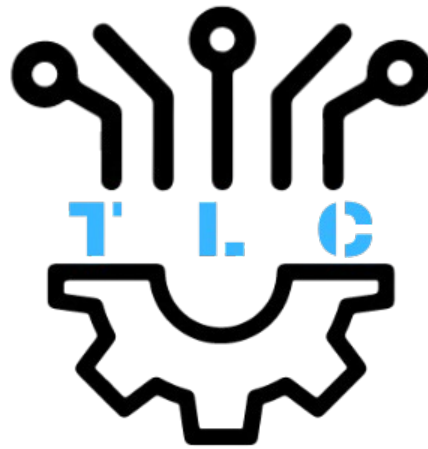


**DEPARTMENT OF COMPUTER SCIENCE & ENGINEERING
THE UNIVERSITY OF TEXAS AT ARLINGTON**

**DETAILED DESIGN SPECIFICATION
CSE 4317: SENIOR DESIGN II
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**TEAM TLC
ROAM_BOT**

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1 INTRODUCTION

The RoamBot should assist with learning to implement autonomous system software through real test simulations. This will be achieved using actual robotic systems. The overall design is controlled by a Raspberry Pi, which acts as the host connecting the different components of the rover. The first section describes the rover's motion and functionality. The second section entails the interface which allows users to upload their algorithm or manually control the rover. The third section is about the path-finding function, which dictates where the rover can move with the use of LIDAR and other sensors.

2 SYSTEM OVERVIEW

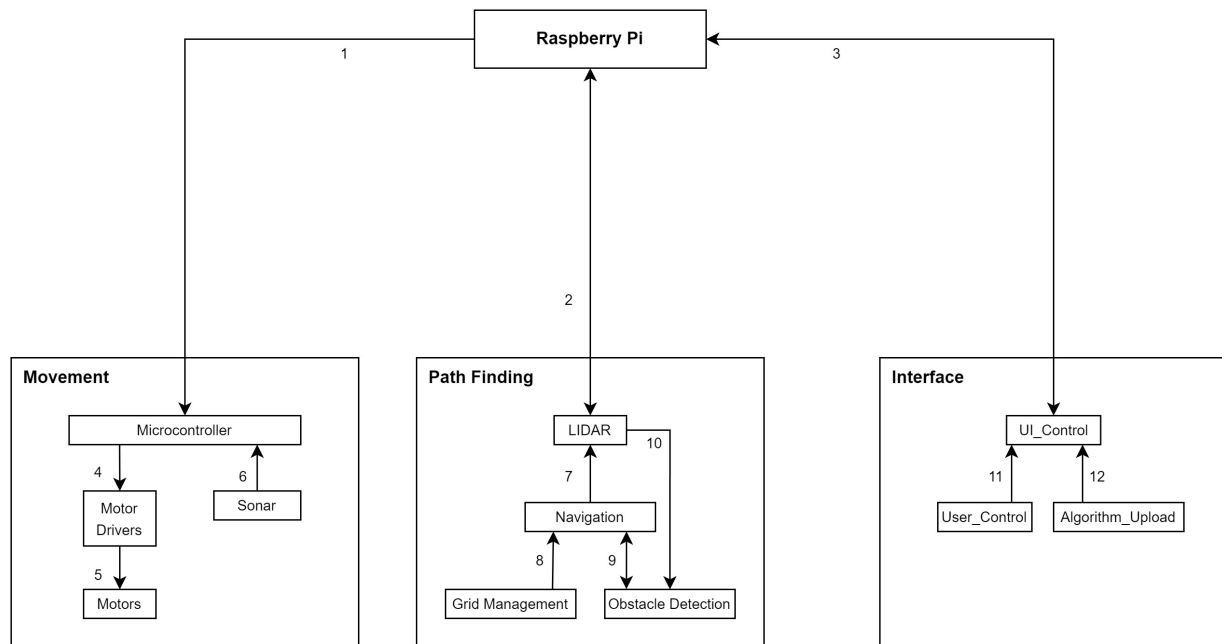


Figure 1: Data Flow Diagram

The architecture of the RoamBot system is structured into three distinct layers: Movement, Path Finding, and Interface, each serving a critical role in the rover's functionality. The Movement Layer is responsible for controlling the rover's motion, including speed, direction, and crash prevention. It utilizes UART to control speed and direction and GPIO for safety features like stopping when obstacles are detected. The Path Finding Layer enables autonomous navigation through LIDAR-based mapping and obstacle detection, using GPIO communication with a TM4C microcontroller to control and guide the movement. Lastly, the Interface Layer acts as the bridge between the user and the system, handling user command interactions, including direct control of the rover and algorithm uploads.

These layers work together to ensure efficient and autonomous operation of the RoamBot. The Movement Layer executes physical actions based on inputs from the Path Finding Layer, which interprets environmental data to determine safe navigation paths. The Interface Layer facilitates user interaction, allowing for both manual and automated control. This structured approach ensures modularity, making each layer functionally independent while maintaining well-defined communication interfaces for seamless operation.

