Pathfinder: Home Assistant

Rory McCulloch, Bonita Ren Ren, Parker Williams, Brayden Jensen, Calum Irwin

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Abstract

This is a document outlining the key needs expressed to us by our client accompanied by further research done on other clients and products to provide an all-encompassing view of the current issues. Our goal is to clearly define the humanitarian issues with killer robots and provide alternative uses for both the robot itself and its programming application.

Table of Contents

1 Introduction 6

1.1 Related Work 6

2 Needs 6

2.1 Identified Needs 6

2.2 Prioritization of Needs 6

3 Needs Detailed 7

3.1 Problem Statement 7

3.2 Summary 7

4 Key Design Criteria 7

4.1 Existing Products with Desirable Attributes 8

4.2 Specifications: 8

4.3 Reflection on Client Needs 9

5 Subsystem Overview 9

5.1 Object Recognition Subsystem 10

5.2 Decision-Making Subsystem 12

5.3 System Reaction Subsystem 13

5.4 Reaction Time Subsystem 14

6 Project Schedule and Cost 16

6.1 Detailed Design Drawing 16

6.2 Project Task Plan & Schedule 17

6.3 Risk Assessment & Contingency Plans 18

6.4 Cost Estimation & Bill of Materials (BOM) 18

6.5 Prototyping & Testing Plan 18

7 Prototype I and Customer Feedback 19

7.1 Client and Customer Feedback Summary 19

7.2 Critical Components Analysis 19

7.3 Prototyping 20

7.4 Prototyping Test Plan 23

8 Prototype 2 and Customer Feedback 25

8.1 Client and Customer Feedback Summary 25

8.2 Analytical Model for Transport Mechanism Stability 27

8.3 Experimental Testing and Validation 27

8.4 Prototyping Test Plan 27
8.5 Future Improvements 29
9 Conclusion.....32

1 Introduction

The company DJI has developed robots that are easily programmable with the intention of simplifying the process, inadvertently popularizing the creation of killer robots that can act autonomously. This document details the key issues that arise from this normalization and explores alternative, ethical applications.

1.1 Related Work

Several organizations and advocacy groups, such as the United Nations, the Red Cross/Red Crescent, human rights organizations, and the tech community, have expressed strong opposition to the development of autonomous weapons and killer robots. Their key needs and requests include the urgent establishment of an international legal framework to ban or regulate autonomous weapons, maintaining human involvement in warfare and transparency in AI development. They encourage support for global disarmament treaties and strengthening ethical AI guidelines to prevent the unchecked proliferation of lethal autonomous systems.

2 Needs

The identified needs and their prioritization based on our research and the needs of our client.

2.1 Identified Needs

- Lack of human judgement and understanding
    - Algorithmic biases
    - Loss of meaningful human control
    - Lack of accountability
- Detach from digital dehumanization
    - Incorporate human decision making
    - Avoid individualization
- Impact on our relationship to technology
    - Inability to explain what happened or why
    - Lowering the threshold to war
    - Assign value aside from monetary value
- Make error proof using exceptions
- Diverge as far from war aspects as possible

2.2 Prioritization of Needs

- High Priority (5):
    - Lack of human judgement and understanding
    - Digital dehumanization
    - Diverge as far from war aspects as possible
- Medium Priority (4):
    - Negatively impacts on our relationship to technology
- Low Priority (3):
    - Make error proof using exceptions

3 Needs Detailed

3.1 Problem Statement

Autonomous weapon systems present ethical challenges by dehumanizing targets through algorithm-driven decisions, lacking empathy and accountability. As AI advances, concerns about bias and control grow. Our goal is to integrate human oversight to reduce risks and build trust. The Robomaster S1 educational robot illustrates key challenges in adaptability, recognition, and durability, highlighting complexities in autonomous deployment. By focusing on peaceful applications like education, we aim to redefine robotics' role, prioritizing ethics and human dignity over conflict.

3.2 Summary

Our client's top priority is detaching the robot from digital dehumanization, which occurs when autonomous weapons analyze visuals algorithmically, removing human judgment and increasing identification errors. Our ethical alternative integrates human decision-making to mitigate mistakes and address accountability concerns. Despite AI advancements, it remains imperfect, raising ethical and legal issues. The robot's impact on technology use requires clear, understandable behaviors to foster confidence and transparency. Shifting the robot's purpose from conflict to peaceful applications, such as teaching, can transform public perception from fear to constructive engagement. Valuing the robot beyond monetary considerations underscores its societal and ethical benefits. Another critical concern is the lack of human judgment in autonomous weapons, exacerbating algorithmic biases, loss of control, and accountability gaps. Without clear responsibility, ethical and legal dilemmas arise. Implementing human oversight ensures decisions are guided by moral values rather than algorithms. The RoboMaster S1, an educational tool, effectively highlights the limitations of autonomous military robots. Despite its engineering strengths, it struggles with terrain navigation, object handling, and durability. Its unreliable recognition software can be bypassed, posing risks in real scenarios. Short battery life and high maintenance further expose practical challenges. These shortcomings provide valuable lessons on the complexities and ethical implications of autonomous systems. Redirecting robotics from military applications to humanitarian and artistic uses fosters ethical development and human connection. Whether in creative projects or humanitarian efforts, the RoboMaster S1 exemplifies robotics' potential beyond warfare.

4 Key Design Criteria

- Oversight
    - Decision limit of importance that the robot can make. The robot needs approval before certain tasks or actions. As well as the ability to stop and override any independently made decision easily and concisely. The robot has strict safety parameters against harming the user or pet.
- Usability
    - Voice commands and or touch interface control and accessibility. Multiple control areas and if possible full navigation and movement potential as well as house integration with

basic house functions (lights, heating, locks, emergency phones, and check ins, reminders).

- Reliability
    - Emergency power, troubleshooting guidance and self-diagnosing errors. The selling client also has full time helpline and door service repair options.
- Object Carrying Capabilities
    - Able to carry various items of different sizes and weights to assist users. Size and weight parameters should be specified to the client before purchase.
- Video Surveillance
    - The system must provide high-definition, low-latency video streaming to ensure real-time visibility of household environments. It should support both live monitoring and video recording with clear image quality under varying lighting conditions.
- User interaction and accessibility
    - It should support intuitive user interactions via mobile apps, voice commands, and touch interfaces. It must be accessible to all age groups and compatible with common smart home ecosystems.

