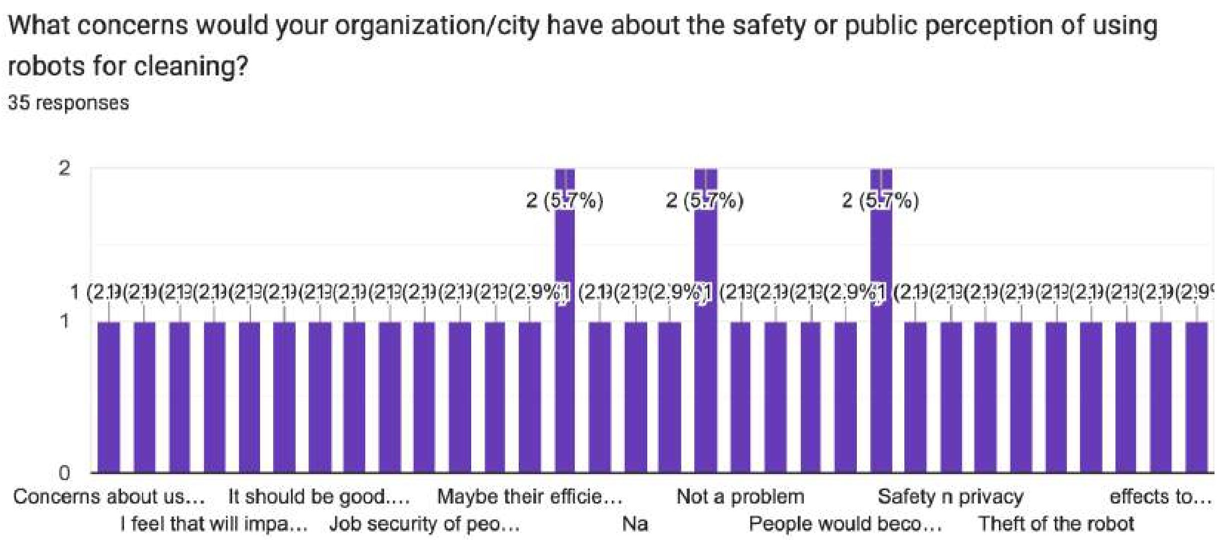


How important is it for the robot to operate quietly in residential areas?
35 responses



What times of the day do you operate cleaning services?
35 responses





Any questions/concerns please leave them here. Thanks

35 responses

N/A

N/a

None

NA

Robots would work better in public areas like parks and alleys etc... In residential areas I hv my doubts.

No all good

What kind of robot will be used?

My personal concern would be just someone misusing the robot, or the robot malfunctioning.

Which area do you plan to have this garbage collector? Also, how often would it come to clean? Would this be year-round or only when there is no snow?

How do we address theft of robots?

What will the battery management of cleaning robots be like

No

Why you want to take jobs from people they can work better but don’t make them unemployed

The robot should be able to work throughout different kinds of terrain.

We have garbage pickers who leave a mess. At times we clean it up otherwise our property will look terrible so we at times we clean it up to avoid this.

thanks!

n/a

What type of robots are we talking about?

No questions

None at the moment

Appendix B: IEEE Standards

IEEE 1625-2008 - IEEE Standard for Rechargeable Batteries for Multi-Cell Mobile Computing Devices

https://standards.ieee.org/standard/1625-2008.html

IEEE 1625-2008 applies to our engineering requirements for powering the robot using a rechargeable battery.

IEEE 1491 - IEEE Guide for Selection and Use of Battery Monitoring Equipment in Stationary Applications

https://ieeexplore-ieee-org.proxy.cc.uic.edu/document/5530299

IEEE 1491-2012 applies to our engineering requirement to measure the charge of the battery to know how much is left.

