Preliminary Design Review

AERO62520 - Robotic Systems Design Project

Year of submission
2023

Student ID
Team 9

School of Engineering

Contents

Word count: 3312

1 Introduction

The Robotic Systems Design Project addresses the challenge of retrieving a randomly located object from an unknown environment, and safely returning it to a designated location. The proposed solution was to design and develop an autonomous mobile robot capable of performing this task. The Leo Rover was chosen for this task due to its stability, customisability, and its ability to withstand any environment. A set of objectives were set to address the challenges identified by the customer:

- Upgrade the mechanical design of the Leo Rover, such that it can fit the PincherX-150 robot arm, the RPLiDAR A2 unit, and the IntelRealsense depth camera D435i
- Integrate the LiDAR and depth camera units with the system, allowing the Leo Rover to navigate through an unknown environment, avoid obstacles, and locate an object autonomously
- Integrate the robotic manipulator with the system, allowing the Leo Rover to pick up the object, and return it safely to the starting point of the robot
- Develop the software of the Leo Rover to operate at the highest possible level of autonomy, ensuring limited to no human intervention during the mission

This preliminary design review covers the fulfilment of the earlier objectives, which includes the mechanical, electrical, and software design of the system proposed to address the identified problem. Additionally, an analysis of the proposed design was conducted using the Requirements Verification Matrix to validate its alignment with the customer's requirements (section 5).

2 System Overview and Electrical Design

This section provides a top-down perspective of the entire system, illustrating the connections among its different components. The following figure shows the system block-diagram of all the components in the robot.

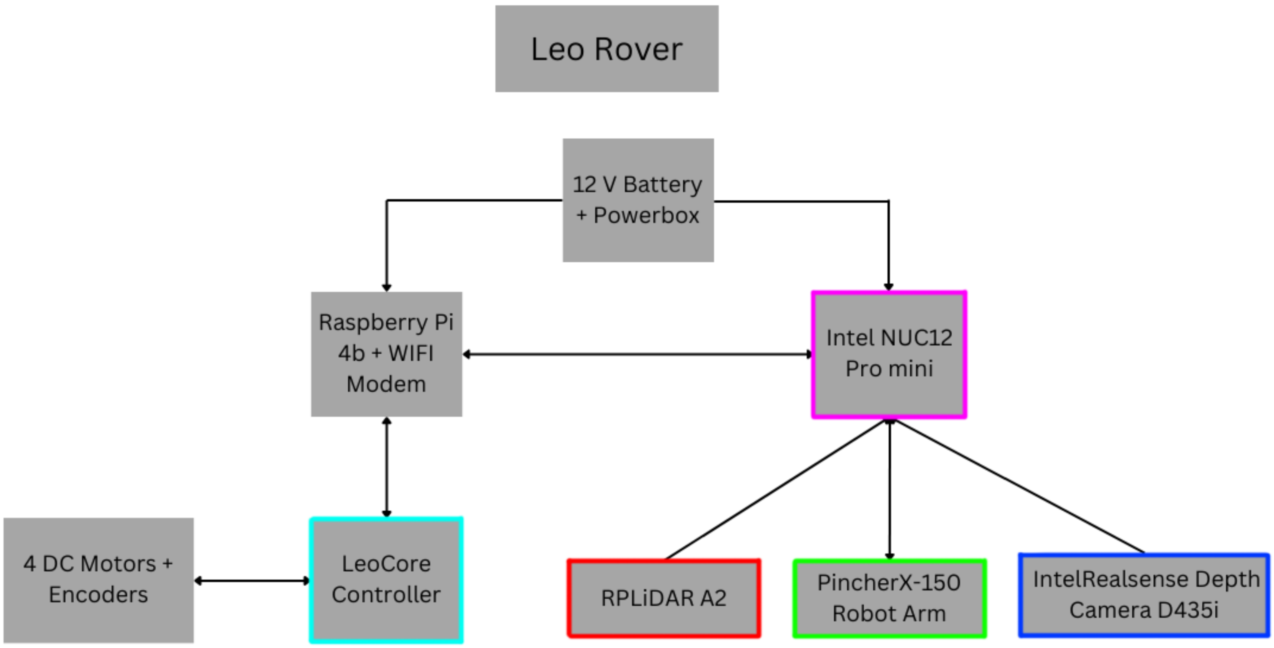

Fig. 1. System block-diagram of all the components

Figure 2 shows a more detailed perspective of the system, which includes how the components of the system are electrically connected.