4.1 Existing Products with Desirable Attributes

- Amazon Astro: smart home integration, remote monitoring
- ElliQ: emotional support and medication reminders
- Temi Robot: video calling and AI assistance
- Roomba: navigation and house mapping, auto charging at night

4.2 Specifications:

Functional:

- Navigation and Movement - obstacle detection, mapping and path planning, same movement system, elevation change system implementation.
- Connectivity - Wi-Fi and bluetooth support for smart home integration
- Emergency response - can contact family/friends or emergency services

Non-functional:

- Size and Weight - small enough for indoor use, smaller or same size, <10kg
- Voice command Response time - <1 second delay

Constraints:

- Maximum load - can carry light loads of items (groceries for example) 20kg
- Battery life - at least 8 hours per charge, charging in down time
- Data Privacy - no cloud storage of user data

4.3 Reflection on Client Needs

Emphasis on ethical AI:

stressing the need for oversight and ethical AI to ensure that robots do not make independent critical decisions that alter and could jeopardize human life. This will lead to multiple safety and override features and a real time monitoring system in the design criteria.

Shift from Military applications:

Autonomous robots are often used for education, this is much better demonstrated in fields and purposes outside of military use as the uses and applications vary to a much larger degree. A home assistant solution would have a broader humanitarian impact.

5 Subsystem Overview

The Home Assistant Robot is divided into four main subsystems, each contributing to its functionality and interaction with the environment. These subsystems work together to enable the robot to navigate, recognize objects, process decisions, and respond to user commands efficiently. The object recognition subsystem is responsible for detecting and identifying objects in the robot's environment using shape-based recognition. It allows the robot to track and follow objects without classifying them as human or non-human, ensuring ethical and adaptable tracking. The system relies on edge detection and contour analysis to identify the nearest object and adjust movement accordingly. The decision-making Subsystem processes data from the Object Recognition and Voice Command subsystems to determine the robot's next action. It evaluates object positioning, user input, and navigation constraints before executing a response. This subsystem ensures that movements and interactions are logical and context aware. The system reaction subsystem translates decisions into physical actions. Once an action is determined, this subsystem sends the appropriate movement or operational commands to the robot's motors and sensors. It ensures real-time execution of navigation, tracking, and response behaviors based on the processed information. The response time subsystem optimizes how quickly the robot processes input and executes actions. It manages computational efficiency, ensuring minimal delay between object recognition, decision-making, and system reaction. A streamlined response time enhances the robot's ability to interact smoothly with its environment.

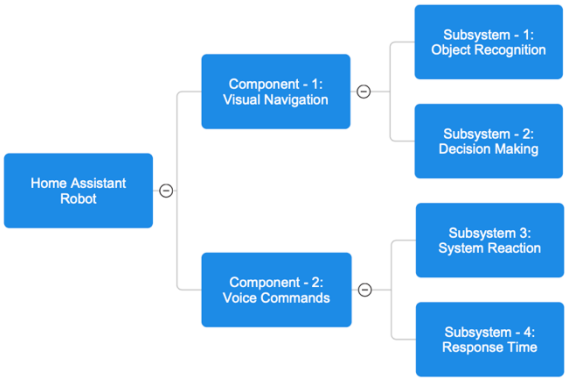

Figure 1. Subsytem Layout

5.1 Object Recognition Subsystem

Overview

The Object Recognition Subsystem is responsible for detecting and tracking objects in the RoboMaster's field of view. This subsystem enables the robot to identify the nearest object without classifying it as a human, maintaining ethical integrity while allowing for dynamic tracking. The system ensures that the robot can recognize predefined objects and adjust its movement accordingly.

Concepts Considered

A. Motion-Based Tracking
    a. Description: The robot detects motion using optical flow and follows the most significant moving object.
    b. Benefits: Works without pre-training on specific objects.
    c. Drawbacks: Can be disrupted by background movement (e.g., TVs, fans, or other non-relevant motion sources).

B. Color-Based Object Tracking
    a. Description: The robot identifies and follows objects based on a specific color range.
    b. Benefits: Simple implementation and efficient tracking.
    c. Drawbacks: Not adaptable to varying environments where lighting conditions may affect color detection.

C. Shape-Based Object Detection (Selected Approach)
    a. Description: Uses contour detection to identify the largest object in the frame and tracks its shape.
    b. Benefits: Works in multiple environments, does not require person recognition, and can follow any sufficiently large object.
    c. Drawbacks: May struggle with overlapping objects or complex backgrounds.

Final Chosen Concept: Shape-Based Object Detection

This method was selected due to its ability to generalize object recognition without requiring explicit human detection as seen in *Figure 2*. It uses edge detection and contour analysis to identify the largest object in front of the RoboMaster. This approach ensures:

- Ethical tracking (does not classify objects as people or non-people).
- Dynamic adaptability (tracks various objects without specific training).
- Compatibility with voice commands to initiate and stop tracking.

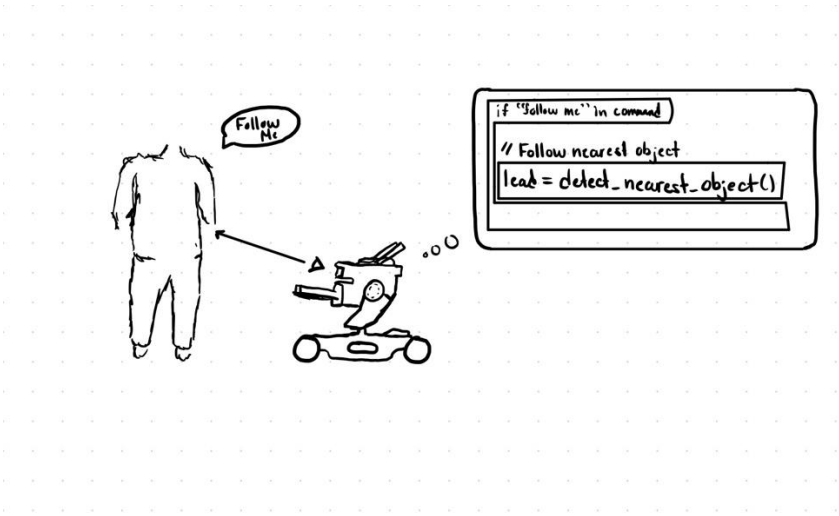

Figure 2. Shape-based recognition

System Implementation

- Hardware Used
  - RoboMaster S1 Built-in FPV Camera
  - Onboard Computer (Connected to RoboMaster via WiFi)
- Software Used
  - OpenCV for image processing
  - YOLO (for optional object detection and training on specific objects)
  - RoboMaster SDK for movement control

Future Improvements

- Machine Learning Integration: Train a YOLO model for specific object recognition.
- Depth Estimation: Integrate stereo vision or LiDAR for distance measurement.
- Obstacle Avoidance Enhancements: Combine with mapping algorithms for better path planning.

5.2 Decision-Making Subsystem

Overview

The Decision-Making subsystem is crucial for the functionality of the Home Assistant Robot, ensuring that it interprets input from object recognition and voice commands to make appropriate, efficient, and context-aware decisions. A well-optimized decision-making system enhances the robot's ability to function autonomously while maintaining user trust and safety. The goal of this subsystem is to prioritize urgent commands, optimize processing efficiency, and maintain adaptability for various household tasks.