IEEE 802.3-2005 - IEEE Standard for Information Technology

https://standards-ieee-org.proxy.cc.uic.edu/standard/802_3-2005.html

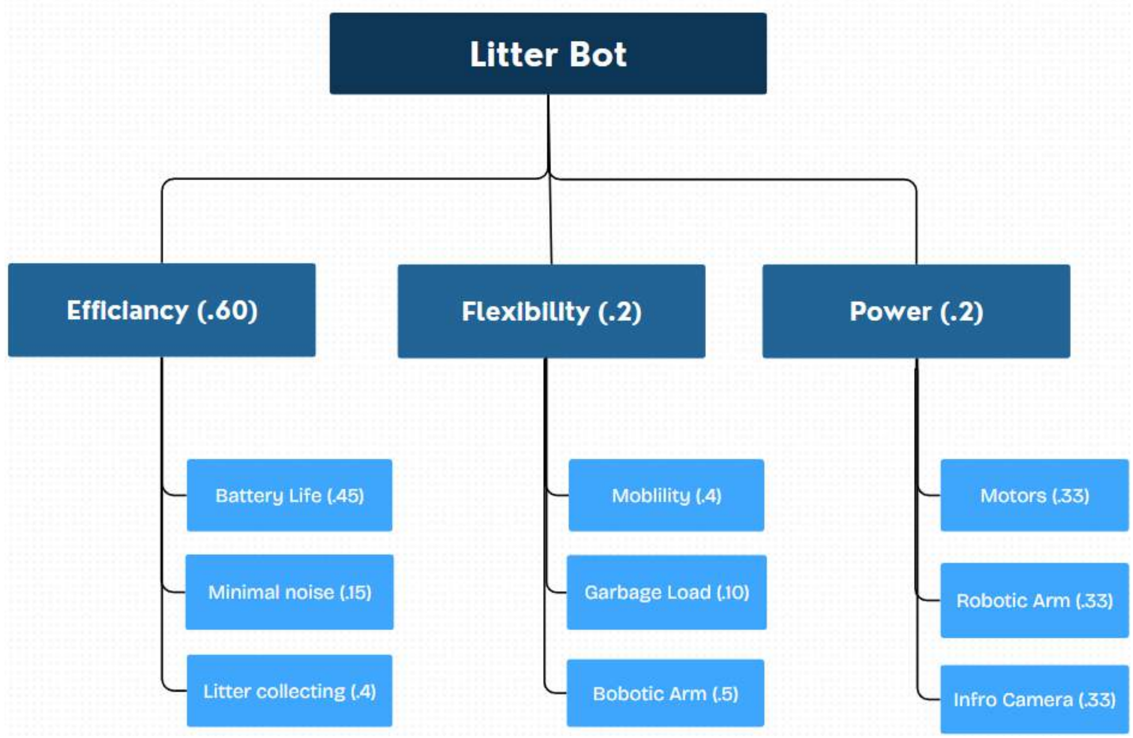
IEEE 802.3-2005 applies to our engineering requirement because our product needs to be able to detect objects in its surroundings to avoid collisions

IEEE 7009-2024 - IEEE Standard for Fail-Safe Design of Autonomous and Semi-Autonomous Systems

https://ieeexplore-ieee-org.proxy.cc.uic.edu/document/10582898

IEEE 7009-2024 applies to our engineering requirements because our product will implement AI and be automated, therefore we must include a fail-safe for safety reasons.

Appendix C: Objective Tree



Appendix D: Concept Map/Design Alternatives

Table D-1: General Concept Map

Function 1: Distance / Obstacle Avoidance Sensor	**Function 2: Micro-Contollers**	**Function 3: Power Source**	**Function 4: Mechanism for Picking Up Trash**	**Function 5: Camera**	**Function 6: Mobility**
Ultrasonic Sensor	Raspberry Pi 4 / 5	Lithium Polymer Battery	Robotic Arm	Intel RealSense D435	Unitree A1 Robot Dog
Time of Flight Sensor	ESP32	Solar Panels	Sweeper Pick	Raspberry Pi AI Camera	Wheels
Raspberry Module 3 (camera)	Arduino Mega 2560	`	Vacuum	Orbbec Astra Pro Camera	Tank Treads Track
	Nvidia Jetson Nano 4gb Ram		Suction Point	Burner Phone with Micro or Type C	

Table D-2: Design Alternative I

Function 1: Distance / Obstacle Avoidance Sensor	**Function 2: Micro-Contollers**	**Function 3: Power Source**	**Function 4: Mechanism for Picking Up Trash**	**Function 5: Camera**	**Function 6: Mobility**
Ultrasonic Sensor	Raspberry Pi 4 / 5	Lithium Polymer Battery	Robotic Arm	Intel RealSense D435	Unitree A1 Robot Dog
Time of Flight Sensor	ESP32	Solar Panels	Sweeper Pick	Raspberry Pi AI Camera	Wheels
Raspberry Module 3 (camera)	Arduino Mega 2560	`	Vacuum	Orbbec Astra Pro Camera	Tank Treads Track
	Nvidia Jetson Nano 4gb Ram		Suction Point	Burner Phone with Micro or Type C	