3 MOVEMENT LAYER SUBSYSTEMS

The Movement Subsystem controls the rover's motion by managing speed, direction, and collision avoidance. It receives navigation commands from the Raspberry Pi and sends signals for motor control, ensuring responsive navigation.

3.1 MICROCONTROLLER

The microcontroller [2] is a hardware component responsible for processing commands and controlling the rover's movement. It manages communication between the control systems and the motor drivers, sending directional and speed commands. Additionally, it handles sensor inputs for obstacle detection and emergency stops, ensuring safe and efficient operation.

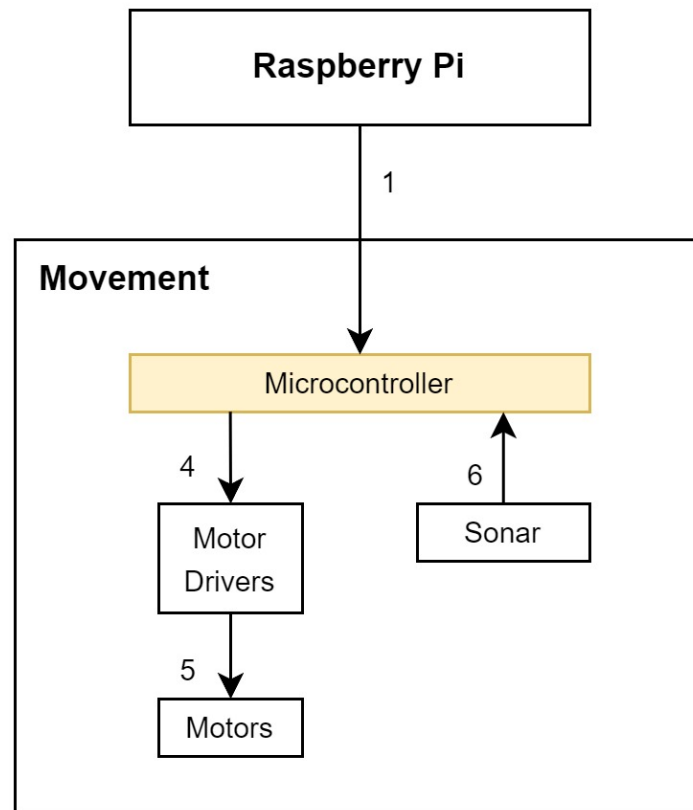


Figure 2: Movement Layer - Microcontroller Subsystem

3.1.1 SUBSYSTEM HARDWARE

- TM4C RedBoard - A microcontroller with built-in UART and GPIO modules, responsible for processing motor control commands and handling sensor inputs (Figure 13).

3.1.2 SUBSYSTEM SOFTWARE DEPENDENCIES

TI Driver Library (Tivaware) - Provides low-level control over the TM4C RedBoard's peripherals, including UART and GPIO.

3.1.3 SUBSYSTEM PROGRAMMING LANGUAGES

The TM4C RedBoard firmware uses C to implement the communication protocols and to control movement functions.

3.1.4 SUBSYSTEM DATA STRUCTURES

- (4x) 1-bit input GPIO control signals, one for each movement direction.
- 8-bit control packets are sent via UART to regulate each motor. Each packet consists of a single byte representing motor-specific commands such as speed and direction. Transmission occurs at 9600 baud with 5V, 8N1 settings, controlling one motor per packet.

3.1.5 SUBSYSTEM DATA PROCESSING

The microcontroller polls movement direction inputs every 100ms, capturing the required state and transmitting four motor control commands (one per motor).

3.2 MOTOR DRIVERS

The motor drivers [1] are hardware components that regulate power to the DC motors based on control packets received from the TM4C RedBoard. These are Sabertooth controllers that process incoming commands to adjust motor speed and direction. They ensure efficient and precise movement of the rover.

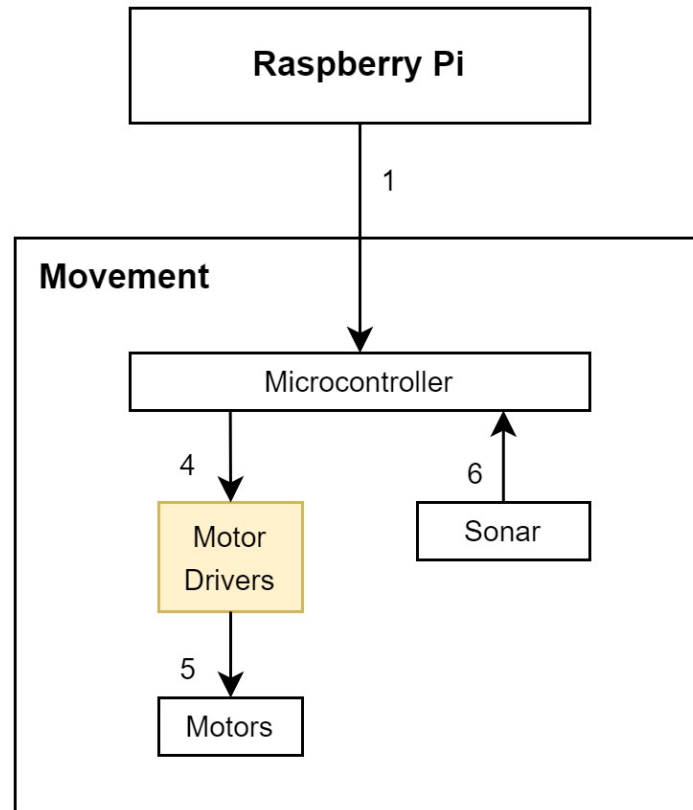


Figure 3: Movement Layer - Motor Drivers Subsystem

3.2.1 SUBSYSTEM HARDWARE

- Two Sabertooth 2x25 Motor Controllers - High-performance dual motor drivers that receive UART commands from the TM4C RedBoard. Each controller independently drives two motors, enabling precise movement control (Figure 14).

