Project Proposal

Project ID: MR02a-24

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- Design and fabricate a self-mobile robot capable of omnidirectional floor movement, equipped to carry required electrical components.
- Develop a system capable of following a specified individual within a 1m distance.
- Integrate the person-tracking algorithm with the robot's navigation system to enable the robot to follow the individual through crowds and potential occlusions.
- Implement facial recognition technology to identify patients with >90% accuracy.
- Engineer a dispensing mechanism that accurately enables retrieval of the correct medication for the identified patient.
- Integrate the above systems in tandem to meet final project goal.

Contents

1 Introduction

1.1 Background and Engineering Problem

The public healthcare system in Hong Kong is currently facing a significant crisis characterized by a critical shortage of nursing staff. This issue has been exacerbated by numerous factors in recent years, including an aging population and the aftermath of the COVID-19 pandemic. As of 2022, there were approximately 66,492 nurses in Hong Kong, but projections suggest a growing shortfall, with estimates indicating a deficit of around 3,000 general nurses by 2030 and up to 5,000 by 2040 [1]. The role of nurses in patient care is critical, particularly in administering medications. Currently, nurses spend a considerable amount of time verifying patient identities and retrieving medications from dispensing areas. This repetitive task of moving between patients' beds and the medication area leads to delays in patient care and increased workloads for nursing staff, further contributing to burnout and attrition rates.

To address these challenges, we propose the development of a nurse-following robot designed to assist nurses in medication administration. At each bed, the robot will scan the patients' faces to identify them, then allow the nurse to retrieve the correct medication for that patient. The engineering problems associated with this project include developing a robust and mobile robot capable of following a nurse through the hospital environment, implementing a reliable facial recognition system that ensures accurate patient identification, and designing a mechanism that allows the efficient retrieval of the correct medications.

1.2 Objectives

This project aims to design and build a person-following robot and apply it to the context of a hospital to follow nurses. Equipped with advanced navigation, tracking, and facial recognition capabilities, the robot will autonomously navigate healthcare environments, identify patients, and dispense the correct medication, thereby enhancing patient care efficiency and accuracy.

1.2.1 Objective Statements

1. Design and fabricate a self-mobile robot capable of omnidirectional floor movement, equipped to carry required electrical components.
2. Develop a system capable of following a specified individual within a 1m distance.
3. Integrate the person-tracking algorithm with the robot's navigation system to enable the robot to follow the individual through crowds and potential occlusions.
4. Implement facial recognition technology to identify patients with >90% accuracy.
5. Engineer a dispensing mechanism that accurately enables retrieval of the correct medication for the identified patient.
6. Integrate the above systems in tandem to meet final project goal.

1.3 Literature Review of Existing Solutions

In the past, numerous implementations utilized basic micro controllers in their designs as the main computation and decision device [2]. This approach has the benefits of being cheap and having an established community of maintained open-sources libraries. However, the significant drawback is the limited computational power of such a setup. Increased computational capabilities are becoming cheaper and cheaper, allowing us to use more sophisticated algorithms that enable new and more accurate navigation methods. One way of increasing the capabilities of a system in the past implementations was to use a portable personal computer as the main computation hub [3][4]. This approach introduces certain drawbacks. It increases the weight of the system, reduces possible payload space, and escalates the complexity of the system with regards to the control of peripheral hardware. Our system relies on Raspberry Pi 5 which is the middle ground between microcontrollers and portable personal computers. It offers great computing power in a small and light package, simultaneously enabling us to use software abstractions of hardware control while retaining low-level understanding and control of the system peripherals.

Additionally, the ability for a robotic system to track and follow a specific person would invite a wide array of applications, such as assistive technologies (which we are currently exploring), surveillance, and Human-Computer Interaction (HCI). However, and due to the inherent breadth of the topic and the approaches thereof, most solutions can be split into 2 categories, those reliant on Electro-Magnetic (EM) waves and a tagging system, such as Infrared (IR) or Ultra-wideband (UWB), and those utilizing machine learning algorithms to categorize features such as You Only Look Once (YOLO) and Simple Online Realtime Tracking (SORT/DeepSORT).