Concepts Considered

A. Rule-Based Decision Making:
   A predefined rule-based system will be implemented to prioritize simple and emergency commands for quick execution. The system will follow a hierarchy where essential commands, such as "Call 911," are processed first, reducing delays.

   a. Advantage: Ensures fast execution of critical commands, minimizing processing complexity.
   b. Advantage: Allows customization for individual users' needs.
   c. Challenge: Limited adaptability to new or complex commands.
   d. Challenge: Requires manual updates to expand command libraries.

B. AI-powered adaptive learning:
   An AI-driven decision-making model will be integrated to learn user behavior and adapt to complex scenarios. This system will analyze past interactions and predict future commands based on context.

   a. Advantage: Improves personalization over time.
   b. Advantage: Enhances flexibility for a broader range of commands.
   c. Advantage: Can optimize decision-making for energy efficiency and task prioritization.
   d. Challenge: Requires continuous training and data collection.
   e. Challenge: Higher computational requirements compared to rule-based systems.

Safety & Fault Handling Mechanisms

- Ensuring safe and reliable decision-making is crucial for user trust. The system integrates multiple safety and fault-handling mechanisms to mitigate potential risks and maintain operational stability.
- Command Verification: High-risk actions, such as unlocking doors at midnight, require multi-step authentication through voice or biometric recognition before execution.
- Backup Mode: If the system encounters a failure, it seamlessly transitions to rule-based operations, ensuring that basic functionalities remain intact even when cloud processing is disrupted.
- Version Reversion: If AI-driven learning malfunctions, the decision-making model automatically reverts to the last known stable version to prevent erratic behavior.
- Manual Override: Users retain complete control through mobile apps, voice commands, or emergency stop buttons, enabling quick correction of unintended actions.

- Power & Network Failure Handling:
    - In case of a power outage, the system switches to low-power emergency mode, prioritizing essential commands.
    - If network connectivity is lost, local processing capabilities ensure uninterrupted execution of critical decisions.

Final Chosen Concept: Hybrid

Based on the evaluation, a hybrid approach was chosen to ensure efficiency, adaptability, and reliability while maintaining reasonable costs and computational loads.

Criteria	Rule-Based System	AI-Powered Learning	Hybrid Approach (Selected)
Response Time (ms)	600	1000	700
Processing Load (%)	Low	High	Medium
Reliability (%)	95	85	93
Cost ($)	Low	High	Medium
Implementation Difficulty	Medium	high	Medium

Figure 3. Comparison of Decision-Making Subsystem Approaches

System Implementation

- Hardware Used
    - Embedded AI processor for adaptive decision-making (e.g., NVIDIA Jetson, Google Coral TPU).
    - Edge computing module for processing decisions locally, reducing reliance on cloud-based AI.
    - Onboard memory to store frequently used decision models for quick execution.
- Software Used
    - Rule-based decision engine to process predefined commands quickly.
    - Machine learning model for adaptive learning and personalized decision-making.
    - Integration with object recognition and voice command subsystems to ensure real-time processing.

By implementing a hybrid decision-making system that combines rule-based efficiency with AI-driven adaptability, the Home Assistant Robot can respond effectively to a wide range of user commands while ensuring accuracy, speed, and user personalization. Future improvements include refining AI learning models and optimizing computational efficiency to further enhance decision-making capabilities.

5.3 System Reaction Subsystem

Overview

The Carrying Platform Subsystem replaces the previous System Reaction Subsystem and is designed to hold small essential items such as medication and a water bottle/cup. The platform provides a stable surface for transportation, integrating seamlessly with the RoboMaster S1's mobility capabilities.

Concepts Considered

A. Fixed Platform
    a. Description: A simple, non-movable tray attached to the RoboMaster.
    b. Benefits: Easy to implement, stable load-bearing capacity.
    c. Drawbacks: No flexibility in handling different terrains.
B. Adjustable Platform (Selected Approach)
    a. Description: A 3D-printed 18x18cm platform, mounted on a slight elevation for balance and attached securely to the RoboMaster.
    b. Benefits: Provides a flat, stable carrying surface for medication/water.
    c. Drawbacks: Requires proper weight distribution to avoid tipping.

Final Chosen Concept: Adjustable Carrying Platform

The 18x18cm carrying platform will be 3D-printed using PLA with an Ultimaker 2+. The design ensures:

- Stability for transporting medication and small containers.
- Lightweight and durable material for minimal impact on mobility.
- Secure attachment using custom fasteners to prevent shifting.

System Implementation

- Hardware Used
    - 3D-printed platform (PLA, Ultimaker 2+).
    - Custom mounting brackets to attach to RoboMaster S1.
    - Non-slip padding for stability.
- Software Used
    - CAD modeling for platform design.
    - Ultimaker Cura for 3D printing preparation.

Future Improvements

- Weight sensors to detect load and adjust movement speed.
- Secure latching system to hold items in place.
- Automatic balancing adjustments based on terrain feedback.

5.4 Reaction Time Subsystem

Overview

Reaction time is a critical performance metric for the home assistance robot, ensuring that voice commands are processed and executed efficiently. A system with minimal delay enhances user

experience, especially for individuals with disabilities or urgent needs. The goal of this subsystem is to achieve a response time of less than one second while maintaining accuracy and reliability.

Concepts considered

A. Edge Computing for Real-Time Processing
    a. Processes voice commands locally on the device rather than relying on cloud-based AI.
    b. Reduces latency by eliminating networking delays and enhances privacy as no data is sent to external
    c. Challenge: Increased processing load on onboard hardware and higher power consumption, ultimately raising the cost of the product.

B. Optimized Algorithm for Decision-Making
    a. Implements a rule-based system to prioritize simple and emergency commands, reducing processing time.
    b. Provides fast response times for predefined commands, such as “Call 911.”
    c. Challenge: Limits adaptability for new or complex commands that require learning AI and extensive pre-programming of command libraries.

C. Hardware Acceleration with AI Co-Processors
    a. Utilizes a fully dedicated AI processing unit such as NVIDIA Jetson or Google Coral TPU to enhance computation speed.
    b. Allows for optimized real-time voice recognition and response, addressing earlier challenges like complex command interpretation efficiency.
    c. Challenge: Increased cost and specialized hardware, leading to potential compatibility integration issues with other household systems.

Final Chosen Concept: Edge Computing

Edge Computing was selected as the primary solution due to its balance of response speed, reliability, and privacy. The Optimized Algorithm will serve as a secondary enhancement to prioritize urgent commands.

Criteria	Edge Computing	Optimized Algorithm	Hardware Acceleration
Response Time (ms)	800	600	500
Processing Load (%)	High	low	medium
Reliability (%)	95	90	98
Cost ($)	Medium	low	high
Implementation Difficulty	Medium	high	medium

Figure 4. Comparison of Reaction Time Subsystem Design Approaches

System Implementation

- Hardware Used
    - Embedded AI module for on-device processing (e.g., NVIDIA Jetson, Google Coral TPU).
    - Microphone array with noise reduction capabilities.