Table D-3: Design Alternative II

Function 1: Distance / Obstacle Avoidance Sensor	**Function 2: Micro-Contollers**	**Function 3: Power Source**	**Function 4: Mechanism for Picking Up Trash**	**Function 5: Camera**	**Function 6: Mobility**
Ultrasonic Sensor	Raspberry Pi 4 / 5	Lithium Polymer Battery	Robotic Arm	Intel RealSense D435	Unitree A1 Robot Dog
Time of Flight Sensor	ESP32	Solar Panels	Sweeper Pick	Raspberry Pi AI Camera	Wheels
Raspberry Module 3 (camera)	Arduino Mega 2560	`	Vacuum	Orbbec Astra Pro Camera	Tank Treads Track
	Nvidia Jetson Nano 4gb Ram		Suction Point	Burner Phone with Micro or Type C	

Table D-4: Design Alternative III

Function 1: Distance / Obstacle Avoidance Sensor	**Function 2: Micro-Contollers**	**Function 3: Power Source**	**Function 4: Mechanism for Picking Up Trash**	**Function 5: Camera**	**Function 6: Mobility**
Ultrasonic Sensor	Raspberry Pi 4 / 5	Lithium Polymer Battery	Robotic Arm	Intel RealSense D435	Unitree A1 Robot Dog
Time of Flight Sensor	ESP32	Solar Panels	Sweeper Pick	Raspberry Pi AI Camera	Wheels
Raspberry Module 3 (camera)	Arduino Mega 2560	`	Vacuum	Orbbec Astra Pro Camera	Tank Treads Track
	Nvidia Jetson Nano 4gb Ram		Suction Point	Burner Phone with Micro or Type C	

Appendix E: Individual Pairwise Comparison and Decision Matrix

Table E-1: individual Pairwise Comparisons

Parin Pandit	**Cost to consumer/ Development cost**	**Your group's technical knowledge about the design alternative**	**Time needed to complete design and development**	**Suitability for demo during EXPO**	**Geometric Mean**	**Weights**
Cost to consumer/ Development cost	1	1/5	3	7	1.43	0.25
Your group's technical knowledge about the design alternative	5	1	7	3	3.2	0.56
Time needed to complete design and development	1/3	1/7	1	1/7	0.29	0.05
Suitability for demo	1/7	1/3	7	1	0.76	0.13

during EXPO						

Key - 1=Equal, 3=Moderate, 5=Strong, 7=Very Strong, 9=Extreme

[Row] is ___KEY___ more important than [Column]

Christian Zamudio	**Cost to consumer/Development cost**	**Your group's technical knowledge about the design alternative**	**Time needed to complete design and development**	**Suitability for demo during EXPO**	**Geometric Mean**	**Weights**
Cost to consumer/Development cost	1	1	5	3	1.97	0.42
Your group's technical knowledge about the design alternative	1	1	1/5	1/3	0.51	0.11
Time needed to complete design and development	1/5	5	1	1/5	0.67	0.14
Suitability	1/3	3	5	1	1.5	0.32

for demo during EXPO						

Key: 1=Equal, 3=Moderate, 5=Strong, 7=Very Strong, 9=Extreme

[Row] is ___KEY___ more important than [Column]

Edwyn Arrezola	**Cost to consumer/ Development cost**	**Your group's technical knowledge about the design alternative**	**Time needed to complete design and development**	**Suitability for demo during EXPO**	**Geometric Mean**	**Weights**
Cost to consumer/ Development cost	1	3	1/5	3	1.16	0.27
Your group's technical knowledge about the design alternative	1/3	1	1/7	5	0.7	0.16
Time needed to complete design and	5	7	1	1/5	1.63	0.38

developme nt						
Suitability for demo during EXPO	1/3	1/5	5	1	0.76	0.18

Key: 1=Equal, 3=Moderate, 5=Strong, 7=Very Strong, 9=Extreme

[Row] is ___KEY___ more important than [Column]