UWB systems, while still relatively novel in consumer applications, are widely recognized for their high accuracy in indoor positioning. As the name suggests, they operate by transmitting signals across a wide spectrum of frequencies, which thereby enhance their ability to measure distances precisely. The tags are small, low power, and can be easily attached/placed on a person, allowing our robot to follow along with ease [5]. Thus, UWB systems outperform many other localization techniques in terms of accuracy, especially indoors, and are also less susceptible to interference from other signals [5] [6]. However, this approach would mandate a robust form of velocity approximation via Kalman filtering or something else, as UWB performance is known to degrade in non-line-of-sight conditions, thus limiting effectiveness in cluttered environments such as those of a hospital [6].

On the other hand, popular machine learning/computer vision approaches have shown significant promise in person-following applications, with the bulk of similar research papers utilizing YOLO and Simple Online and Realtime Tracking (SORT) derivations. YOLO is a real-time object detection system that is highly efficient and capable of detecting multiple objects of multiple given classes in a single frame. Its unified architecture allows it to process images quickly, thereby being very suitable for real-time applications where speed is critical [7]. However, and even barring any trade-offs in accuracy, YOLO alone will not be sufficient, as we will need to implement further re-identification models to allow the robot to resume following after any given partial occlusion or losses in vision (ie; sharp turns) [7]. Thus, approaches such as SORT and DeepSORT were also considered, which combine deep learning for object detection with a Kalman filter for trajectory estimation, which allows for robust tracking and consistent identification even in crowded scenes [8]. Still, the combination of detection, tracking and re-identification can introduce a large computational overhead, and might lead to slowdowns on less powerful hardware, ie; our Raspberry Pi 5 [8].

2 Methodology

2.1 Overview

2.1.1 System Description

The main design pattern for this robot is a tower structure with three wheels. The base of the robot will consist of core electronic components including the battery, motors and their encoders, driver circuits, and essential computing hardware. The carriage will include three motors with Swedish 90°wheels in a triangular configuration to allow full omnidirectional movement. Another layer will be built above this, which will carry the medication access mechanism and environment scanning sensors, including the camera and LIDAR sensor. Presently, we envisage the medication access mechanism to consist of an array of electromagnetic locks that hold pre-dispensed medication in paper cups.

The power supply consists of wall AC-DC adapter which allows us to disregard complexities that arise from battery-powered design, however, the DC bus is designed to allow interchangeability between Lithium Ion batteries and a cable supply. As shown in Fig. 1, the power source is connected to the DC terminal from which we wire two separate DC-DC converters. One is for providing suitable power and voltage to the logic circuits, and the other for supplying adequate voltage and current to the DC motors. This design ensures full decoupling between low current logic circuits and high current and high volatility motors circuits, ensuring stable supply for both systems. However, our main goal is to use lithium ion battery packs as the main power supply since they enable the robot to move freely around the hospital.

The main software architecture is based on the Robot Operating System 2 (ROS2) on Ubuntu 24.04 Noble Numbat. It allows us to abstract hardware interfaces while maintaining lower-level control; ROS2 also provides a set of patterns to base our system design on. In our design we will utilize a node-based approach, where each node is a single entity responsible for controlling one piece of hardware or doing one set of adjacent computations. The nodes will then communicate between themselves on a server-client basis using a set of message types defined by us beforehand. This approach introduces additional modularity, enabling easier testing and prototyping of different parts of the system.