    - Low-power processing unit for optimized decision-making.

- Software Used
    - Rule-based command prioritization algorithm.
    - Edge-computing optimized speech-to-text module.
    - Integration with smart home APIs for seamless connectivity.

By implementing an Edge Computing approach with rule-based prioritization, the Home Assistance Robot can achieve a reaction time of less than one second while ensuring accuracy and reliability. Future work includes testing real-world response times and refining the algorithm for greater efficiency.

6 Project Schedule and Cost

6.1 Detailed Design Drawing

A refined technical drawing will summarize all major components of the system, including:

- Hardware Components (RoboMaster S1, camera, microcontroller, wiring, fasteners, power supply, sensors, etc.).
- Software Components (OpenCV for object recognition, RoboMaster SDK for movement control, optional YOLO model for future enhancements).
- Integration Details (How object recognition interacts with decision-making and movement subsystems).

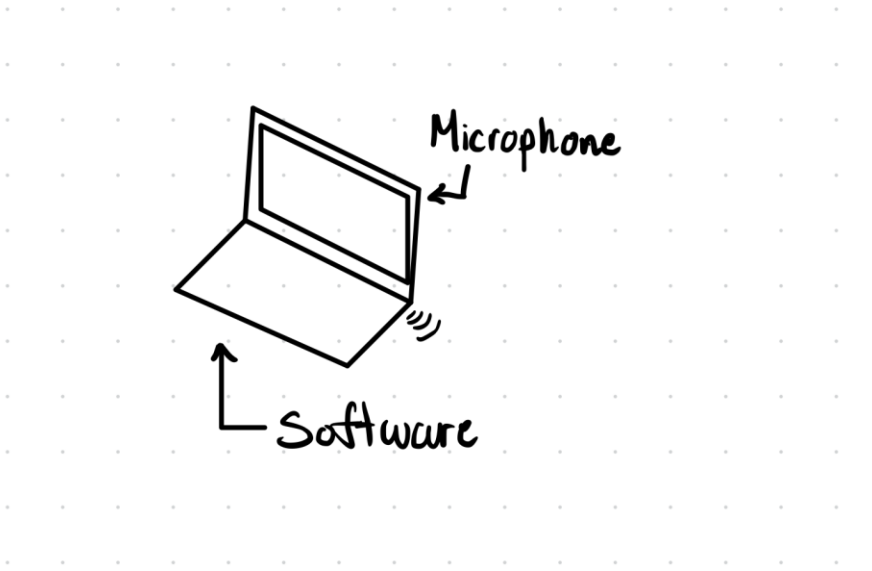

Figure 5. Built-In Microphone and Software Applications

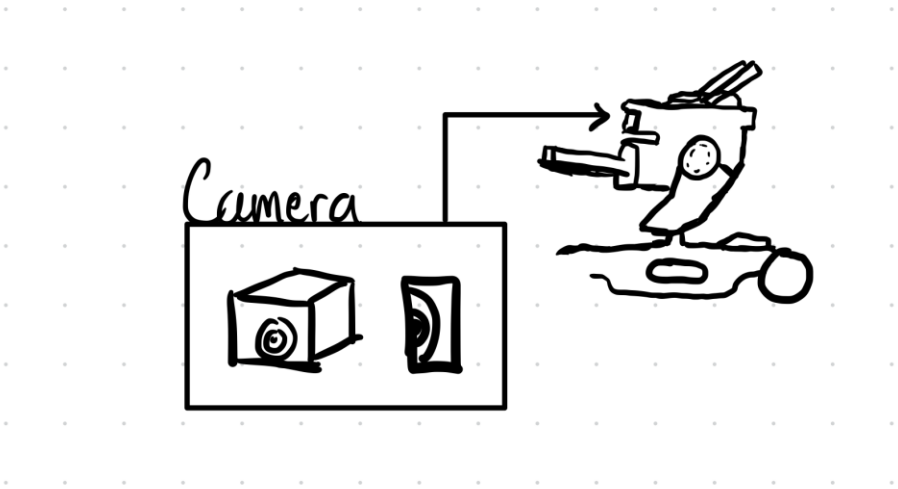

Figure 6. Built-In RoboMaster S1 Camera

6.2 Project Task Plan & Schedule

The project will be executed in structured phases with clearly assigned tasks.

Task	Assigned To	Estimated Duration	Dependencies
Object Recognition Code Implementation	Rory	2 weeks	OpenCV Installed
Voice Command Integration	Bonita	1 week	Object Recognition Completed
Movement Testing & Calibration	Brayden	2 weeks	Hardware Setup Complete
UI/Control Panel Setup	Parker	1 week	Connectivity Established
Hardware Assembly & Wiring	Calum	2 weeks	Component Availability
System Integration & Final Testing	Team	2 weeks	All subsystems functional

Figure 7. Scheduling and Task Assignment

Project Timeline Overview

- Week 1-2: Develop object recognition and integrate with RoboMaster.
- Week 3-4: Implement movement tracking and decision-making.
- Week 5-6: Integrate voice commands and UI interaction.
- Week 7-8: Conduct final system testing and refine the design.

6.3 Risk Assessment & Contingency Plans

Identifying risks and mitigating potential setbacks ensures project stability.

Task	Assigned To	Estimated Duration
Object recognition fails to detect shapes properly	High	Debug detection logic, optimize edge detection parameters
Delay in software integration	Medium	Develop movement and UI in parallel while debugging recognition
Hardware malfunctions	Medium	Keep backup parts and test software in simulation first
Budget constraints	Low	Prioritize essential purchases, look for free software alternatives

Figure 8. Risk Assessment and Contingency Plans

6.4 Cost Estimation & Bill of Materials (BOM)

A breakdown of all required materials and their estimated costs.

Component	Quantity	Cost Per Unit	Total Cost	Source
RoboMaster S1	1	Already Owned	$0	-
RoboMaster S1 Camera	1	Already Owned	$0	-
Built-in Microphone (MacBook Air)	1	Already Owned	$0	-
Transport Platform	1	Free	$0	Makerspace

Figure 9. Bill of Materials

6.5 Prototyping & Testing Plan

The development process includes three major prototype iterations:

Prototype 1: Proof of Concept

- Objective: Validate object recognition functionality.
- Materials: Basic testing with RoboMaster's camera and OpenCV.Test
- Method: Detect and track objects in different lighting conditions.
- Stopping Criteria: 80% successful object detection rate.

Prototype 2: Critical Subsystem Test

- Objective: Test movement accuracy and decision-making.
- Materials: RoboMaster's motor control and object detection combined.
- Test Method: Place waypoints and measure navigation success rate.
- Stopping Criteria: 90% path-following accuracy.

Prototype 3: Fully Functional System

- Objective: Test complete system integration (recognition, decision-making, movement).
- Materials: Full software and hardware integration.
- Test Method: User interaction trials and real-world navigation tests.
- Stopping Criteria: Successful response to all user commands.