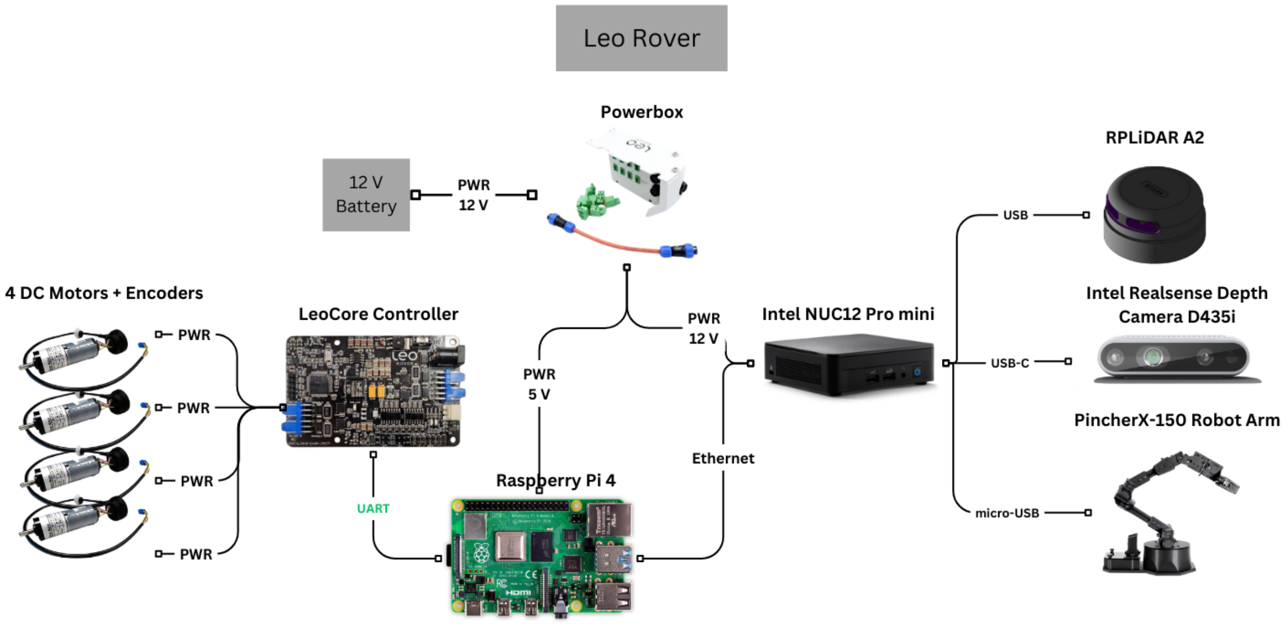

Fig. 2. Power Connection Diagram

As seen on the system block-diagram (see figure 1), the system has two main computing components: Raspberry Pi and Intel NUC12 Pro mini. The Raspberry Pi serves as an interface between the LeoCore Controller (controlling the motors) and the NUC (receiving sensor data and controlling robot arm). Finally, the system is powered through a 12 volts battery.

3 Software Design

This section presents the system's initial RQT graph (see figure 3). The various colors in the graph can be connected to the system's block diagram (see figure 1), illustrating the interactions among different components. It also depicts the topics utilized for communication and includes information about the rates at which messages are published to these topics.

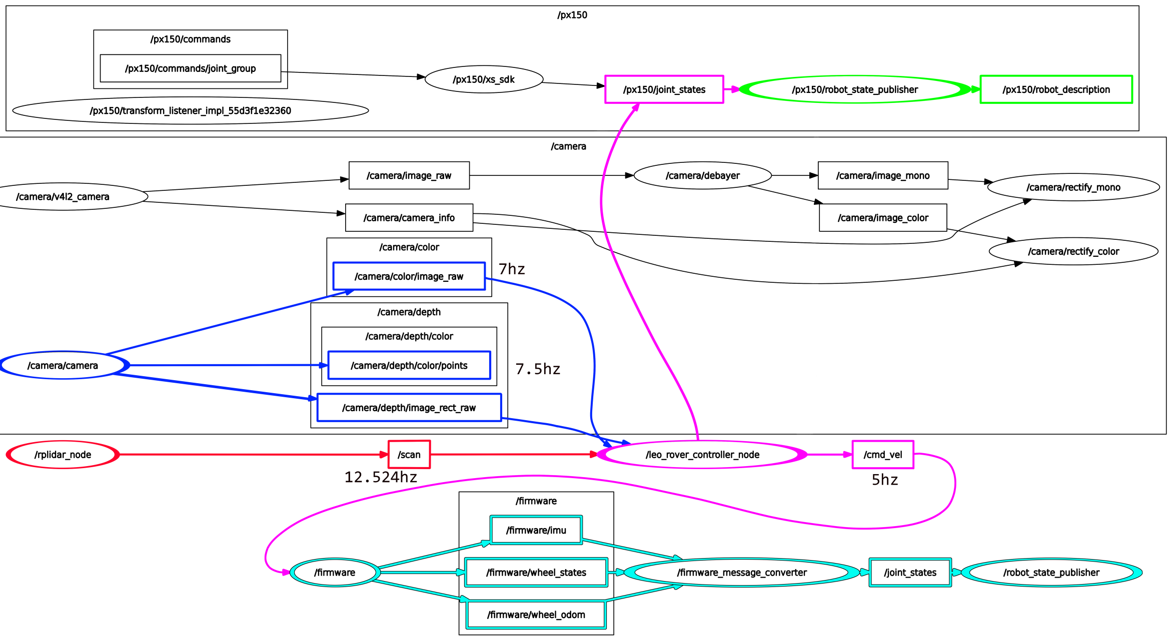

Fig. 3. RQT Graph of the system

To facilitate the integration of various system components, the '/leo_rover_controller_node' is employed. This node serves to interconnect different peripherals within the system and can publish diverse messages to modify the robot's behavior based on sensor readings. You can explore the GitHub repository for this node and potential future nodes by clicking here.

4 Mechanical Design

This section focuses on the design of the payload sled mounted on top of the Leo Rover. The sled is created to accommodate all the necessary peripherals required to fulfill the task outlined by the customer, as mentioned in the document's introduction.