2.1.2 System Block Diagram

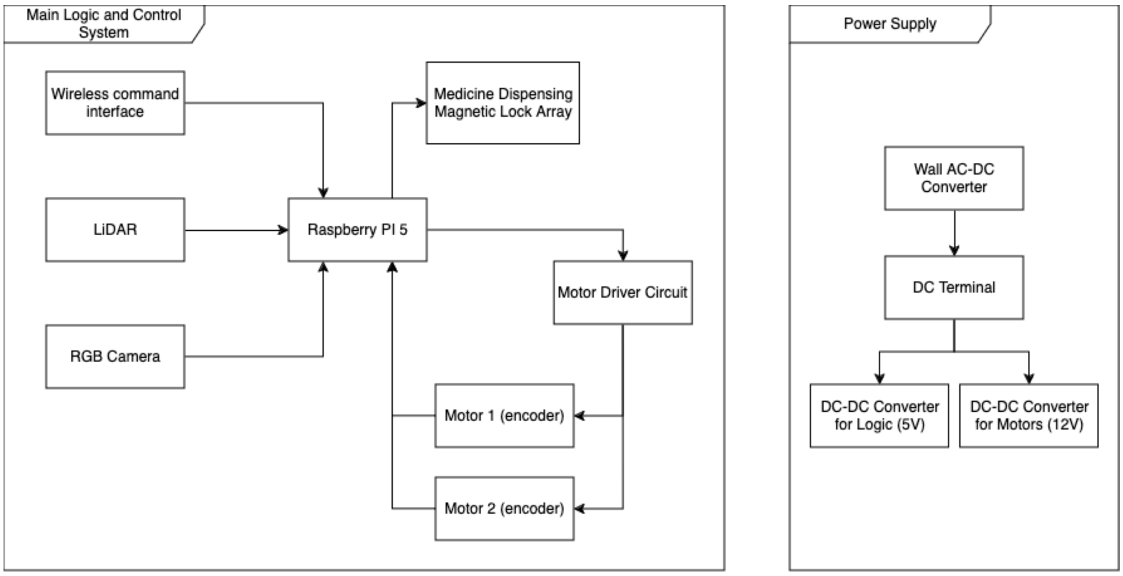

Figure 1: Block diagram of the main system components.

2.1.3 Components List

Item	Specifications/Model	Quantity
LiDAR	DFR0315	1
Lithium Ion Battery	11.1V 6Ah	4
Breadboard	170 tie points	1
DC-DC Converter	DFR0946	1
DC-DC COnverter 120W 12V@10A	FIT0170	1
Motor Driver 12A Dual Channel	DFR0601	2
Robot chassis with omni wheels	ROB0124	1
Raspberry PI 5 Camera module	SC0870	1

Table 1: Main component list.

2.1.4 ECE Knowledge

In our project we extensively utilize knowledge from many ECE and COMP courses, be it required courses or electives:

- ELEC 2400 Electronic Circuits – This course taught us the basics of electronic circuits which will aid us in designing the power supply system for our robot.

- ELEC 3300 Introduction to Embedded Systems – From this course we learnt project planning in the context of integrating embedded systems. This knowledge is foundational to this project.
- ELEC 3210 Introduction to Mobile Robotics – This course is the basis of our navigation and mapping subsystems. It also taught us how to use Robot Operating System which we also utilise in our project.
- COMP 2011 Programming with C++ – Provided us with fundamental knowledge of programming.
- COMP 2012 Object Oriented Programming and Data Structures – Provided us with fundamental knowledge in data organization and object oriented approach to system design which we utilize in our Robot Operating System approach.