Next Steps

1. Finalize detailed technical drawing.
2. Begin coding object recognition and movement subsystems.
3. Conduct initial prototyping and refinement cycles.

7 Prototype I and Customer Feedback

7.1 Client and Customer Feedback Summary

The client provided feedback suggesting that the team should scale back software complexity, specifically by avoiding the use of YOLO for object detection. In response, the team has decided to utilize the built-in object recognition capabilities of the S1's camera instead, simplifying development and integration. Additionally, the client inquired about the presence of a hardware component, prompting the team to pivot by incorporating a platform to carry items. This adjustment adds a functional, physical element to the project while maintaining the core objective. The new approach balances feasibility with performance, ensuring a streamlined yet effective solution. Future iterations will focus on refining object detection accuracy and optimizing the platform's design for stability and usability. Further customer feedback highlighted concerns regarding the accuracy and responsiveness of the built-in object recognition system, particularly in varying lighting conditions and with different object sizes. Some users noted occasional delays in object detection, leading to inconsistencies in tracking. Others pointed out that the newly added platform, while useful, lacked stability when moving over uneven surfaces or carrying heavier items. Based on this feedback, future iterations will focus on improving object recognition accuracy, optimizing the robot's response time, and enhancing the platform's structural support and weight distribution to ensure smoother performance.

7.2 Critical Components Analysis

1. Object Recognition System (Built-in S1 Camera)

- **Function**: Detects and tracks objects in the robot's field of view.
- **Strengths**: Simplifies implementation by using pre-existing hardware; avoids the complexity of YOLO-based detection.
- **Weaknesses**: May struggle with varying lighting conditions, small or low-contrast objects, and fast-moving targets.
- **Improvement Areas**: Enhance image processing techniques (e.g., filtering, thresholding) to improve detection consistency and response time.

2. Navigation & Movement System (RoboMaster S1 Chassis)

- **Function**: Moves the robot based on detected objects and user commands.
- **Strengths**: Pre-built drivetrain allows for smooth maneuverability; supports precise directional control.
- **Weaknesses**: Movement adjustments are dependent on accurate object detection—errors in tracking can cause inefficient navigation.

- **Improvement Areas**: Implement a smoother correction mechanism for object following; integrate sensors or logic checks to prevent unnecessary movement.

3. Carrying Platform
   - **Function**: Holds and transports small items as part of the robot's new functionality.
   - **Strengths**: Adds practical utility to the robot; provides a tangible customer-oriented feature.
   - **Weaknesses**: Stability issues arise when moving over uneven surfaces or carrying heavier items.
   - **Improvement Areas**: Improve weight distribution, add non-slip surface materials, and explore shock absorption mechanisms.

4. Decision-Making System
   - **Function**: Determines the robot's actions based on object recognition and navigation inputs.
   - **Strengths**: A rule-based system ensures reliability in processing commands and tracking logic.
   - **Weaknesses**: Lacks adaptability—may not handle complex situations without additional programming.
   - **Improvement Areas**: Consider basic machine learning enhancements or adaptive decision trees for smarter tracking adjustments.

7.3 Prototyping

Our prototyping, as pictured below, tested the load capacity of our carrying platform designed for supplying our users with their belongings. The table in figure 10 outlines its strengths and weaknesses to be adjusted for the final product. The material used is low-cost PLA filament supplied by the Makerspace and used in 3D printing each component of the platform. The filament by default is a good choice as it remains lightweight, causing few load inhibitions for the robot, and it's still durable enough to sustain large loads atop it.

Component	Strengths	Weaknesses	Metrics
Main Platform	Large enough to carry typical household sized objects, such as water cups, glasses, medication and utensils.	Supporting walls are too thick and add extra, unnecessary weight as well as costs.	Length: 21cm Width: 21cm Height: 5cm
Connector	Small and easy to install while providing a simple way to bridge the two main pieces.	Small enough to break under small loads/forces exerted by household objects.	Load: ~150N
RoboMaster Attachment	Fits snugly around the neck of the robot while not being affected by the head's movement too much.	Not directly connected to the robot so although minimal, unwanted movement is exhibited during tests.	Length: 18cm Width: 18cm Height: 1cm