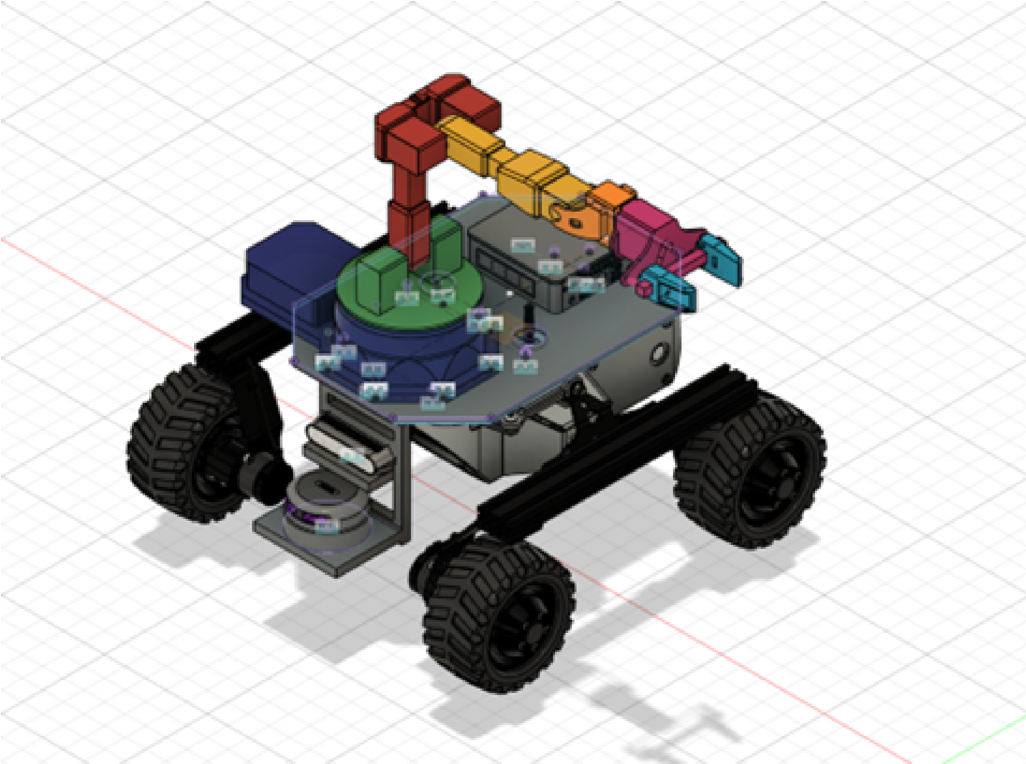

Fig. 4. Robot Isometric View

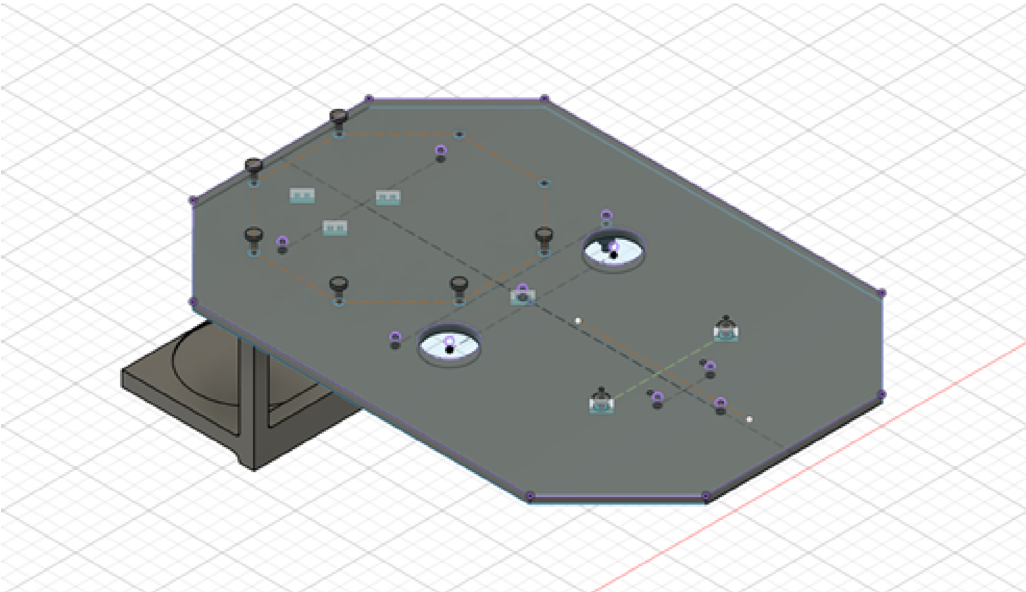

Fig. 5. Sled Isometric View

The design files can be accessed on our GitHub repository here.

5 Design Analysis

This section aims to highlight the previously proposed designs in the document, and assess if they align with the customer's requirements. To facilitate this evaluation, the requirements verification matrix from the "Design Requirements Analysis," available in Appendix C, will serve as a foundation.

5.1 Mechanical Design

The mechanical design of the robot is a key factor that directly affects the overall performance of the system. Three key factors were analysed: size, function, and stability.

5.1.1 Size

Consideration of the robot's size is crucial in the design, impacting handling, workspace accessibility, and task performance. The dimensions of the chassis of the robot (including the payload sled) are 410x450x330 mm. According to these dimensions, the width of the payload matches the width of the robot, which aligns with the environment requirements (Appendix B.2).

5.1.2 Function

The positioning of the sensors and manipulator on the robot is crucial for the success of the mission. The LiDAR is placed at the front, such that it can detect obstacles at a distance in the 0.15 m - 5 m range, which meets the autonomy requirements (Appendix B.1).

Installed in a groove on our platform, the depth camera has a complete front vision, allowing it to detect objects at a distance in the 0.28 m - 5 m range, meeting object identification requirements (B.4).

The manipulator is placed on top of payload sled, which is 0.2 m above the ground, which allows it to pick up objects comfortably, aligning with task requirements (Appendix B.5).

5.1.3 Stability

The payload sled, with a low center of gravity, optimal weight distribution, and robust structure, ensures balance during tasks and minimizes collision risks. This stability is vital for smooth manipulator functioning and manoeuvring, reducing risk of dropping objects, and ensuring robot safety (Requirements 2, 4a and 9).

5.2 System Design Analysis

The following table shows the role of the different electrical components of the robot, and the ROS2 topics allocated to that specific hardware. The connection between the different components was analysed to verify that the proposed system design aligns with the functional requirements, and the overall task.

ROS 2 serves as the foundation of the robot software architecture, facilitating the communication between the different components of the system. We will examine various topics and nodes to ensure that the software design is in compliance with customer requirements, as outlined in the verification matrix (Appendix C).

System	Actuation	Sensing and Perception	Compute and Control	Power	Interaction
Hardware	4 DC motors + wheels	RPLiDAR A2, Intel RealSense Depth Camera D435i, encoders	LeoCore Controller, Raspberry Pi, Intel NUC12	12 V battery, powerbox	PincherX-150 robot arm
Software	/firmware, /cmd_vel	/scan, /camera/color/image_raw, /camera/depth/image_rect_raw	/leo_rover_controller	N/A	/px150/joint_states

Table 1. Software and Electrical Design Summary of Leo Rover System

5.2.1 Power and Compute

The main power source of the system is a 12 volts battery, connected to a powerbox, which allows a DC output of either 5 V or 12 V. The computing and control equipment, which provides intelligence to the robot, consists of the LeoCore controller, Raspberry PI 4 and Intel NUC12. Using these three devices together, a hierarchical control system can be achieved, from real-time control at the bottom (microcontrollers), to more complex algorithms at the top (Intel NUC). Moreover, these devices are connected through ethernet, ensuring stable communications. The 'leo_rover_controller' node serves as the central hub for collecting and distributing data, and is computed on the NUC. It receives information from the LiDAR and Camera, and sends control signals to both the manipulator and wheels. This versatile node performs tasks based on the sensor readings, such as determining when to pick up objects and avoiding obstacles. It also tracks the robot's position, enabling it to return to the original position, fulfilling requirement 9.