2.2 Objective Statement Execution

1. **Design and fabricate a self-mobile robot capable of omnidirectional floor movement, equipped to carry required electrical components.**
   Tasks:
   (a) Design the robot's base and wheel system for omnidirectional movement.
      i. Create/design a robot chassis that would support omnidirectional movement. This involves selecting appropriate wheel types, such as regular, Mecanum or omni-wheels, to allow smooth and flexible navigation, as well as an appropriate shape, layer structure, turning mechanism.
   (b) Select and integrate motors and motor controllers suitable for the design. Choose motors and controllers that are compatible with the chosen wheel system design.
      i. Ensure the motors provide sufficient torque and speed given our projected weight/speed/duration estimates. Also integrate motor controllers to facilitate precise control over movement, as well as testing the setup for responsiveness and reliability.
   (c) Design and implement the power distribution system, including battery placement and wiring.
      i. Develop a power distribution system to efficiently deliver power to all components. Focus on battery selection and placement, wiring design, and implementing safety features. Further test the system for load management and efficiency.
   (d) Mount and secure the additional layers, LiDAR sensor, camera and other peripheral components.
      i. Securely mount the LiDAR sensor, camera, and other peripherals (or equally sized/weighted mocks thereof) onto the robot. Also design mounts that minimize vibration and ensure stable data collection. Proper alignment and calibration will be performed to optimize performance.
   (e) Test the robot's movement capabilities and make necessary adjustments.
      i. Conduct tests to evaluate the robot's movement capabilities. Also set up various tracks and courses to assess the robot's ability to maneuver and make necessary adjustments if needed to improve performance.
2. **Develop a system capable of following a specified individual within a 1m distance.**
   The objective is to follow a specific individual (i.e. a nurse) with leeway of at least 1 meter, through lesser degrees of occlusion, and simple turning.
   Tasks:
   (a) Select and configure a suitable tracking device to be placed on the individual.
      i. Choose a suitable tracking device for the individual and configure it for seamless operation. Ensure the device works effectively within a 1-3m range and handle all of the aforementioned challenges.
   (b) Develop the software to receive and process signals from the tracking device.
      i. Create software to process signals from the tracking device, and map it to 3D point coordinates to be later implemented with the robot's navigation system. Focus on consistency and reliability across various ranges and occlusions.

(c) Test the tracking system in controlled environments with varying conditions.

    i. Conduct tests in controlled environments to evaluate the tracking system's performance. Gather data on system accuracy and adjust algorithms as needed.

3. **Integrate the person-tracking algorithm with the robot's navigation system to enable the robot to follow the individual through crowds and around obstacles, even with potential occlusions.**
   Integrate the person-tracking algorithm with the robot's navigation system: The goal is to seamlessly integrate the person-tracking algorithm with the robot's navigation system, allowing it to adeptly follow the designated individual through dense crowds and navigate around obstacles, even when facing potential occlusions.
   Tasks:

   (a) Develop an interface to connect the tracking system with the robot's navigation software.

      i. Create an interface to connect the tracking system with the robot's navigation software. Ensure smooth data flow and compatibility between systems.

   (b) Implement distance calculation algorithms to maintain an optimal following distance.

      i. Develop algorithms to maintain optimal following distance. Test and refine these algorithms to ensure the robot follows individuals accurately, even in crowds.

   (c) Test the integrated system in controlled environments with dynamic obstacles.

      i. Evaluate the integrated system in dynamic environments with obstacles and crowds. Analyze performance and make necessary adjustments to improve reliability.

4. **Implement facial recognition technology to identify patients with >90% accuracy.**
   Develop and deploy facial recognition technology to accurately identify individuals and retrieve their medical information from an existing patient database, achieving an accuracy rate of over 90%.
   Tasks:

   (a) Develop and train a facial recognition model using a relevant dataset.

      i. Train a facial recognition model using a relevant dataset. Focus on optimizing accuracy and speed, ensuring the system meets the >90% accuracy target.

   (b) Implement a mock patient database with CRUD for information retrieval.

      i. Create a mock database and minimal API backend with CRUD functionalities for testing information retrieval. Ensure the system can retrieve data quickly and reliably.

   (c) Test the facial recognition system for accuracy and reliability.

      i. Test the facial recognition system for accuracy and reliability. Conduct tests using diverse facial images to ensure consistent performance.

5. **Engineer a dispensing mechanism that accurately enables retrieval of the correct medication for the identified patient.**
   Design a precise dispensing mechanism that reliably provides the correct medication to the identified patient, ensuring accuracy and safety in medication distribution.
   Tasks:

   (a) Design the mechanical components of the dispensing mechanism.

      i. Design the mechanical parts of the dispensing mechanism. Focus on precision and reliability, ensuring the mechanism can dispense medication accurately with little lag.