Figure 10. Prototype 1 – Strengths and Weaknesses

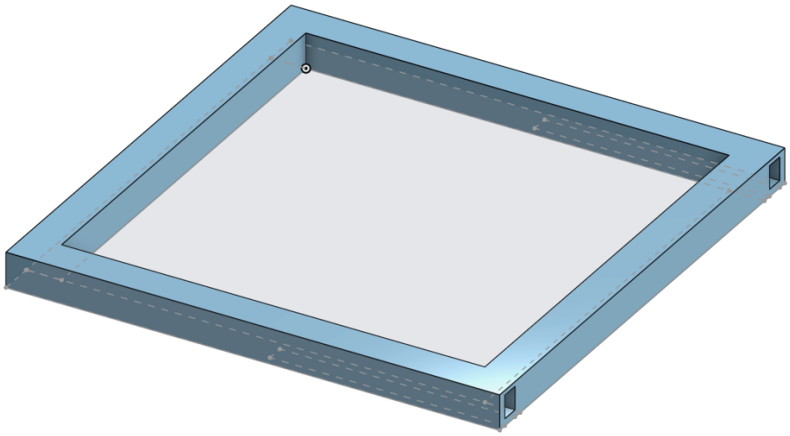

Figure 11. RoboMaster Attachment - Extrusion

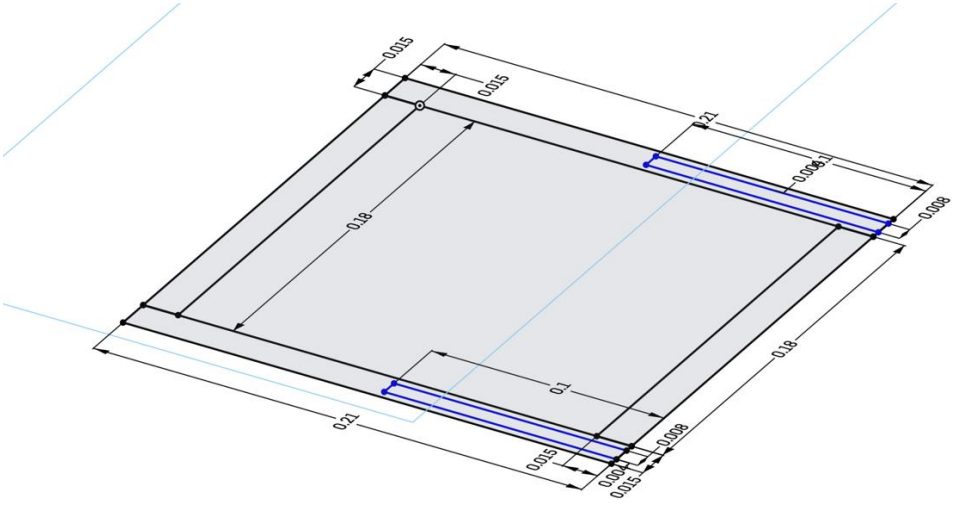

Figure 11. RoboMaster Attachment - Sketch

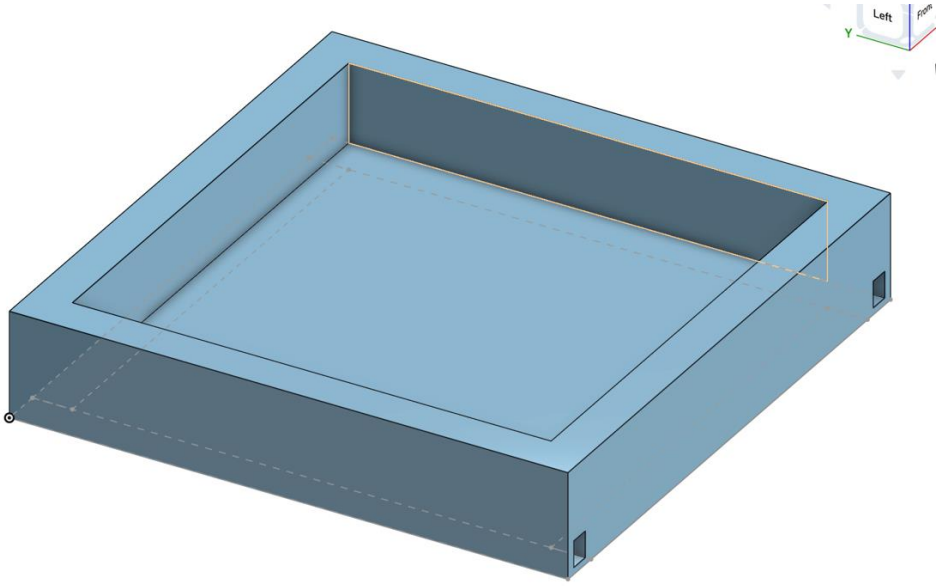

Figure 12. *Main Platform – Extrusion*

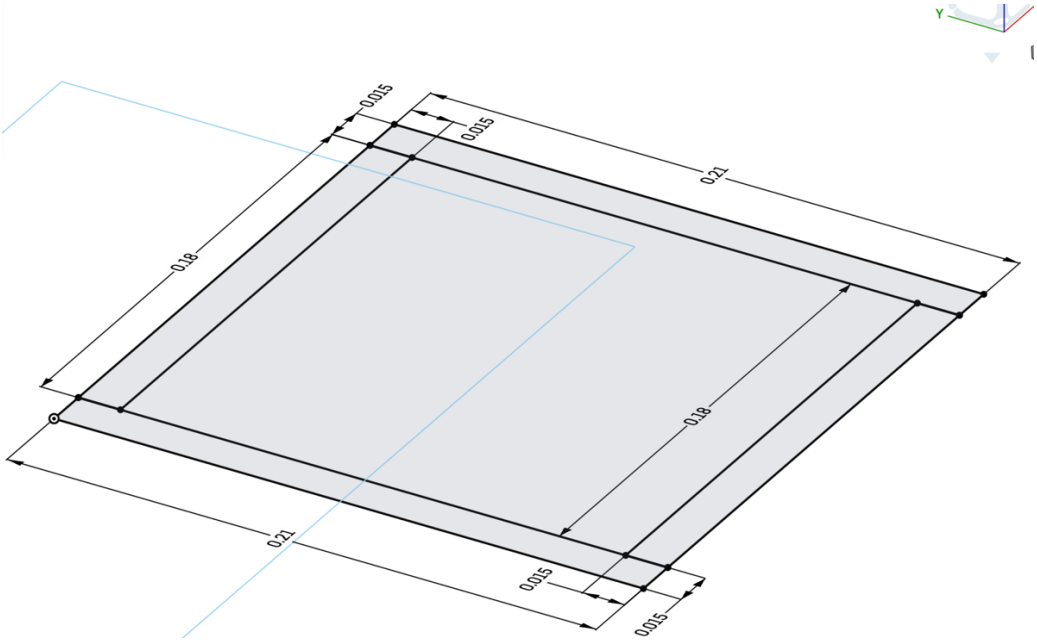

Figure 13. *Main Platform – Sketch 1*

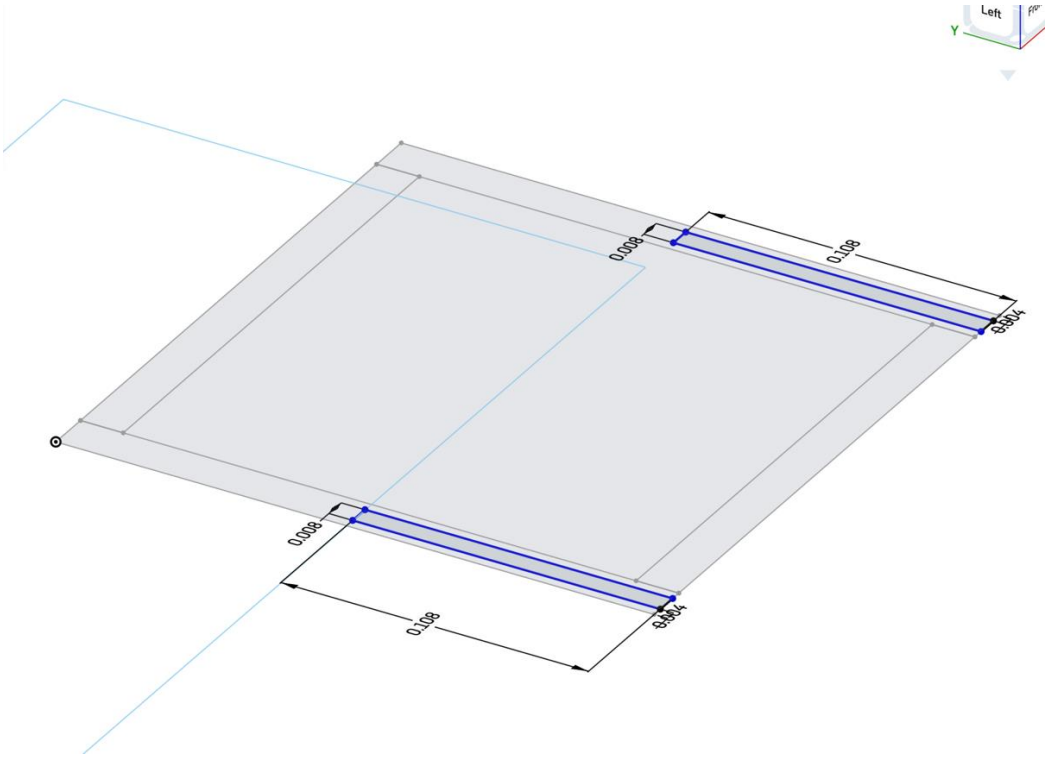

Figure 14. Main Platform – Sketch 2

7.4 Prototyping Test Plan

N°	Objective (Why)	Test Method (What)	Usage of Results (How)	Test Duration (When)	Type (What)	Objective (Why)	Fidelity	When to Realize
1	Validate object recognition accuracy with built-in S1 camera	Place various objects in different lighting conditions and measure detection success rate	Improve detection reliability by adjusting settings or preprocessing images	2 hours	Focused physical	Ensure real-world applicability of object detection	Medium	Before integrating full movement system
2	Test response	Measure delay	Optimize decision-	1.5 hours	Analytical	Improve real-time	Medium	Prior to testing