5.2.2 Actuation

The Leo Rover contains four DC motors which it uses to move and traverse the environment. The motors receive electrical input signals from the LeoCore controller, which are transmitted via messages on the ROS2 topic /cmd_vel through the /firmware node. Thus, the velocity of the robot is regulated and the robot could attain speeds up to 0.35 m/s, fulfilling requirement 2a.

5.2.3 Sensor Fusion

The system uses two main sensors to perform obstacle avoidance, and identify the target object: RPLiDAR A2 unit and Intel RealSense Depth Camera D435i. Both sensors are connected to the Intel NUC12 through USB, and send sensor data to the NUC through the ROS2 topics /scan and /camera respectively. The /scan topic enables the robot to generate real-time maps and identify obstacles in the test site, thereby fulfilling requirement 1. Data regarding depth and RGB values for each pixel is transmitted through their respective /camera topics, allowing the robot to locate and determine the distance of an object to be picked up, and perceive colours within its field of vision. Therefore, satisfying requirements 4a and 5.

5.2.4 Interaction

The PincherX-150 robot arm is used to pick up the target object. It is connected to the Intel NUC12 through micro-USB, and can receive instructions on the /px150/joint_states ROS2 topic, enabling the /leo_rover_controller node to set angles of different joints, and control the clamp to pick up objects, which aligns with requirement 4a.

Appendices

A Equality, Diversity, Inclusion and Accessibility Policy

Our Policy's Purpose

Within Team 9, we aspire to create an environment for all team members, free of bullying, harassment, victimisation and discrimination, towards each other and other people. Our goal is accomplished by having all members committed to treating everyone with equality, respect and dignity. In accordance with our established policies and regulations, all voices are valued, and all team members can express themselves openly without facing unjust criticism or the worry of retaliation.

Team 9 is committed to provide an inclusive, equitable and respectful workplace that promotes diversity and accessibility for all. Equal opportunities, fair treatment, and an inclusive decision-making process is ensured for all team members regardless of age, disability, gender, marriage, race, religion or belief, and sexual orientation.

Team rules

1. Freedom of speech is protected and encouraged to help give the ability for everyone's views to be heard, viewed and considered equally.
2. Provide constructive feedback and be open to receiving it.
3. Always give the benefit of the doubt, assuming good intentions.
4. Team members are responsible to complete their task on time, based on the deadline and the task loads. If someone needs assistance, they should inform other people as early as possible to avoid delay.
5. Try the best to speak English during meetings, labs, and online. Be patient if anyone encounters difficulty in expressing their thoughts.
6. Actively seek input from all team members during the decision-making process. Major decisions to be made by majority vote. If in the event of a tie, it will be discussed until a compromise is made or until the majority agrees.
7. Maintain confidentiality: Keep sensitive information confidential to foster trust.
8. Weekly updates for personal and meeting logs are required, ensuring accurate records of each team member's contributions and achievements.
9. Consider accessibility requirements when organising shared folders, ensuring that naming rules and structures are clear for all team members.
10. Ensure that code documentation is inclusive and understandable to all team members, taking into account the diversity level of programming experience.

11. Working Hours: Tuesday meeting (11 am - 12 pm), Wednesday lab (2 - 6 pm) , Friday meeting (11 am - 1 pm) - No work on weekends (unless there is a submission)

Our Approach to Grievances

In the case of any conflict, misunderstanding, harassment, or a member was offended by a discussion or treatment by another team member, a plan of action has been established to address the problem rapidly and resolve it:

1. If possible, the grievance is solved between the members that feel offended and the offender, calmly talking to each other, and ensuring all parties involved understand the problem, avoiding misunderstandings. Otherwise, the following steps will take place.
2. Considering all members' timetables, a meeting is organised at the earliest convenience. The member in question should discuss his experience and feelings with the others, brainstorming potential solutions, until a consensus or meeting ground is reached.
3. A vote is then made after the discussion, objectively considering the best approach to be taken. Subsequently, the team will adhere to the best solution.
4. In case the discussion becomes unproductive, there will be a pause to make sure all members communicate effectively. A follow-up meeting will then be organised.
5. In the event that the issue is beyond the responsibility or capability of the team, all team members have the option to consider escalation. Staff can step in and mediate the situation to ensure the safety of all members involved.

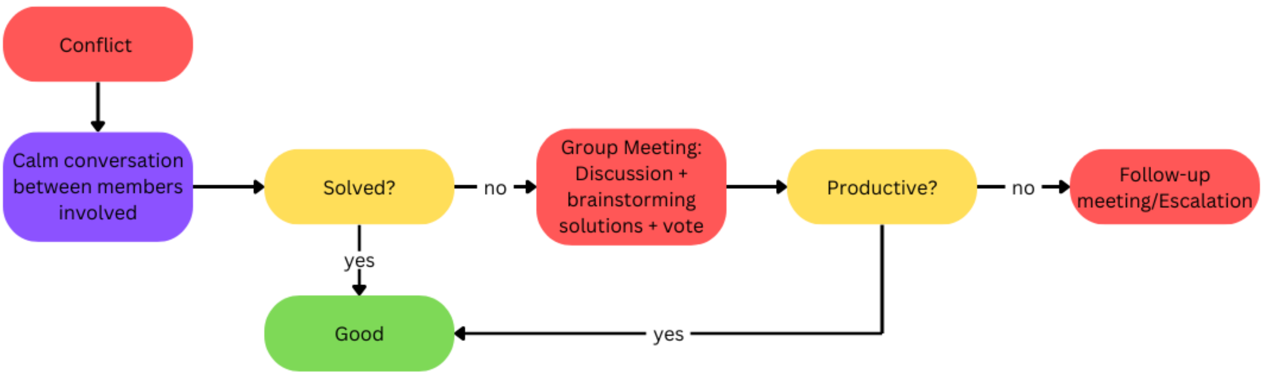

Fig. 6. Conflict Resolution Flow Chart

Preferably, any signs of conflict should be recognised early on, and an open communication within the team should be encouraged, where members feel safe expressing their concerns.