   (b) Develop the software to control the dispensing process based on patient identification.

      i. Create software to manage the dispensing process based on patient identification (ie; connecting it to the aforementioned API). Test the system to ensure it dispenses the correct medication without errors.

   (c) Test the dispensing mechanism for accuracy and reliability.

      i. Conduct tests to evaluate the accuracy and reliability of the dispensing mechanism. Refine the system as needed to ensure consistent performance.

3 Project Planning

3.1 Project Schedule

Objective Statements	Task	Group Member in Charge	WK1	WK2	WK3	WK4	WK5	WK6	WK7	WK8	WK9	WK10	WK11	WK12	WK13	WK14	WK15	WK16	WK17
Design and fabricate a self-mobile robot capable of omnidirectional floor movement, equipped to carry required electrical components.																			
	Design the robot's base and wheel system for omnidirectional movement.	Armaan																	
	Select and integrate motors and motor controllers suitable for the design.	Wiktor																	
	Design and implement the power distribution system, including battery placement and wiring.	Ujaan																	
	Mount and secure the additional layers, LiDAR sensor, camera and other peripheral components.	Wiktor																	
	Test the robot's movement capabilities and make necessary adjustments.	Armaan																	
Develop a system capable of tracking a specified individual within a 1m distance and varying levels of occlusion.																			
	Select and configure a suitable tracking device to be placed on the individual.	Ujaan																	
	Develop the software to receive and process signals from the tracking device.	Ujaan																	
	Implement algorithms to maintain a consistent lock on the tracking device's signal.	Ujaan																	
	Test the tracking system in controlled environments with varying conditions.	Armaan																	

Objective Statements	Task	Group Member in Charge	WK1	WK2	WK3	WK4	WK5	WK6	WK7	WK8	WK9	WK10	WK11	WK12	WK13	WK14	WK15	WK16	WK17
Integrate the person-tracking algorithm with the robot's navigation system to enable the robot to follow the individual through crowds and around obstacles, even with potential occlusions.																			
	Develop an interface to connect the tracking system with the robot's navigation software.	Ujaan																	
	Implement distance calculation algorithms to maintain an optimal following distance.	Ujaan																	
	Test the integrated system in controlled environments with dynamic obstacles.	Armaan																	
Implement facial recognition technology to identify individuals and retrieve their medical information from an existing patient database with >90% accuracy.																			
	Develop and train a facial recognition model using a relevant dataset.	Armaan																	
	Implement a mock patient database with CRUD for information retrieval.	Ujaan																	
	Test the facial recognition system for accuracy and reliability.	Armaan																	
Engineer a dispensing mechanism that accurately provides the correct medication to the identified patient.																			
	Design the mechanical components of the dispensing mechanism.	Armaan																	
	Develop the software to control the dispensing process based on patient identification.	Ujaan																	
	Test the dispensing mechanism for accuracy and reliability.	Armaan																	

Table 2: Gantt chart of the project timeline.

3.2 Budget

Item	Specifications/Model	Quantity	Price (HKD)	Link
LiDAR	DFR0315	1	$810,00	https://www.digikey.hk/en/products/detail/dfrobot/DFR0315/7597150
Lithium Ion Battery	11.1V 6Ah	4	$200,00	*Link*
Breadboard	170 tie points	1	$23,75	https://www.digikey.hk/en/products/detail/dfrobot/FIT0008-R/7597068
DC-DC Converter	DFR0946	1	$72,89	https://www.digikey.hk/en/products/detail/dfrobot/DFR0946/18069286
Power Converter DC-DC 12V@10A	FIT0170	1	$101,00	https://www.dfrobot.com/product-584.html
Motor Driver 12A Dual Channel	DFR0601	2	$226,00	https://www.dfrobot.com/product-1861.html
Robot chassis with omni wheels	ROB0124	1	$4 334,94	https://www.dfrobot.com/product-1494.html
Raspberry PI 5 Camera module	SC0870	1	$409,50	https://www.digikey.hk/en/products/detail/raspberry-pi/SC0870/17278640
Total (HKD)	**$7 004,08**			

Table 3: Component list with associated unit prices and quantities.