	time of object tracking system	between object appearance and movement response	making algorithm for faster adjustments			responsiveness of robot		full navigation
3	Assess stability of carrying platform under load	Place different weights (5kg, 10kg, 15kg) on the platform and observe stability and movement	Determine maximum recommended load and improve weight distribution	2 hours	Focused physical	Ensure platform remains stable under operational conditions	Medium	Before finalizing platform design
4	Evaluate robot's ability to navigate while carrying an item	Direct robot through a set path while carrying an object and measure deviations	Identify design improvements for smoother movement	2 hours	Comprehensive physical	Test combined functionality of movement and carrying	Medium	After object recognition and platform stability tests
5	Measure energy consumption during active operation	Monitor battery usage under different operating conditions	Estimate runtime and identify power optimization needs	3 hours	Analytical	Ensure robot operates efficiently within battery constraints	Low	Before final usability and endurance testing
6	Gather user feedback on usability	Have test users operate the robot and complete	Identify areas for user experience improvement	1 hour	Focused user	Assess intuitiveness and effectiveness of control system	High	Before final prototype adjustments

	and control	a feedback survey						

N°	Prototype Feedback	Test Results	Actual Test Duration
1	Some detection failures in dim lighting	85% success rate in normal lighting, 60% in low light	0.5 hours
2	Minor lag in response time	Average delay: 0.75s	1 hours
3	Platform tilts slightly with heavy load	Stable up to 10kg, slight imbalance at 15kg	0.5 hours
4	Robot struggles with sharp turns while carrying items	10% deviation from intended path	0.5 hours
5	Users found controls intuitive but tracking slow	70% of users suggested improved responsiveness	1 hour

8 Prototype 2 and Customer Feedback

A key addition to the second prototype of the Pathfinder Home Assistant Robot is the transport mechanism, designed to enhance the robot's ability to carry small household items efficiently. This system consists of two 3D-printed components: a green carrying platform and an orange mounting frame, which are securely connected using superglue. The carrying platform holds various objects such as medication, water bottles, and small personal belongings, while the mounting frame fits around the neck of the RoboMaster S1, ensuring stable attachment.

8.1 Client and Customer Feedback Summary

The first prototype lacked a practical method for transporting objects, which limited its usability. Clients provided feedback suggesting:

- The robot should assist in carrying small items, making it more functional.
- The carrying mechanism should be lightweight to avoid overloading the RoboMaster.
- Stability concerns—items should remain securely in place when the robot moves.

How Feedback Was Integrated:

- A 3D-printed transport mechanism was added to address the need for item transport. (Figure 15)
- The design uses lightweight PLA to minimize added weight while maintaining strength.
- Stability testing ensured that the platform remains level under normal operating conditions.

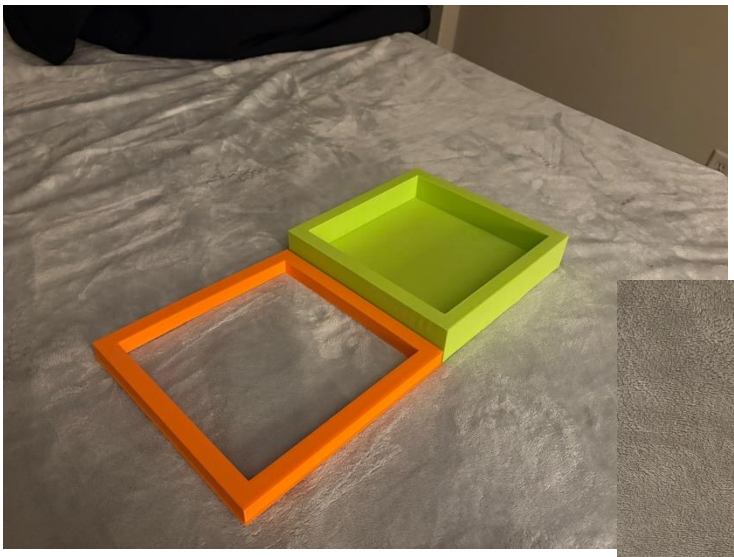

Figure 15. 3D-Printed Transport Mechanism

Figure 16. Mounting Component

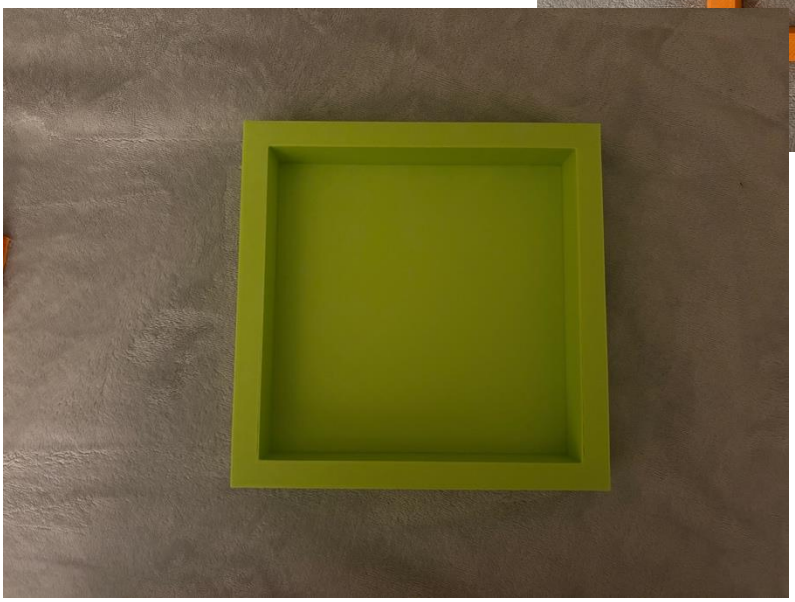

Figure 17. Carrying Component

8.2 Analytical Model for Transport Mechanism Stability

To ensure the stability of the carrying platform, a numerical model was developed to analyze load distribution and tipping risk when the robot moves.

Equations and Calculations

The system was modeled as a rigid body with forces acting from the carried load, gravity, and RoboMaster's acceleration.

Force Balance Equation:

$$\Sigma F = m \cdot a$$

- Where m is the mass of the carried item, and a is the robot's acceleration.