3.2.2 SUBSYSTEM DATA STRUCTURES

- 8-bit control packets regulate motor operations. Each packet consists of a single byte representing speed and direction commands. The packets are received over UART at 9600 baud with 3.3V, 8N1 (1 start bit, 8 data bits, 1 stop bit) settings, controlling one motor per packet.

3.2.3 SUBSYSTEM DATA PROCESSING

Each Sabertooth controller processes incoming UART packets every 100ms. Two packets (one per motor) are received per controller, spaced 50us apart to ensure proper sequencing and avoid command overlap.

3.3 MOTORS

The motors are the primary actuators responsible for the physical movement of the rover. These are high-performance DC motors controlled by the motor drivers to achieve the desired speed and direction. The motors receive regulated power from the motor drivers, ensuring smooth movement.

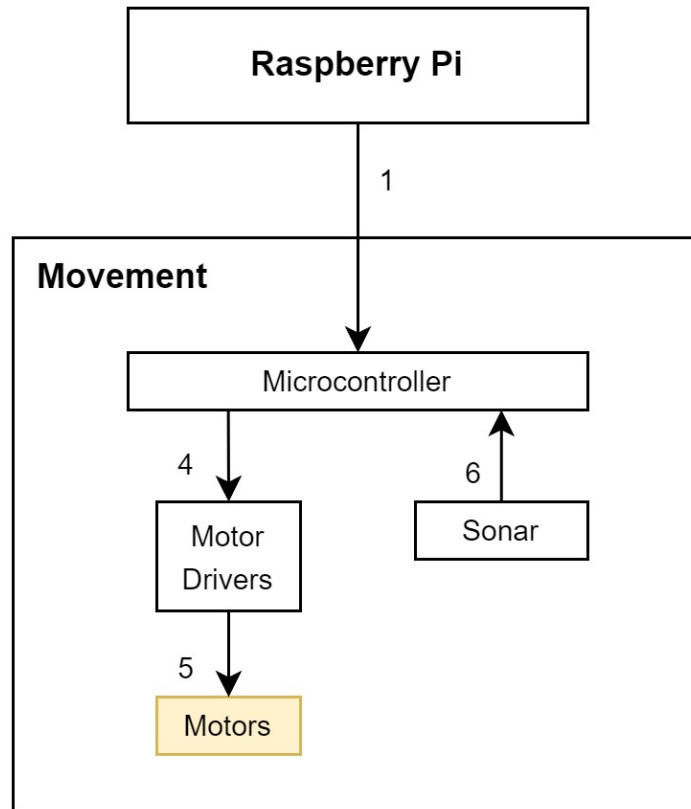


Figure 4: Movement Layer - Motors Subsystem

3.3.1 SUBSYSTEM HARDWARE

- Four DC Motors - Generate the mechanical power required for rover movement. The motors are grouped into front and rear pairs, each controlled independently by the motor drivers to regulate speed and direction.

3.4 SONAR

The Sonar subsystem utilizes ultrasonic sensors to detect obstacles in the rover's path. The system works by emitting sound waves and measuring the time it takes for the waves to bounce back after hitting an obstacle. The data is processed to determine the distance to the nearest object, enabling the rover to take last-minute actions to avoid collisions.