Juan Estrada	**Cost to consumer/ Developm ent cost**	**Your group's technical knowledge about the design alternative**	**Time needed to complete design and developme nt**	**Suitability for demo during EXPO**	**Geometric Mean**	**Weights**
Cost to consumer/ Developm ent cost	1	1/5	1/7	1	0.41	0.07
Your group's technical knowledge about the design alternative	5	1	1	5	2.24	0.39

Time needed to complete design and development	7	1	1	7	2.65	0.46
Suitability for demo during EXPO	1	1/5	1/7	1	0.41	0.07

Key: 1=Equal, 3=Moderate, 5=Strong, 7=Very Strong, 9=Extreme

[Row] is ___KEY___ more important than [Column]

Table E-2: Average Weights of Pairwise Comparisons

	Parin Pandit	Christian Zamudio	Edwyn Arrezola	Juan Estrada	Average of Weights
Cost to consumer/Development cost	0.25	0.42	0.27	0.07	**0.25**
Your group's technical knowledge about the design alternative	0.56	0.11	0.16	0.39	**0.31**
Time needed	0.05	0.14	0.38	0.46	**0.26**

to complete design and development					
Suitability for demo during EXPO	0.13	0.32	0.18	0.07	**0.18**

Table E-3: Rating of Design Alternatives Relative to Criteria

	Cost to consumer/Development cost	**Your group's technical knowledge about the design alternative**	**Time needed to complete design and development**	**Suitability for demo during EXPO**
Design Alternative 1	1	5	5	3
Design Alternative 2	3	3	3	1
Design Alternative 3	3	1	1	3

Key: 1=Does not meet the criterion, 3=Partially meets the criterion, 5=Completely meets the criterion

Table E-4: Decision Matrix

Criteria	**Average of Weights**	**Design Alternative 1**	**Design Alternative 2**	**Design Alternative 3**
Cost to consumer/Development cost	**0.25**	1	3	3
Your group's technical knowledge about the design alternative	**0.31**	5	3	1
Time needed to complete design and development	**0.26**	5	3	1
Suitability for demo during EXPO	**0.18**	3	1	3
Score		**3.64**	**2.64**	**1.86**