Accountability and Monitoring

Failure to comply with the policy can result in the matter being escalated. This is to help adhere to the policy and have all members be held accountable for their actions. The team leader could monitor the behaviour of the team and ensure that the policy and team rules are respected.

B Functional and Product Design Requirements

This section highlights the functional and design requirements of the robot, allowing it to achieve the objectives set out in the problem statement (Section 2 of this document).

B.1 Autonomy Requirements

1. The robot shall autonomously avoid obstacles observable by the robot.
   (a) The LiDAR should be able to detect obstacles at a distance in the range of 0.15 m - 5 m, to be able to perform obstacle avoidance.

B.2 Environment Requirements

2. The robot shall be able to traverse indoor environments
   (a) The robot shall be able to move at a maximum speed of 0.35 m/s, to be able to complete the task within the robot's battery life.
   (b) The designed payload will not exceed the width of the robot, which is 450 mm, such that the robot can navigate between obstacles (assuming that the minimum gap between obstacles can only fit the Leo Rover chassis).
3. The robot should navigate the environment, perform obstacle avoidance, and pick up the object autonomously, with no human intervention.

B.3 Object Retrieval Requirements

4. The robot should be able to pick-up lightweight objects that are within the size and torque capability of the grippers
   (a) Robot arm shall be able to pick up cuboid wooden objects of sizes up to 0.04 m x 0.04 m x 0.04 m, with a maximum weight of 50 g.
   (b) Robot arm should be able to pick up spherical wooden objects of sizes up to a diameter of 0.04m, with a maximum weight of 50 g

B.4 Object Identification Requirements

5. The robot shall be able to identify the target object by colour.
6. The robot should identify the target object with limited human intervention (e.g. inputting object colour and shape).
7. The robot will be equipped with a vision system that can identify objects by colour, distinguishing between a predefined range of colours under standard laboratory lighting conditions.

8. The robot will integrate a depth camera to identify the object.
    (a) Depth camera should be able to detect objects as small as 0.02 m x 0.02 m x 0.02 m at a distance in the range of 0.28 m - 5 m.

B.5 Task Requirements

9. The robot shall be able to bring picked up objects back to the robots original starting location.
10. The payload will be no more than 0.25 m above the ground level to allow the robot to pick up objects from the ground comfortably, as the working area of the manipulator is a sphere with diameter 0.63 m.

B.6 Robot Safety and Debugging Requirements

11. The combined weight of the designed payload, LiDAR, NUC, and depth camera will not exceed 5 kg.
12. The robot should include an emergency stop feature that can be activated by the operator to immediately cease all movement and operations.
13. The robot should provide a log of its activities, including objects picked up, paths taken, and any errors or obstacles encountered.

C Requirements Verification Matrix

This section addresses the Requirements Verification Matrix, illustrating the methods for confirming whether the design aligns with the specified requirements. All the requirements outlined in the matrix are detailed in Section 3 of this document.

Requirement No	Paragraph	Shall Statement	Verification Success Criteria	Verification Method
1	3.1 Autonomy Requirements	The robot shall autonomously avoid obstacles observable by the robot.	1. The LiDAR will be tested with various objects of different colours and sizes placed within the specified range (0.15 m - 5 m) to see if the objects are detectable. 2. The LiDAR will then be placed on the robot ensuring the obstacles are detected then traversed around. This will be tested in various environments and against various obstacles. The success rate criterion is set to exceed 95%.	Test
2	3.2 Environment Requirements	The robot shall be able to move at a maximum speed of 0.35 m/s, to be able to complete the task within the robot's battery life.	The robot's speed will be tested to see if the robot can maintain a speed of 0.35 m/s and not exceed this, further testing the controller limits of the software. This is checked by having measurements on the floor of the lab and timing how long it takes to traverse over a set distance. The success rate criterion is set to exceed 95%.	Test
4a	3.3 Object Retrieval Requirements	Robot arm shall be able to pick up cuboid wooden objects of sizes up to 0.04 m x 0.04 m x 0.04 m, with a maximum weight of 50 g.	A wooden cube of various sizes ranging from 0.02 m to 0.04 m and various weights up to 50 g will be attempted to be picked up by the robot arm. The success rate criterion is set to exceed 90%.	Test
5	3.4 Object Identification Requirements	The robot shall be able to identify the target object by its colour.	The robot will return a message of the correct colour of the certain area from the image information. The success rate criterion is set to exceed 90%.	Test
9	3.5 Task Requirements	The robot shall be able to bring picked up objects back to the robot's original starting location.	1. Starting from the foundation of the requirement 3 test. 2. The robot will then traverse the lab at a speed of around 0.35 m/s to verify that the manipulator can maintain control of the block over the course of the objective. 3. The robot and wooden block will then be placed in random locations in the environment, the robot will retrieve the block, then return to its starting location. The success rate criterion is set to exceed 90%.	Test