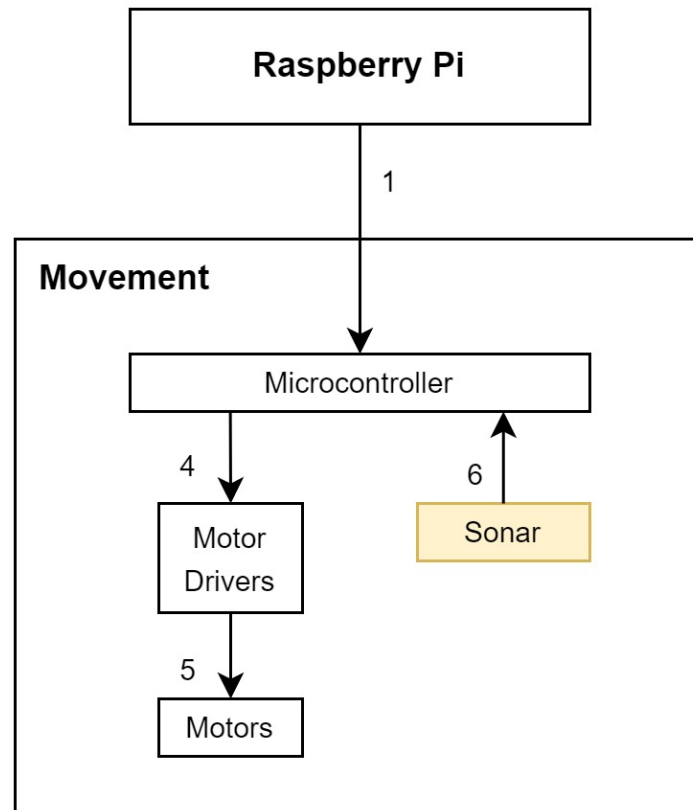


Figure 5: Movement Layer - Sonar Subsystem

3.4.1 SUBSYSTEM HARDWARE

- Ultrasonic Distance Sensor (HC-SR04) - Commonly used sensors that emit sound waves and listen for the echo, allowing for precise distance measurements to obstacles in the rover's path.

3.4.2 SUBSYSTEM DATA STRUCTURES

- 8-bit distance value (in centimeters) transmitted from the sensor to the microcontroller. This value represents the distance to the nearest obstacle detected by the sonar.

3.4.3 SUBSYSTEM DATA PROCESSING

The microcontroller sends a 10 μ s pulse to the sensor's trigger pin, which causes the sensor to emit an ultrasonic wave. The time taken for the echo to return is measured to compute the distance. The system continuously polls the sensor at regular intervals (every 100ms) to update the obstacle detection distance. If an obstacle is detected within a defined threshold (50 cm), the rover will stop.

4 PATHFINDING LAYER SUBSYSTEMS

The Pathfinding Subsystem controls the rover's movement, by utilizing the rover's LIDAR to create a map of the terrain. The subsystem will then create a costmap grid, and then applying an A* pathfinding algorithm to find the most efficient and safest path.

4.1 LIDAR

The LIDAR subsystem is a hardware component responsible for environmental perception and obstacle detection. It operates by emitting laser pulses and measuring the time it takes for them to reflect off surrounding objects, generating a point cloud representation of the environment. This data enables the differential mobile robot to construct a real-time map, detect obstacles, and facilitate autonomous navigation. The LIDAR subsystem integrates with the robot's path planning and localization systems, providing critical spatial awareness for efficient and collision-free movement.

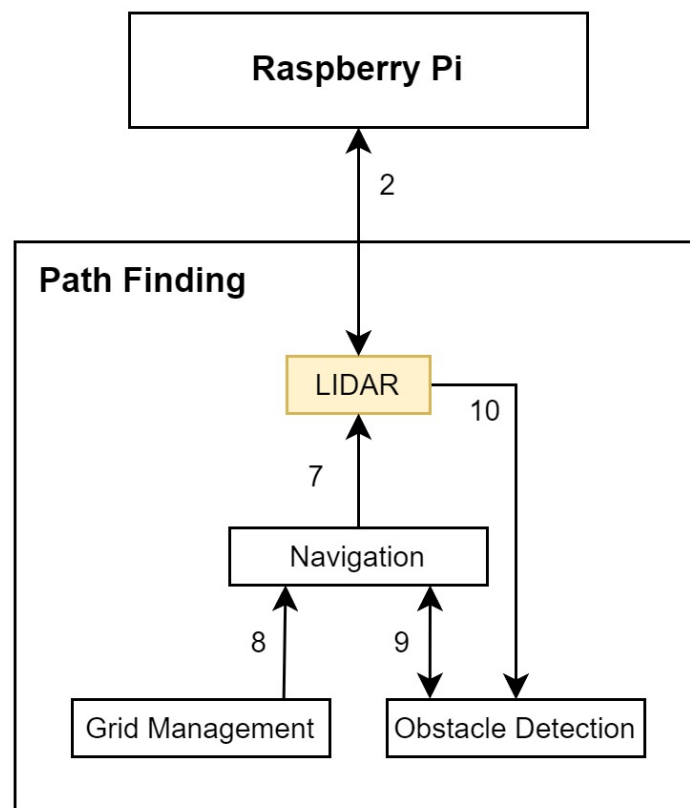


Figure 6: Pathfinding Layer - LIDAR Subsystem

4.1.1 SUBSYSTEM HARDWARE

Slamtec RPLIDAR A1 - 360-degree laser range scanner. With a maximum range of 100 meters and a sampling frequency of a little over 2500 samples a second, measures distances and angles to create a 2D cloud point representation of the surroundings.

4.1.2 SUBSYSTEM OPERATING SYSTEM

The LIDAR is compatible with both Windows and Linux.

4.1.3 SUBSYSTEM DEPENDENCIES

The LIDAR system utilizes the RPLIDAR SDK developed by Slamtec to facilitate its operation and data processing.

4.1.4 SUBSYSTEM PROGRAMMING LANGUAGES

The RPLIDAR SDK developed by Slamtec is primarily written in C++.

4.1.5 SUBSYSTEM DATA STRUCTURES

The RPLIDAR will be used to make a linked list of all data points so that it can be transferred to the navigation system and let it know where any obstacles are.