4 Conclusions

In conclusion, the development of a nurse-following robot presents a promising solution to the critical nursing shortage in Hong Kong's healthcare system. Our project aims to enhance patient care efficiency by leveraging advanced technologies in robotics, navigation, tracking, and facial recognition. We successfully outlined a comprehensive plan that includes designing a self-mobile robot capable of omnidirectional movement, implementing an effective obstacle avoidance system, and integrating a robust person-tracking algorithm. The facial recognition system is designed to achieve high accuracy in identifying patients, which is crucial for ensuring safe and accurate medication administration.

The integration of these systems will not only streamline medication delivery processes but also alleviate the workload on nursing staff, allowing them to focus more on direct patient care. By addressing the engineering challenges identified in our literature review and utilizing modern computational tools like Raspberry Pi and ROS2, we are confident in our approach. As we move forward, continuous testing and refinement will be vital to ensure the robot's reliability and effectiveness in real hospital environments. This project has the potential to significantly improve healthcare delivery, and we look forward to its successful implementation and positive impact on patient care.

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Appendicies

Appendix A—Meeting Minutes

Initial Meeting with Supervisor - 1 hour

Date: 15/06/2024
Time: 11:00 AM
Location: HKUST, ECE Commons
Attendees: Armaan, Wiktor, Ujaan, Professor Murch (Supervisor)
Minutes taken by: Armaan

- The group introduced the idea of a robot capable of following a nurse in a hospital setting.
- Professor Murch provided feedback, suggesting starting with the tracking system and navigation before adding advanced features like facial recognition.
- Discussed potential tracking systems such as **UWB (Ultra-Wideband)** and **camera-based systems**.
- Armaan proposed using **omnidirectional wheels** for smooth movement, which was well received by the group.
- Professor Murch recommended using **ROS (Robot Operating System)** for software integration due to its modularity and community support.
- Basic ideas regarding motors and battery requirements were discussed, but no firm decisions were made.

Action Item to be completed	By when	By whom
Research tracking systems: UWB vs. Camera-based	20/06/2024	Ujaan
Draft initial robot design and chassis concept	22/06/2024	Armaan
Review ROS documentation for potential integration	23/06/2024	Wiktor
Set up project repository for code and documentation	17/06/2024	Ujaan
Follow up with Professor Murch on recommended motor specifications	18/06/2024	Armaan

Table 4: Action Items for Next Meeting

Follow-up Meeting and Presentation with Supervisor - 1 hour

Date: 29/06/2024
Time: 10:30 AM
Location: HKUST, ECE Commons
Attendees: Armaan, Wiktor, Ujaan, Professor Murch (Supervisor)
Minutes taken by: Ujaan

- Followed up on previous meeting's actions. Ujaan completed research on tracking systems, Wiktor completed ROS review, Armaan still finalizing the chassis design.
- The team presented a basic overview of **ROS** and discussed tracking systems:
  - **Camera-based object detection** vs. **tagging systems** (UWB or RFID). Pros and cons were discussed.
  - Camera-based systems are flexible but could face occlusion challenges in crowded environments.
  - Tag-based systems are reliable in crowded environments but less flexible for general-purpose tracking.
- Armaan proposed using **Li-ion batteries** to balance size and capacity, aiming for a 1-hour battery life for initial testing.

- The team also discussed starting with a **basic object detection** test using a camera before finalizing the tracking system.
- Facial recognition and integration with a **mock patient database** were discussed but will be secondary focus.
- Division of labor was confirmed:
  - Armaan to focus on mechanical design (chassis and wheels).
  - Wiktor to handle motor controllers and ROS integration.
  - Ujaan to research tracking systems and power distribution.