Table 2. Requirements Verification Matrix

D Mechanical Design - Other Perspectives of Design

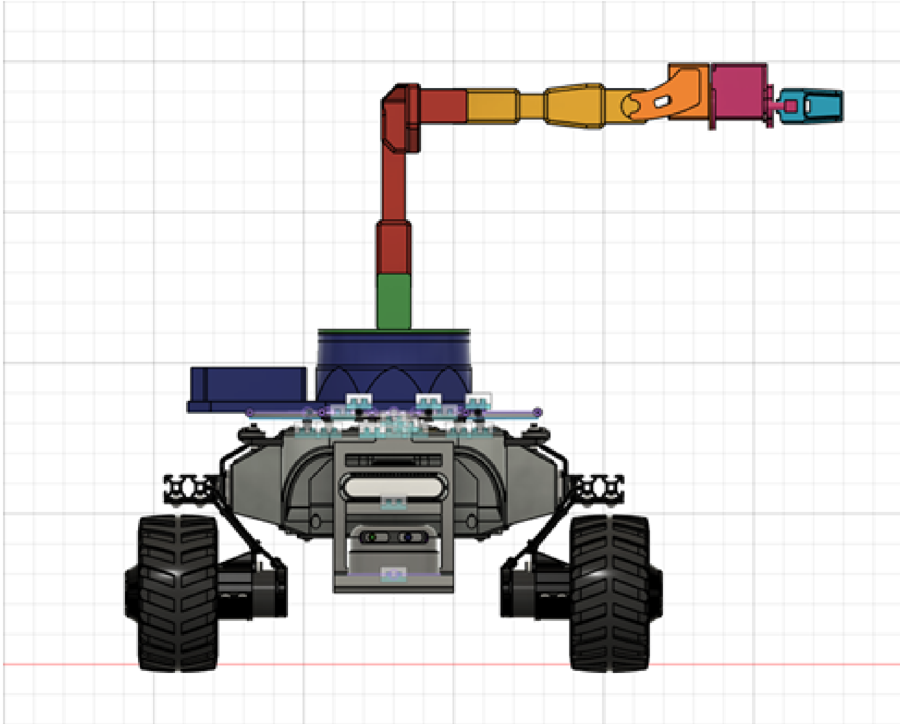

Fig. 7. Robot Front View

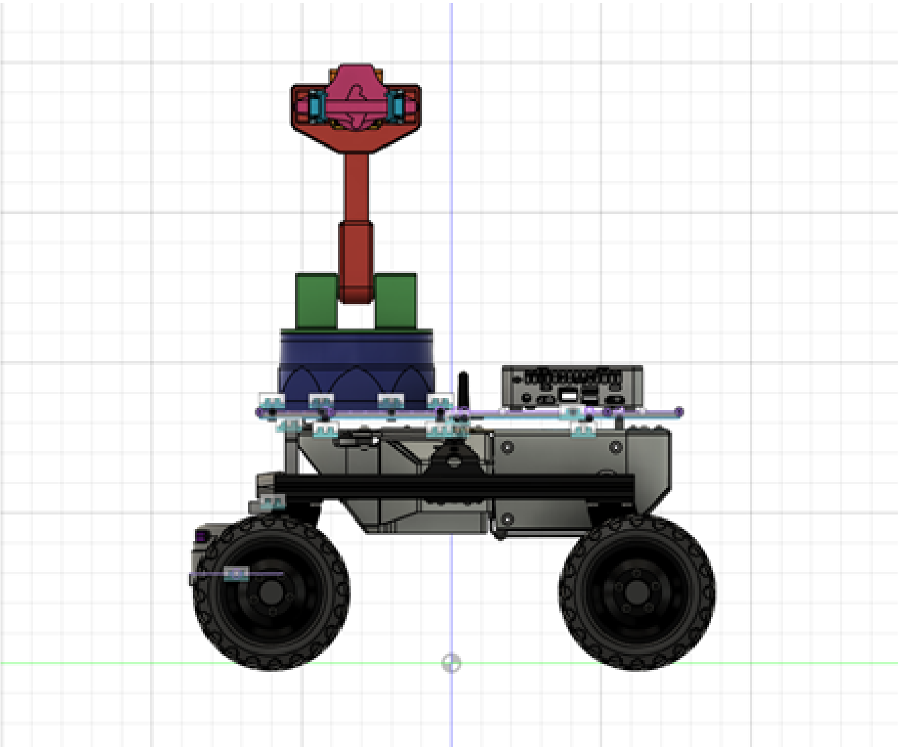