4.1.6 SUBSYSTEM DATA PROCESSING

The LIDAR system acquires raw data points in the form of a point cloud by measuring the distances between emitted laser pulses.

4.2 NAVIGATION

The Navigation subsystem software integration that allows a Raspberry Pi 5 to compute and execute navigation commands for a robot. It enables autonomous movement by processing sensor data, calculating an optimal path, and sending motor control signals to drive the robot accordingly.

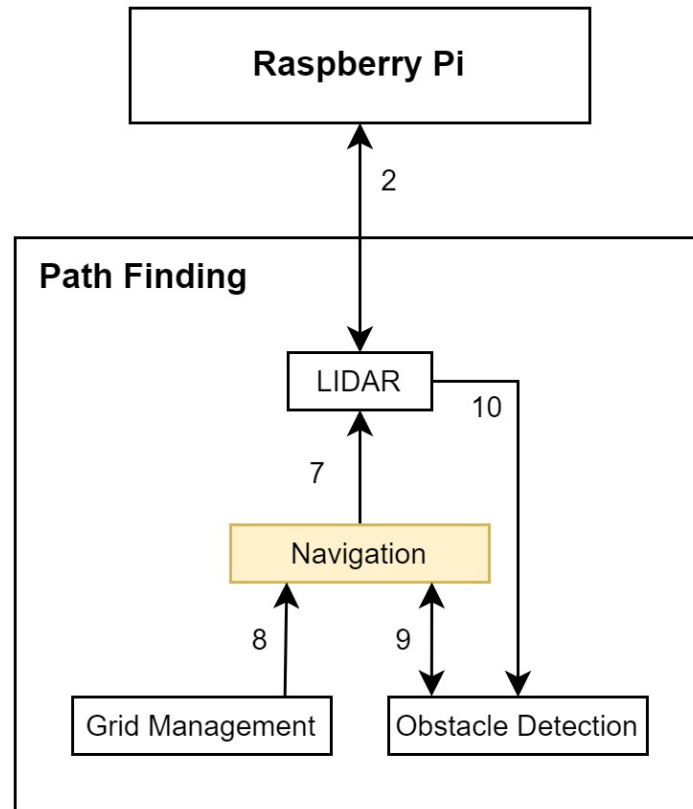


Figure 7: Pathfinding Layer - Navigation Subsystem

4.2.1 SUBSYSTEM OPERATING SYSTEM

The navigation subsystem will be run on ROS2 Jazzy which requires Ubuntu 24.04 (Noble Numbat) or higher for compatibility.

4.2.2 SUBSYSTEM SOFTWARE DEPENDENCIES

The Navigation Subsystem uses Nav2 and ROS2 to develop the pathfinding algorithm and design the path for the rover to follow, and ROS2 to manage the robot's movements.

4.2.3 SUBSYSTEM PROGRAMMING LANGUAGES

Nav2 is primarily implemented in C++ to ensure optimal compatibility with ROS2, which is also C++-based. However, it also provides a Python API for additional flexibility.

4.2.4 SUBSYSTEM DATA PROCESSING

The pathfinding subsystem employs the A* algorithm due to its ability to determine the most optimal path while maintaining lower computational overhead compared to alternative pathfinding methods.

4.3 GRID MANAGEMENT

The Grid Management subsystem operates on ROS2 Jazzy, which will be hosted on the Raspberry Pi 5.

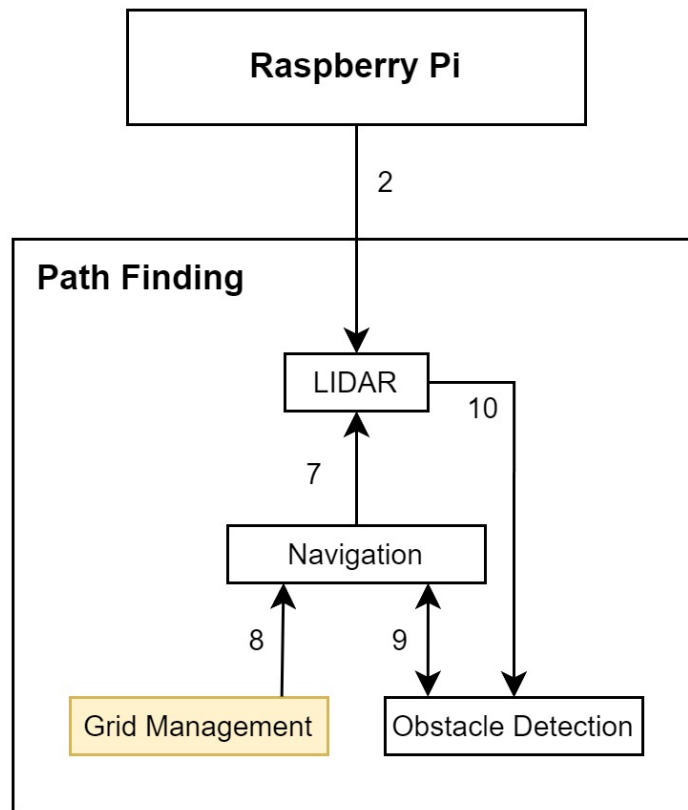


Figure 8: Pathfinding Layer - Grid Management Subsystem

4.3.1 SUBSYSTEM PROGRAMMING LANGUAGES

The Grid Management Subsystem creates a costmap using C++.