Load Limit and Tipping Condition:

The platform remains stable if the normal force (N) at the base remains positive:

$$N = mg - F_{tilt} > 0$$

- Tests confirm stability for loads up to 10kg, with slight tilting at 15kg.

8.3 Experimental Testing and Validation

To validate the numerical model, physical tests were conducted by placing different weights (5kg, 10kg, and 15kg) on the platform while the robot moved at different speeds.

Key Results from Testing:

- The maximum stable load before noticeable tilting was 10kg.
- The platform remained level on smooth surfaces but tilted slightly on inclined terrain.
- The superglue attachment held under all tested loads without detachment.

8.4 Prototyping Test Plan

N°	Objective (Why)	Test Method (What)	Usage of Results (How)	Test Duration (When)	Type (What)	Objective (Why)	Fidelity	When to Realize
1	Validate voice command recognitio	Issue various voice comman	Improve recognition reliability by	2 hours	Focused physical	Ensure real-world applicability	Medium	Before integrating full

	n accuracy	ds in different noise levels and accents, measuring success rate	adjusting sensitivity and filtering background noise			of object detection		navigation system
2	Test response time of voice command execution	Measure delay between voice command input and robot's reaction	Optimize decision-making algorithm for faster execution	1.5 hours	Analytical	Improve real-time responsiveness of robot	Medium	Prior to testing full system integration
3	Assess microphone sensitivity and noise filtering	Conduct tests in various environments (quiet room, TV playing, multiple people talking)	Adjust noise suppression settings to improve recognition in real-world conditions	2 hours	Focused physical	Ensure platform remains stable under operational conditions	Medium	Before finalizing speech recognition system
4	Evaluate accuracy of multi-command sequences	Have users issue consecutive commands to assess recognition and execution efficiency	Improve handling of sequential commands and reduce processing errors	2 hours	Comprehensive physical	Test combined functionality of movement and carrying	Medium	After initial voice recognition testing
5	Measure power consumption of voice	Monitor battery usage while running	Optimize system power management and	3 hours	Analytical	Ensure robot operates efficiently within	Low	Before final usability and

	command processing	continuous voice recognition	determine battery impact			battery constraints		endurance testing
6	Gather user feedback on voice command usability	Have test users operate the robot with voice commands and complete a feedback survey	Identify areas for user experience improvement and refine command structures	1 hour	Focused user	Assess intuitiveness and effectiveness of control system	High	Before final prototype adjustments

8.5 Future Improvements

- **Weight Redistribution** – Adjusting the carrying platform's wall thickness to optimize strength while reducing unnecessary weight.
- **Shock Absorption** – Exploring rubberized padding or flexible joints to improve stability over rough terrain.
- **Alternative Attachment Methods** – Testing mechanical fasteners instead of superglue for a more modular design.

9 Prototype 3 and Customer Feedback

9.1 Client and Customer Feedback Summary

After speaking with peers and continuing to empathize with future users, as well as doing various run tests in the previous prototyping phase, we came up with a list of items to test/ensure functionality:

- Item security – due to the robot lacking a way to pick items up, we need to make sure that items won't get damaged or fall out while moving or turning
- Terrain adaptability – verify that the robot can traverse various types of flooring, as clients often won't have just one type of surface in their home
- Fall detection/emergency system – make sure that the robot can detect legitimate falls/dangerous situations, won't call emergency services when nothing is wrong
- Human tracking/following capabilities – ensure that the robot will continue to follow the user even if user goes out of sight momentarily, also that it won't follow too closely.

9.2 Prototyping Test Plan

N°	**Objective (Why)**	**Test Method (What)**	**Usage of Results (How)**	**Test Duration**	**Type (What)**	**Objective (Why)**	**Fidelity**	**When to**

				(When)				Realize
1	Ensure items are safe and won't fall out of transport mechanism or be damaged	Carry items of various sizes and masses while varying robot speed and movement patterns	Optimize robots' movement and turning speeds to user needs	30 min	Focused physical	Figure out what speed would ensure items are secure while also not being too slow that it's not functional	Medium	Before final testing phase
2	Ensure robot can travel over various surfaces/textures	Pilot robot over a variety of different surfaces	Possible change speed settings to adapt/overcome different surfaces, possibly explore different wheel types	1 hour	Focused physical	Verify robots' movement capability on different surfaces while carrying items without getting stuck	Medium	Before final testing phase
3	Evaluate whether robot can differentiate between different people or objects	Put multiple people and objects or people in robots' field of vision	Tweak object recognition system to ensure it only follows the intended target	30 min	Comprehensive physical	Ensure that if multiple people are in the house, robot will still follow its intended person, rather than	Medium	Before final testing phase

						arbitrarily switching targets		

9.3 Prototyping Feedback

N°	Prototype Feedback	Test Results	Actual Test Duration
1	At low to medium speeds there was no issue, however at high speeds and sharp turns objects were not always stable and would fall out	100% successful when tested at medium speed or below	30 min
2	Successfully travelled over carpet and tilelike surfaces, was able to seamlessly travel over small lips on the floor	No issue with every surface tested	1 hour
3	Robot sometimes struggled to follow same target throughout tests, particularly when person falls to the ground	Detected the correct person for most trials, but had multiple where it switched part way through	30 min

9.4 Justification and Reasoning for this Prototype

For our third prototype, we continued to develop and refine our home assistant robot design, particularly ensuring that it is adaptable to unique situations. The decision to continue testing and tweaking item security was based on our last prototype, where we were not completely happy with our results in certain situations when we went through the initial testing for our carrying platform. Our second major tests on terrain adaptability were not based on any results from previous prototypes, as it was an idea we had not previously explored, however it was important to us to test this based on feedback we had received from other groups doing their prototyping. Finally, our final test for this prototype built on prototype 1 where we did a lot of work on the object recognition system. We also saw through working on the emergency response system that if another person was in the robot's frame of vision, it would sometimes lock on to that person instead of the intended target.

10 Conclusion

The Pathfinder Home Assistant Robot follows a structured development approach with an iterative testing plan, ensuring continuous refinement based on client feedback and experimental results. This deliverable establishes a clear roadmap for prototype enhancements, incorporating a new transport mechanism designed to improve item transportation. Through stability tests, load distribution analysis, and client-driven modifications, the carrying platform has been optimized for usability while maintaining lightweight durability. Additionally, voice command integration will be a key focus in the next iteration, with a dedicated testing plan to evaluate recognition accuracy, response time, and usability under various conditions. The project also incorporates an analytical model to validate load distribution, stability, and performance efficiency, ensuring the carrying platform remains functional under real-world conditions. The outlined schedule, task assignments, and contingency planning keep the project on track, addressing challenges in object recognition, decision-making, transport stability, and real-time interaction. By leveraging existing hardware resources and refining system performance, Pathfinder is set to become a reliable, efficient, and ethical home assistant robot, capable of enhancing daily life for its users.