Fig. 8. Robot Side View

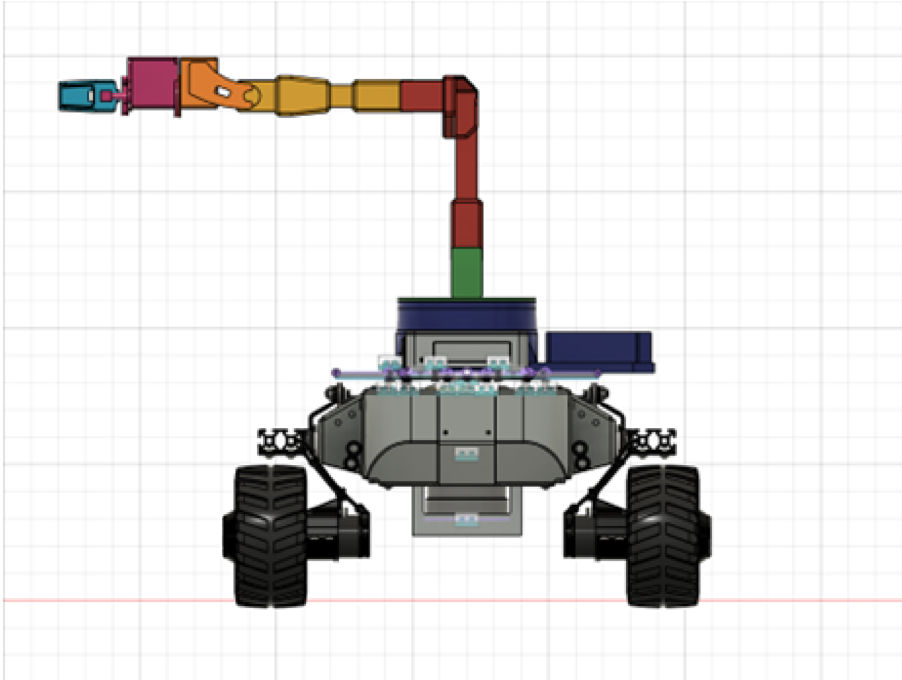

Fig. 9. Robot Back View

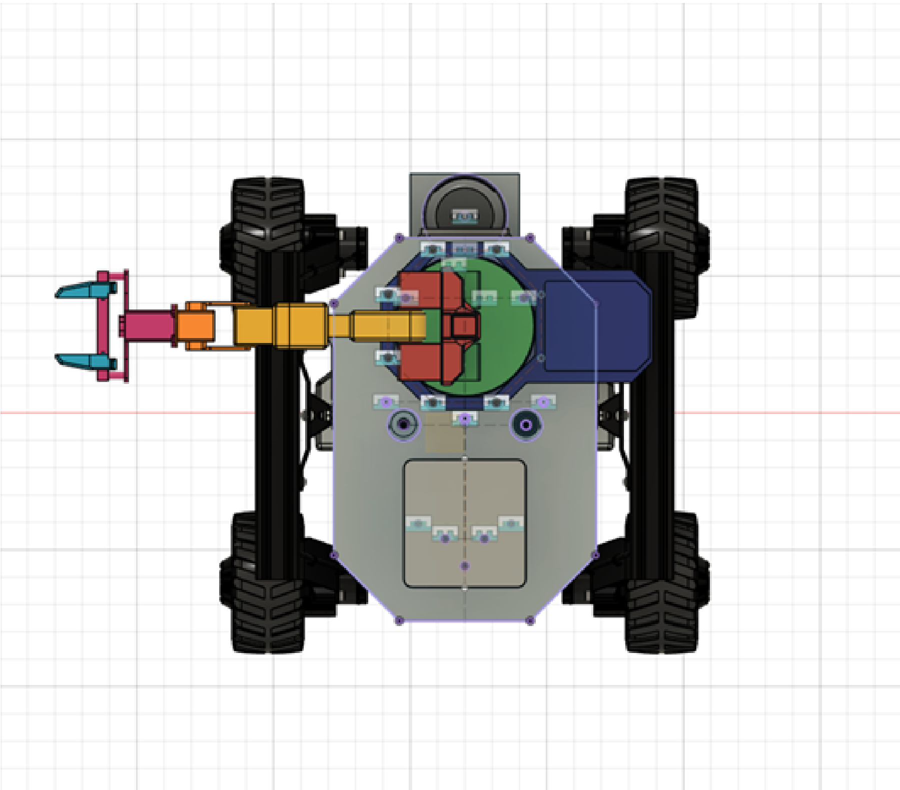

Fig. 10. Robot Top View

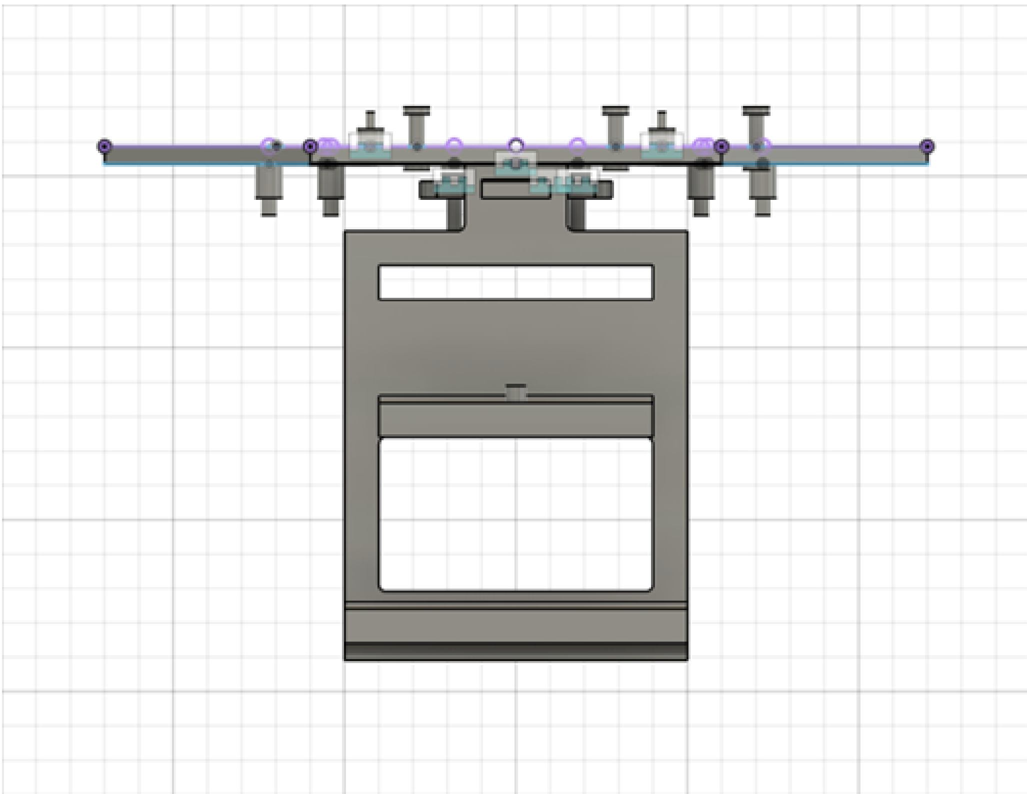

Fig. 11. Sled Front view