4.4 OBSTACLE DETECTION

The Obstacle Detection subsystem leverages the costmap generated by the Grid Management Subsystem to assess the robot's environment. It assigns a numerical value to each grid cell based on the proximity of surrounding objects, with higher values indicating closer objects and lower values representing areas free from obstacles.

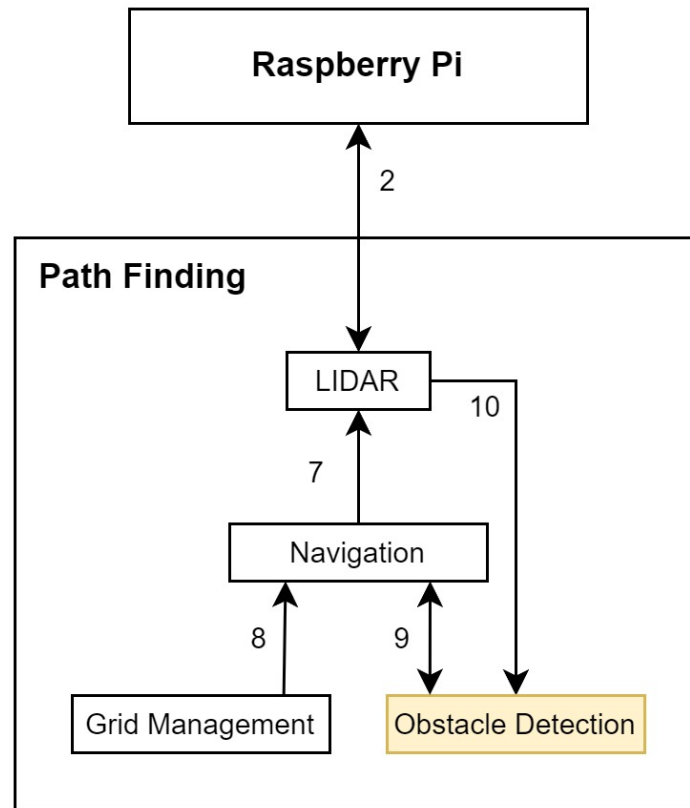


Figure 9: Pathfinding Layer - Obstacle Detection Subsystem

4.4.1 SUBSYSTEM OPERATING SYSTEM

ROS2 Jazzy requires Ubuntu 24.04 (Noble Numbat) or higher for compatibility.

4.4.2 SUBSYSTEM SOFTWARE DEPENDENCIES

The Grid Management Subsystem uses Nav2 to develop the pathfinding algorithm and design the path for the rover to follow, and ROS2 to manage the robot's movements.

4.4.3 SUBSYSTEM PROGRAMMING LANGUAGES

Nav2 is primarily in C++, so it can better configure with ROS2 which is also in C++, but Nav2 does allow for a Python API.

4.4.4 SUBSYSTEM DATA PROCESSING

The pathfinding subsystem utilizes the A* pathfinding for its ability to find the most optimal path while being less computationally inexpensive than the other pathfinding subsystems.

5 INTERFACE LAYER SUBSYSTEMS

The interface subsystems of the RoamBot are responsible for processing user input and translating it into commands for the rover. These subsystems are implemented using C, C++, and Python and operate on the Raspberry Pi 5.

5.1 LAYER HARDWARE

The Raspberry Pi 5 serves as the core interface hardware for the RoamBot, providing robust computational power with its quad-core ARM Cortex-A76 processor and 16GB of LPDDR4x RAM. It efficiently handles real-time pathfinding and decision-making processes. Additionally, its USB 3.0 ports and GPIO pins allow for direct connection to sensors and motor controllers.

5.2 LAYER OPERATING SYSTEM

The operating system used for the interface layer is Ubuntu 24.04, providing a stable environment for development and execution.

5.3 LAYER SOFTWARE DEPENDENCIES

The interface subsystems rely on the ROS2 framework for robotic control. These libraries are utilized for implementing communication protocols, control algorithms, and user input processing.

5.3.1 LAYER PROGRAMMING LANGUAGES

This layer is implemented using C, C++, and Python to efficiently process user commands and algorithm decisions and communicate with the motor control system.

5.4 UI CONTROL

The UI control subsystem serves as the top-level software interface for managing user interactions. It enables switching between direct user control and automated algorithmic control.