Action Item to be completed	By when	By whom	Status
Research tracking systems: UWB vs. Camera-based	20/06/2024	Ujaan	Completed
Draft initial robot design and chassis concept	22/06/2024	Armaan	In Progress
Review ROS documentation for potential integration	23/06/2024	Wiktor	Completed
Set up project repository for code and documentation	17/06/2024	Ujaan	Completed
Follow up with Professor Murch on recommended motor specifications	18/06/2024	Armaan	Completed

Table 5: Action Items from Previous Meeting

Action Item to be completed	By when	By whom
Begin basic object detection tests using a camera	05/07/2024	Ujaan
Finalize initial robot chassis design with selected wheels	07/07/2024	Armaan
Begin motor controller integration with ROS	08/07/2024	Wiktor
Investigate Kalman Filter or predictive algorithms for occlusion	10/07/2024	Ujaan
Research potential battery configurations and power requirements	09/07/2024	Armaan

Table 6: Action Items for Next Meeting

Proposal Planning - 4 hours

Date: 04/09/2024
Time: 12pm
Location: HKUST, ECE Commons
Attendees: Armaan, Wiktor, Ujaan
Minutes taken by: Ujaan Das

- We met as a group on campus to discuss our objective statements and some specifics and will finalize most of them by the end of the week.
- Wiktor presented research on various hardware components such as Raspberry Pi and ROS. The group discussed the advantages of using ROS and minimal hardware, such as higher levels of abstraction and more modular components due to the aforementioned.
- Armaan discussed battery options and proposed using Li-ion batteries to balance size and capacity for longer operation. Anyhow, the group agreed on targeting a battery life of 1 hours for initial testing.
- Ujaan raised the need for a UWB-based tracking device for robust person-following in occluded environments. The group discussed potential integration challenges with the navigation system.

Action Item	Due Date	Assigned To	Status
Draft Introduction	11/07/2024	Armaan	In Progress
Complete Literature Review	11/07/2024	Wiktor, Ujaan	In Progress
Create Hardware Diagram	11/07/2024	Wiktor	In Progress
Create Software Diagram	11/07/2024	Armaan	In Progress
Create Gantt Chart	11/07/2024	Ujaan	In Progress

Table 7: Action Items for Proposal Development

Proposal Section	Assigned To	Due Date
Introduction	Armaan	11/07/2024
Literature Review	Wiktor, Ujaan	11/07/2024
Hardware Diagram	Wiktor	11/07/2024
Software Diagram	Armaan	11/07/2024
Gantt Chart	Ujaan	11/07/2024

Table 8: Proposal Planning Timeline

Pre-Proposal Submission Meeting with Supervisor - 30 minutes

Date: 06/09/2024
Time: 12pm
Location: ZOOM
Attendees: Prof. Ross Murch, Armaan, Wiktor, Ujaan
Minutes taken by: Wiktor Kowalczyk

- We met with our project supervisor, Professor Murch, to discuss our progress in designing the system throughout the summer term.
- We discussed simplification of our initial design and setting realistic and achievable goals with metrics to quantify our solutions by.
- We discussed splitting the project into phases to take the advantage of the *Divide-and-Conquer* approach for managing complexity.

Action Item to be completed	By when	By whom	Status
Introduction	11/07/2024	Armaan	Completed
Literature Review	11/07/2024	Wiktor, Ujaan	Completed
Hardware Diagram	11/07/2024	Wiktor	Completed
Software Diagram	11/07/2024	Armaan	Completed
Gantt Chart	11/07/2024	Ujaan	Completed

Table 9: Action Items from Previous Meeting

Action Item to be completed	By when	By whom
Creation of precise budget and order list	15/09/2024	Wiktor, Armaan
Creation of high-level architecture for server-client in ROS2	15/09/2024	Ujaan

Table 10: Action Items for Next Meeting