Appendix F: Preliminary Design

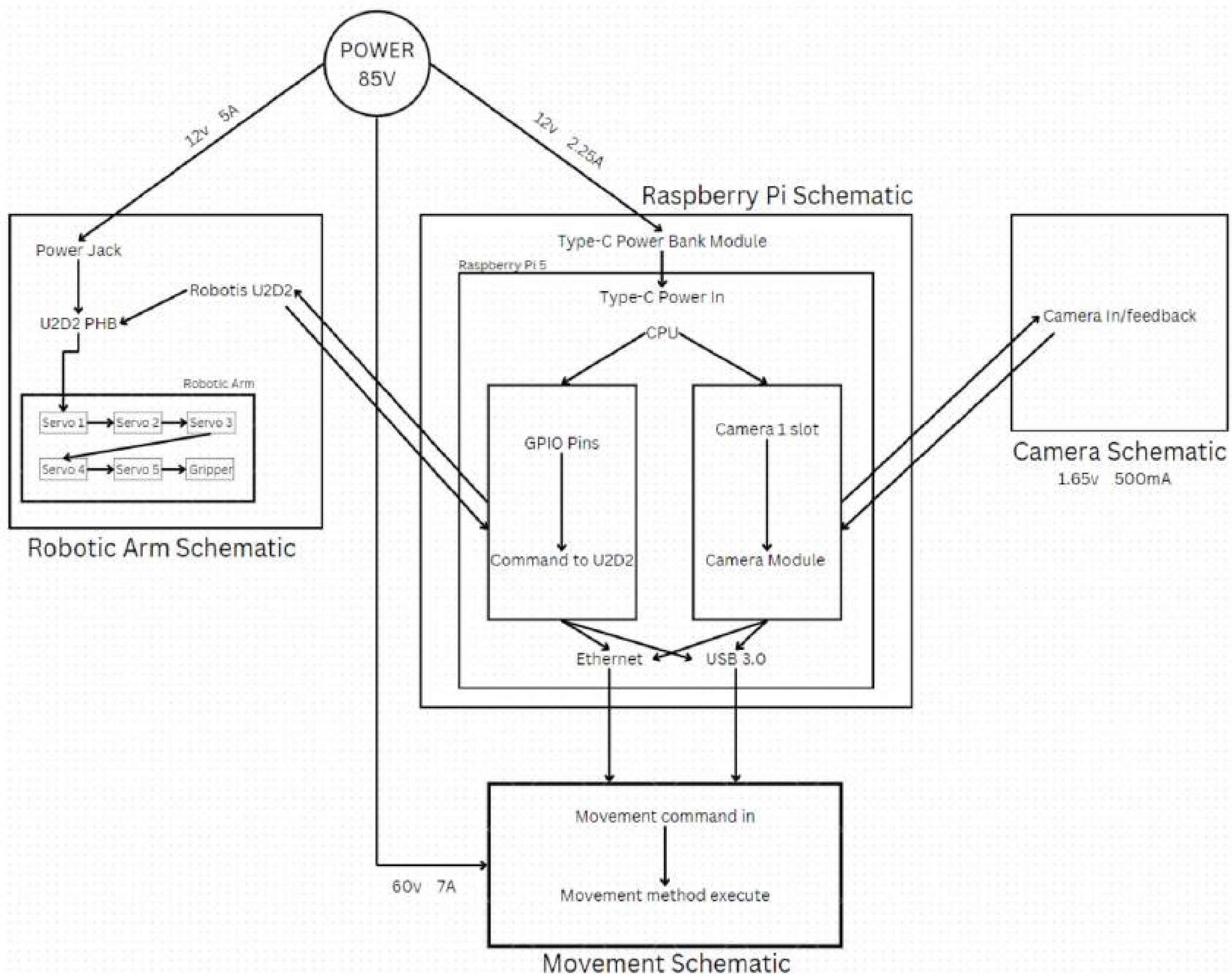


Figure F-1: Level 1 Schematics

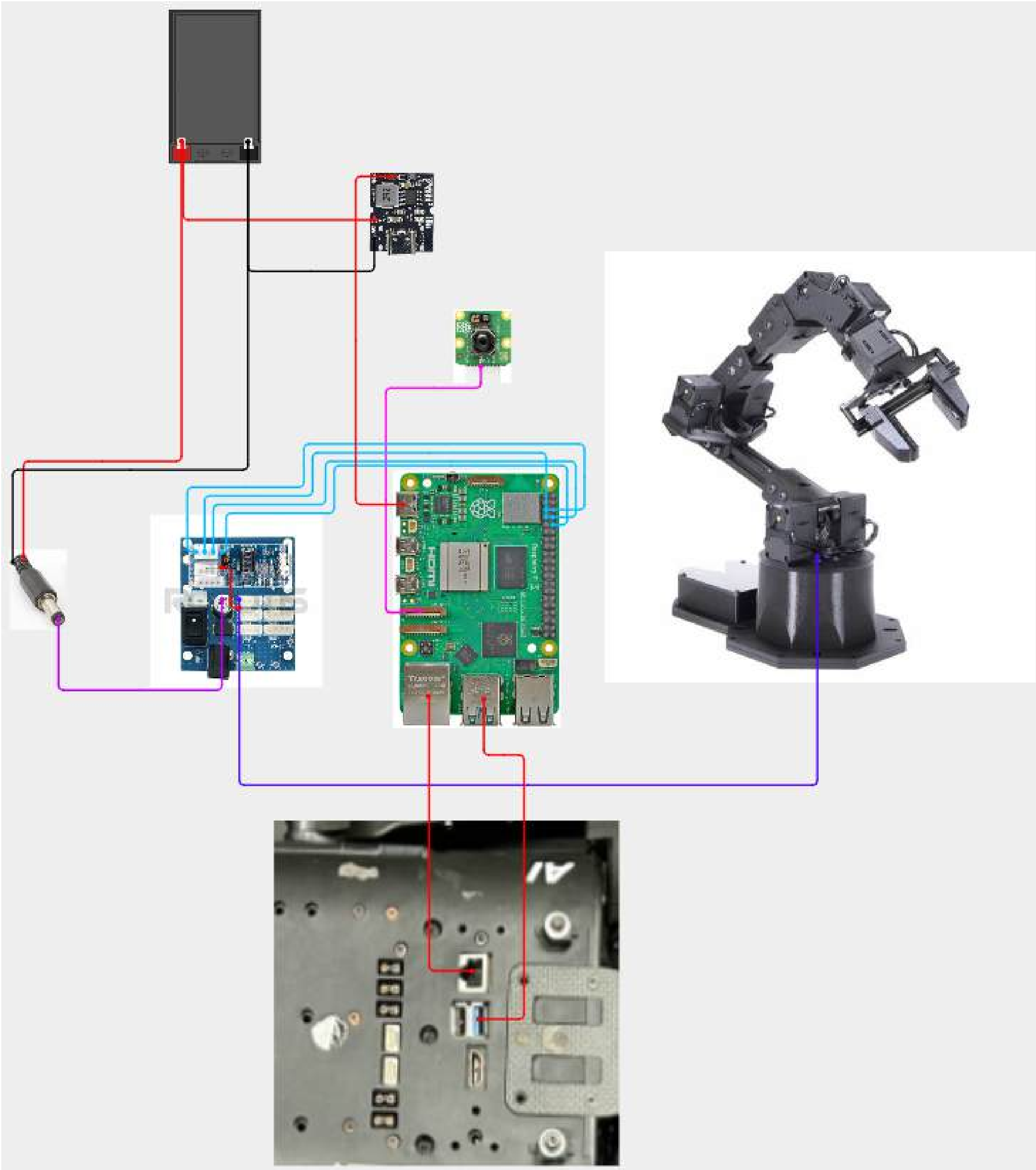


Figure F-2: Raspberry Pi or Arduino Circuit Schematic

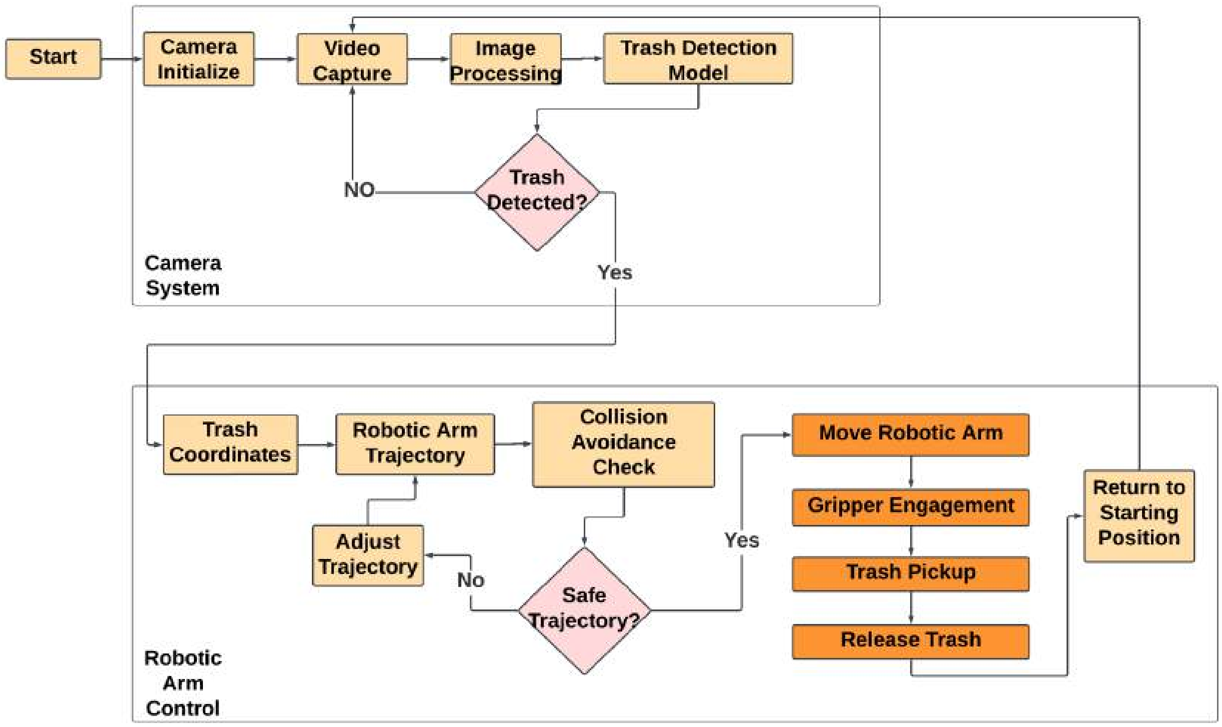


Figure F-3: Software Architecture

Appendix G: User Manual

Placement on platform: **(FIGURE 9)**

- Have a modeled platform base in a T-shape, this base is going to be used to hold the openMANIPULATOR-X, the Intel RealSense D435 camera and both converters (one for the microprocessor and the other for the robotic arm).
- Have the front side of the OpenMANIPULATOR-X facing towards the stem of the T-shaped base, this is where its orientation is going to be placed, make sure it lines up with the holes on the unitree robot to hold it into place.
- Grab the RealSense camera and place it around 3-4 inches away from the base of the OpenMANIPULATOR-X in such a way that it's right below the arm, once you have the placement of the camera, you can screw it in to lock it in place.
- Now you can place the converters on both ends of the horizontal side of the T-shape base with wires sticking outside of the base, you can use double sided tape to secure these converters.

Connection: **(FIGURE 10)**

Connections are essential for the operation of the of system, make sure that:

- The buck converter has an output voltage of 5V and 3A, this is enough power to operate the Pi.
- Plug in the INPUT side of the buck converter to Port 8 on the Unitree, this port offers 12V/2A, which is perfect for our Pi.
- Plug in the OUTPUT side of the convertor to the Raspberry Pi and make sure it works properly.
- Use the openManipulator converter offered by professor Pranav and stick the INPUT side of the converter to Port 9 on the initree, this port offers 19V/2V which is enough power to operate the arm.
- Plug in the OUTPUT side of the robot arm convertor to the U2D2 board right into the screw terminals and lock them in.

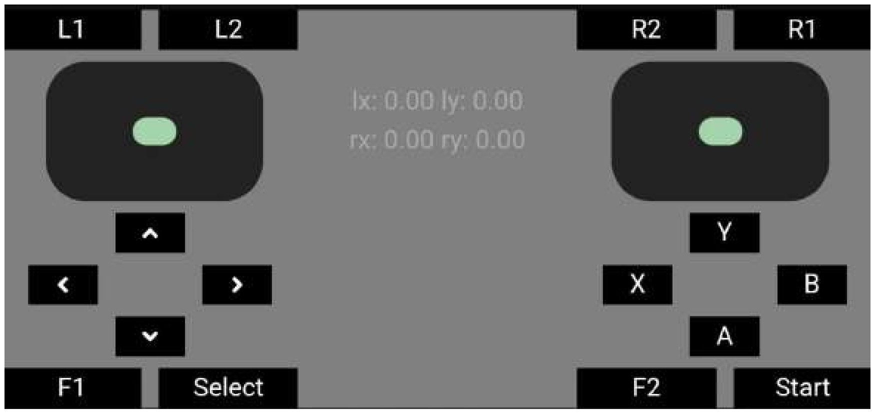
Once these 2 convertors are nice and snug, you can connect the REAL sense camera to the Pi as well as your HDMI, and mouse/keyboard.

<u>Unitree A1 operation:</u>

- Place the Unitree robot on the floor, make use that all four of its legs are closed and all the joints are touching the floor perfectly, failing to do so, the robot will not start up properly.
- Once you verify that everything is plugged in, you can proceed to turn on the Unitree A1 controller (press one time, release and press/hold until you hear the beep) then you can turn on the robotic dog (press one time, release and press/hold until you hear the robot starts).
- Once the robot's fans are enabled, stand back and wait until the robot dog is standing up. The default code that it runs, glitches and the robot starts drifting left, quickly moving the right joystick towards the left, this would help stabilize the dog.
- Press the start button on the lower right of the controller to make the dog stop moving (this might take a few tries due to the robot drifting right).
- Move the left joystick down to make the dog bend down (in this position the robot does not drift).
- Plug in professor Pranav's custom Unitree code on the ethernet port and enable it by using the following commands in the command prompt on the laptop:
  ./a1_move.sh
  - **Press enter**
  - **Put password (given by professor)**
  - **Press enter**

- Once the commands above are executed the robot dog is going to jerk. Make sure you hold it tight to prevent off balance and that it's as close to the ground as possible to avoid an accident.

- Robot dog will stand up and start walking in place. Press B to be still and with the arrows on the left side of the controller you can use up/down to change height. Use the left and right arrow to adjust tilt.
- Press A to start walking (you now have more control and there is no drift). Use the right joystick to drift left and right. Use the left joystick to move forward/backward and turn.