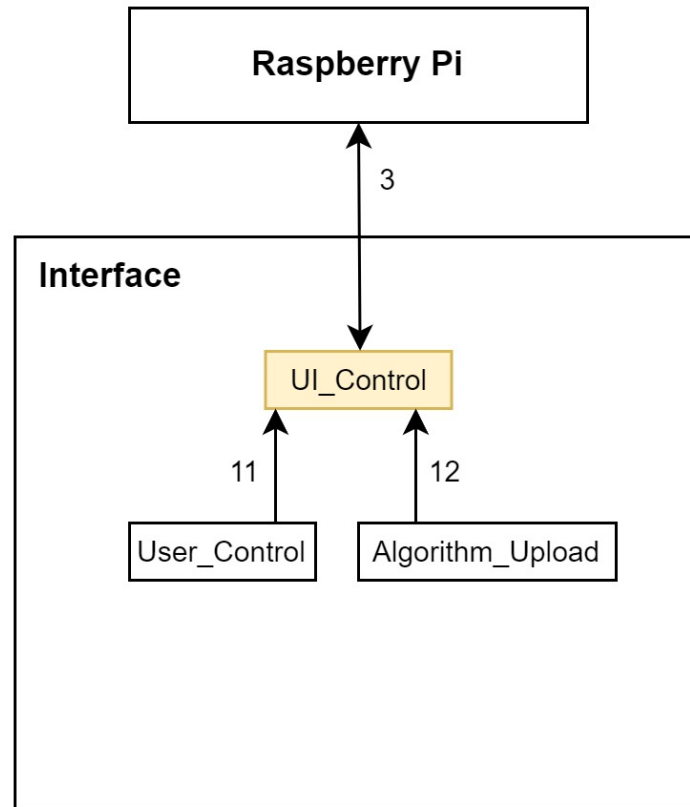


Figure 10: Interface Layer - UI Control Subsystem

5.4.1 SUBSYSTEM DATA STRUCTURES

The subsystem uses flag-based data structures to manage control mode status, with flags indicating whether the rover is in manual or autonomous mode. These flags are checked in real-time to determine which set of functions or commands should be executed.

5.4.2 SUBSYSTEM DATA PROCESSING

The UI control subsystem processes incoming user commands to switch between manual and automated modes by interpreting the mode. When a switch occurs, the system either routes input to the manual control system, allowing the user to directly guide the rover, or to the autonomous system, where the rover executes pre-programmed algorithms.

5.5 USER CONTROL

The User Control subsystem allows direct manipulation of the RoamBot's movement in real-time. It processes immediate user inputs, and translates the input into motion instructions. This subsystem ensures that users have precise control over speed and direction, allowing manual operation when needed.

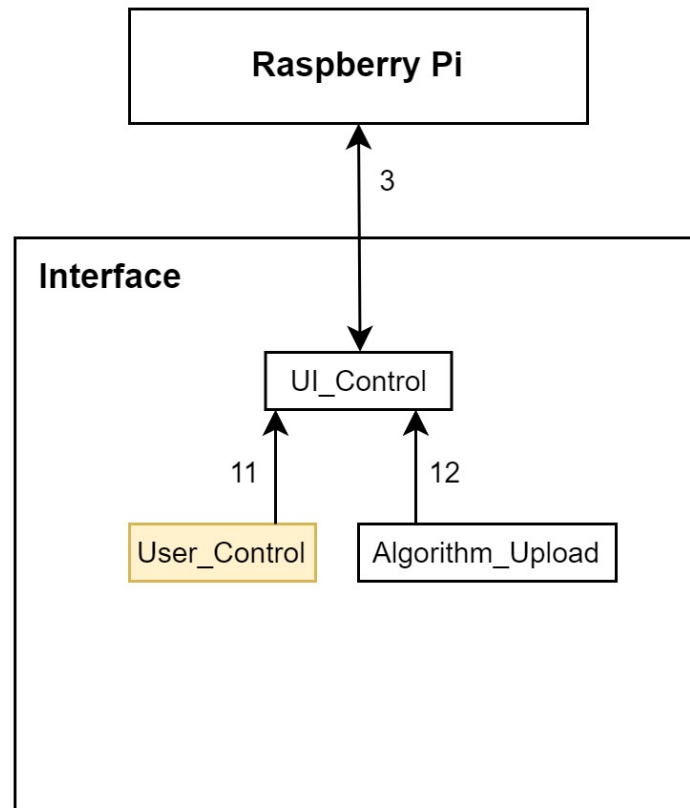


Figure 11: Interface Layer - User Control Subsystem

5.5.1 SUBSYSTEM PROGRAMMING LANGUAGES

This subsystem is implemented using C, C++, and Python to efficiently process user commands and communicate with the motor control system.

5.5.2 SUBSYSTEM DATA PROCESSING

User inputs are converted into structured motion commands that control the rover's speed and direction. These commands are processed in real time to ensure responsiveness.

5.6 ALGORITHM UPLOAD

The Algorithm Upload subsystem allows users to upload pre-programmed pathfinding algorithms to enable autonomous navigation. It processes these algorithms and integrates them into the rover's control system, ensuring that the RoamBot can follow predefined paths without manual intervention.