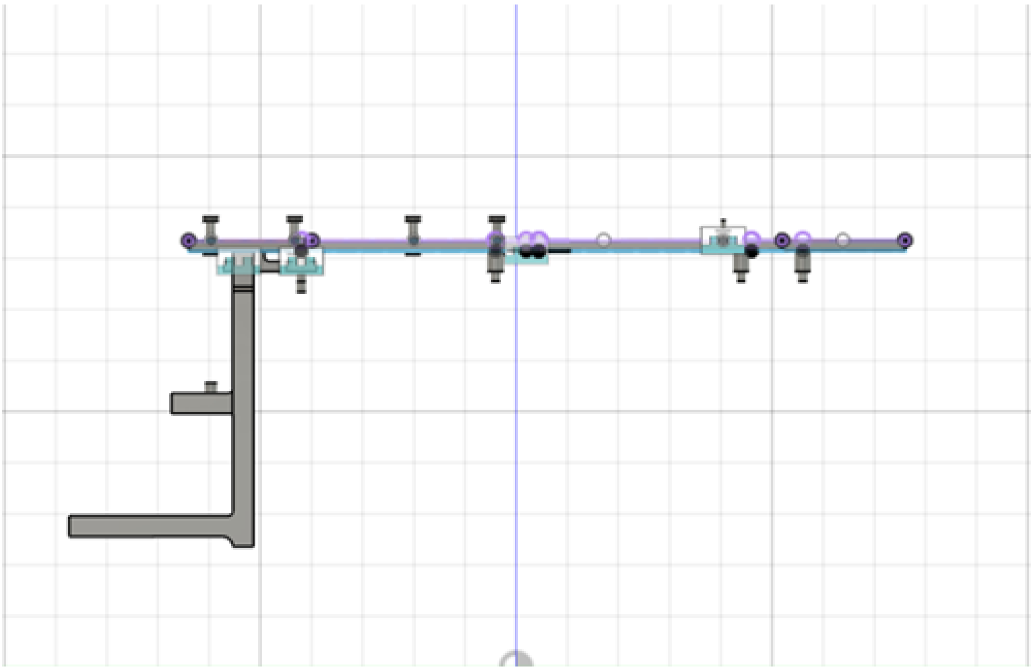

Fig. 12. Sled Side View

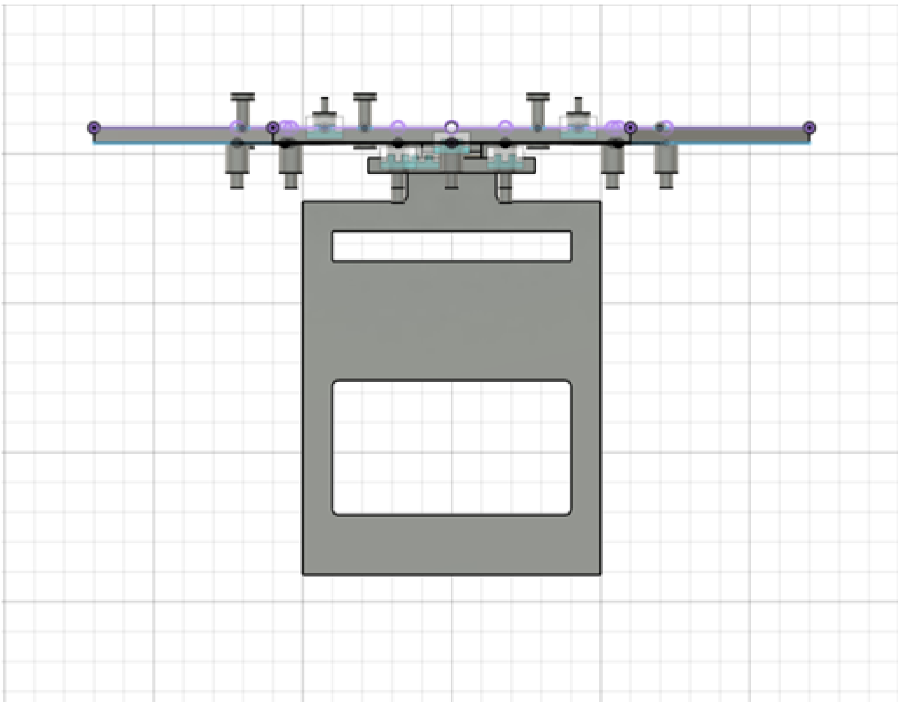

Fig. 13. Sled Back View

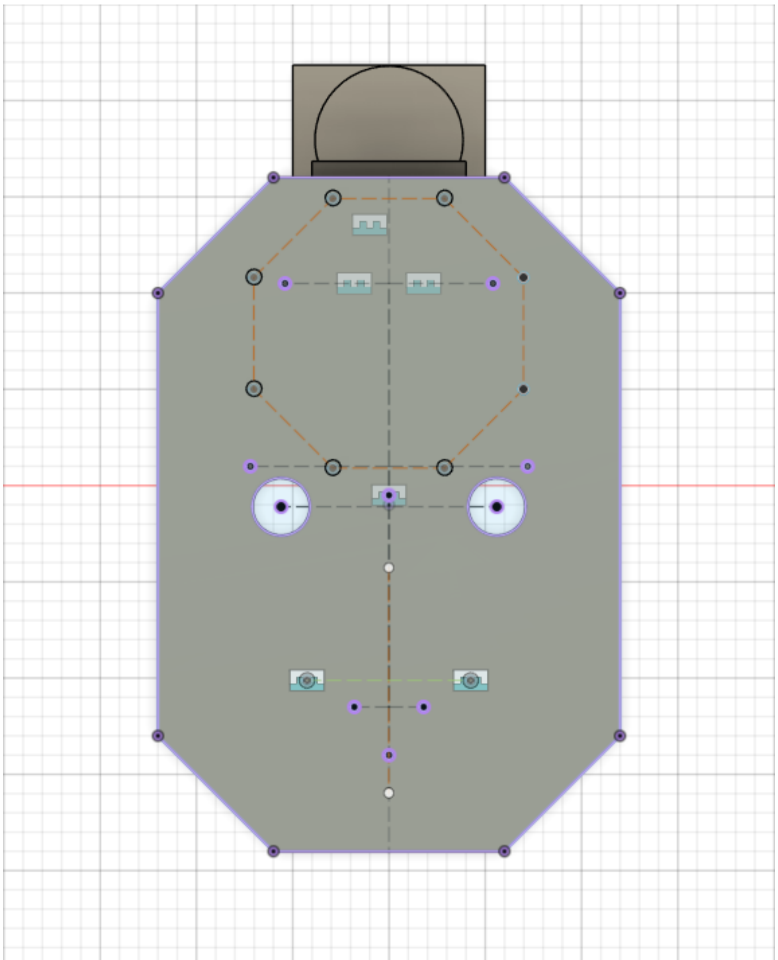

Fig. 14. Sled Top View