Appendix H: Task Allocation and Timeline

Table H-1: Task Allocation Breakdown

Week	Start Date:	End Date:	Number of Weeks	Team Lead	Task	Description
1	01/13/25	02/03/25	4	Juan	Order Parts	Order all necessary parts to start, if more parts are needed order within the number time frame given.
2	01/20/25	02/10/25	3	Edwyn	Program in Python (Machine learning)	Work on programming the machine learning code for litter detection.
3	01/27/25	02/03/25	1	Parin	Test and Verify Camera reliability	Debugging code and ensuring it runs.
4	02/03/25	03/17/25	2	Christian	Program for	Program code for

					Intel RealSense Camera D435	Intel RealSense Camera D435 data.
5	02/10/25	03/17/25	1	Edwyn	Test and verify Intel RealSense Camera D435 reliability	Debugging Intel RealSense Camera D435 data.
6	02/17/25	03/03/25	2	Christian	Program robotic arm functions	Work on code for movement function of robotic arm
7	02/24/25	03/03/25	1	Parin	Test and verify robotic arm functions	Debugging any error in robotic arm movement code.
8	03/03/25	03/17/25	2	Juan	Integrate all components with robot dog	Attach all sensors, microcontrollers, and any other components together.
9	03/10/25	03/17/25	1	Christian	Test and verify integrations functionality	Debbing any error from connecting all components together.
10	03/17/25	03/24/25	1	Edwyn	Fix any bugs left for any code	Run code and components together, debug if any errors appear.
Break	03/24/25	03/28/25			NULL	NULL
11	03/31/25	04/14/25	2	Juan	Finalize and test overall project	Testing the entire system as a prototype
12	04/07/25	04/14/25	1	Parin	Last minute debugging and touch ups	Working on last minute changes, fixing remaining

						bugs.
13	04/14/25	04/21/25	1	Christian	Finalize expo display	Finalize display and other material needed for expo.
EXPO	04/25/25	04/25/25		All	Expo	Expo

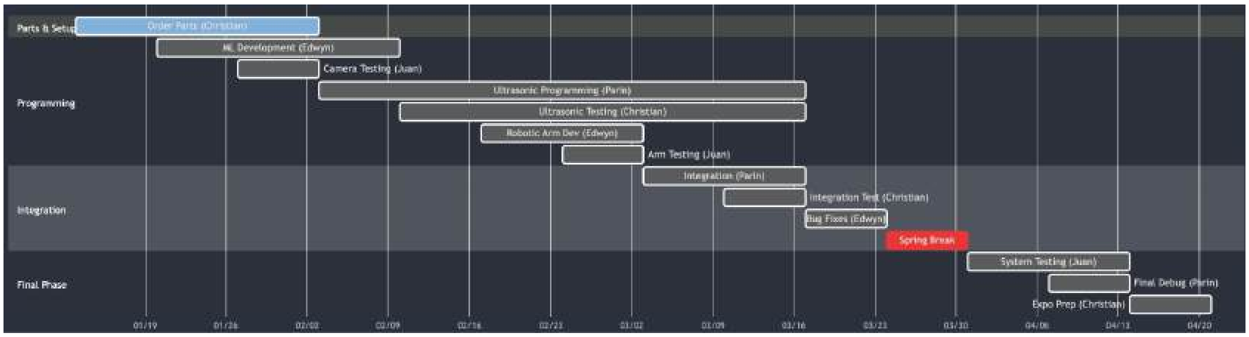


Figure H-1: Task Development Timeline

Appendix I: Terminal Results for Object Detection + Position Coordinates

```
data: '{"item_0": {"class": "bottle", "confidence": 0.867, "position_xyz": [0.263, -0.03, 0.004]}}'
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data: '{"item_0": {"class": "bottle", "confidence": 0.851, "position_xyz": [0.267, -0.031, 0.002]}}'
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data: '{"item_0": {"class": "bottle", "confidence": 0.889, "position_xyz": [0.264, -0.032, 0.0]}}'
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data: '{"item_0": {"class": "bottle", "confidence": 0.881, "position_xyz": [0.264, -0.033, -0.001]}}'
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data: '{"item_0": {"class": "bottle", "confidence": 0.888, "position_xyz": [0.264, -0.033, 0.0]}}'
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```

Figure I-1: Terminal Results