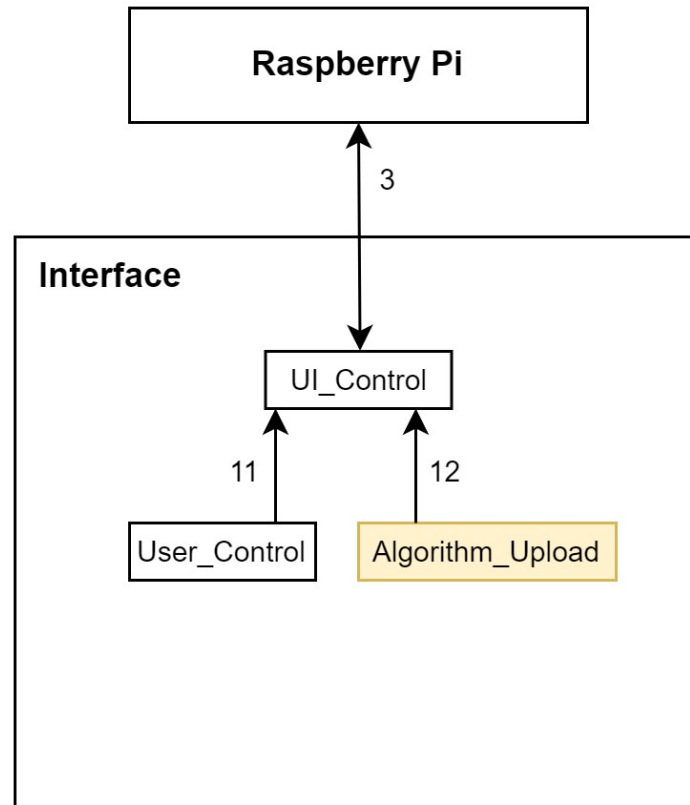


Figure 12: Interface Layer - Algorithm Upload Subsystem

5.6.1 SUBSYSTEM DATA STRUCTURES

The Algorithm Upload subsystem uses data structures like pathfinding grids or graphs to represent the environment, with nodes storing position and cost values. The resulting path is stored as a sequence of waypoints.

5.6.2 SUBSYSTEM DATA PROCESSING

Data processing involves parsing the algorithm, running pathfinding algorithms like A* to generate a path, and converting it into motion commands. These commands are then sent as ROS2 messages to the motor control system for autonomous navigation.

6 APPENDIX

Figure 1-1. Tiva C Series TM4C123G LaunchPad Evaluation Board

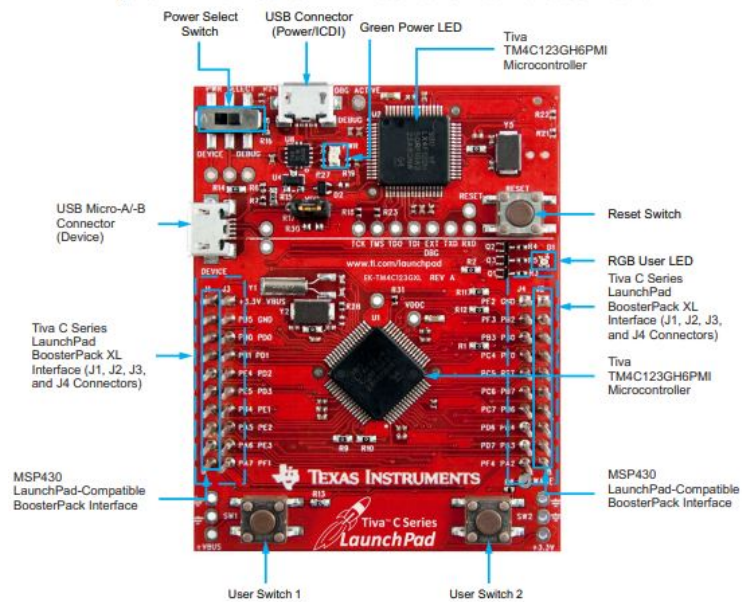


Figure 13: Movement Layer - Microcontroller Circuit

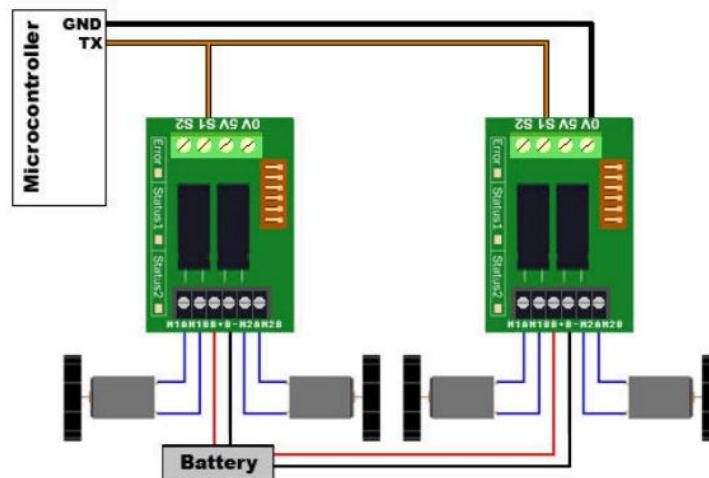


Figure 14: Movement Layer - Motor Drivers Circuit

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- [1] Dimension Engineering. Sabertooth 2x25 motor driver datasheet. Accessed: 2025-02-28. URL: <https://www.dimensionengineering.com/datasheets/Sabertooth2x25.pdf>.
- [2] Texas Instruments. Tiva c series tm4c123g launchpad evaluation board user guide. Accessed: 2025-02-28. URL: <https://www.ti.com/lit/ug/spmu296/spmu296.pdf?ts=1740733005566>.