ROBUST ANALYTICAL VEHICLE FOR EXPLORATION AND NAVIGATION (RAVEN)

A PROJECT PHASE II REPORT

Submitted by

AMITH MATHEW TITUS (ATP21EC009)

MANUKUTTAN P. (ATP21EC028)

MOHAMED AFRAN (ATP21EC031)

VIGNESH V. (ATP21EC045)

to

the APJ Abdul Kalam Technological University
in partial fulfillment for the award of the Degree of

BACHELOR OF TECHNOLOGY
in
ELECTRONICS AND COMMUNICATION ENGINEERING

under the supervision of

Ms. ASHA ARVIND

Department of Electronics and Communication Engineering

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Place: Palakkad

Date:

Signature:

Name: Amith Mathew Titus

Reg. No.: ATP21EC009

Signature:

Name: Manukuttan P.

Reg. No.: ATP21EC028

Signature:

Name: Mohamed Afran

Reg. No.: ATP21EC031

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Name: Vignesh V.

Reg. No.: ATP21EC045

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Name: Manukuttan P.

Reg. No.: ATP21EC028

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Place: Palakkad	Signature:
Date:	Name: Mohamed Afran
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Place: Palakkad	Signature:
Date:	Name: Vignesh V.
	Reg. No.: ATP21EC045

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Ms. Asha Arvind	Dr. V. Balamurugan
Department of ECE	Department of ECE
Signature:	Signature:
Date:	Date:

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APJ Abdul Kalam Technological University
End Semester Evaluation

I, **AMITH MATHEW TITUS (ATP21EC009)**, Semester VIII, hereby submit this report for the ECD416: Project Phase II viva-voce examination held on . . . .

Examiner 1	**Examiner 2**	**Examiner 3**

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ABSTRACT

The Robust Analytical Vehicle for Exploration and Navigation (RAVEN) aims to create an advanced platform capable of supporting a variety of exploration and navigation tasks in challenging environments. Leveraging cutting-edge technologies in robotics and sensor integration, RAVEN is designed to operate autonomously while providing real-time data analysis and decision-making capabilities. This project addresses the need for reliable exploration tools in sectors such as environmental monitoring, disaster response, and defence application, where traditional methods may fall short due to hazardous conditions or remote locations.In addition to its innovative design, RAVEN incorporates a modular architecture, allowing for easy customization and enhancement of its functionalities based on specific mission requirements. The vehicle's robust analytical capabilities enable it to process extensive datasets, aiding in the identification of patterns and anomalies critical for effective navigation and exploration. Through a series of field tests and simulations, the project will evaluate RAVEN's performance, ensuring its reliability and efficiency in real-world applications. Ultimately, this project seeks to contribute significantly to the fields of robotics and exploration, enhancing our ability to navigate and analyze the unknown.

CONTENTS

LIST OF FIGURES

ABBREVIATIONS

Abbreviation	Expansion
AGV	Automated Guided Vehicle
AMCL	Adaptive Monte-Carlo Localizer
API	Application Programming Interface
CSM	Correlation Scan Matching
CSV	Comma-Separated Values
CUDA	Compute Unified Device Architecture
DDS	Data Distribution Service
DNN	Deep Neural Network
GPS	Global Positioning System
GPU	Graphics Processing Unit
GUI	Graphical User Interface
IMR	Indoor Mobile Robot
IMU	Inertial Measurement Unit
L4T	Linux for Tegra
LiDAR	Light Detection and Ranging
LTS	Long-Term Support
Nav2	Navigation2
OpenCV	Open-Source Computer Vision Library
ROS	Robot Operation System
SDK	Software Development Kit
SLAM	Simultaneous Localization and Mapping
TensorRT	Tensor Runtime
UGV	Unmanned Ground Vehicle
UKF	Unscented Kalman Filter
URDF	Unified Robot Description Format
VS Code	Visual Studio Code

Chapter 1

INTRODUCTION

The ever-growing demand for reliable and versatile exploration tools in challenging environments has led to significant advancements in robotics and autonomous systems. In fields such as environmental monitoring, disaster response, and defense, traditional methods often fall short due to hazardous conditions, remote locations, and the need for real-time data and autonomous decision-making. Addressing these challenges requires a robust platform capable of navigating diverse terrains, analyzing complex data, and operating autonomously.

The Robust Analytical Vehicle for Exploration and Navigation (RAVEN) project aims to fill this need by developing an advanced autonomous vehicle designed for a wide range of exploration and navigation tasks. RAVEN leverages the latest innovations in robotics, sensor integration, and data analytics to deliver a flexible, modular, and reliable solution for critical missions in unpredictable settings. With its modular architecture and real-time analytical capabilities, RAVEN is engineered to adapt to diverse mission requirements, allowing seamless customization for specific applications.

1.1 Socio-Economic Relevance Of The Project

The RAVEN holds significant socio-economic relevance across various domains. Its deployment can lead to impactful benefits that extend beyond technological advancements, influencing societal and economic aspects positively. Below are key areas where RAVEN contributes:

1. **Industry Growth:** By improving exploration and navigation skills, RAVEN can stimulate growth in businesses such as environmental monitoring, mining, agriculture, and disaster management, resulting in more economic activity and

investment.

2. **Cost-Effectiveness:** Businesses and governmental organizations can cut operating expenses by utilizing RAVEN's autonomous capabilities, which will enhance return on investment and facilitate more effective resource allocation.

3. **Disaster Response:** RAVEN might potentially save lives and minimize damage in emergencies by providing timely data and support for disaster response activities.

4. **Environmental Protection:** RAVEN can help monitor and analyze environmental changes, thereby helping to better natural resource management and sustainability.

5. **Accessibility:** The vehicle can access remote or hazardous areas, enabling research and exploration that would otherwise be difficult or impossible, thus expanding knowledge and awareness of diverse ecosystems and regions.

1.2 Existing System

In the current market, there are UGVs available that offer advanced features. Key aspects of existing UGVs include:

- **Features:**
  - They can navigate on their own, using GPS, LiDAR, & computer vision.
  - These vehicles have sensors that help them spot & avoid obstacles in real time.
- **Drawbacks:**
  - They often have trouble in rough or unpredictable terrains. This restricts their applications.
  - The advanced technology needed can be costly to create & keep up, making it. hard for smaller operations to use them.

- Bad weather can mess with their performance, which may lead to data inaccuracies.

Overall, while UGVs have impressive features, there are still challenges they must overcome.

1.3 Motivation

The motivation behind the RAVEN project stems from a critical need to enhance current exploration and navigation capabilities across various sectors, including but not limited to robotics, autonomous vehicles, and environmental monitoring. This need is driven by several factors:

1. **Advancements in technology**

   - **Innovation potential:** New developments in artificial intelligence, robotics, & sensor tech creates an amazing chance to build a vehicle that uses these advances for better exploration and navigation.
   - **Integration of technologies:** By combining various technologies into one platform, RAVEN aims to be a flexible tool that meets many operational needs.

2. **Addressing current limitations**

   - **Terrain adaptability:** Many current systems struggle in tough or isolated areas. RAVEN is made to work well in difficult terrains, allowing for reliable data collection & navigation where older systems often fail.
   - **Operational efficiency:** The current methods for exploration can be expensive & slow. RAVEN looks to boost efficiency by cutting down the need for humans to intervene & lowering operational costs through automation.

3. **Societal needs**

   - **Environmental monitoring:** With increasing worries about climate change & environmental harm, RAVEN will help keep a closer watch on our natural resources, aiding in efforts to conserve them.
   - **Disaster response and recovery:** The ability to navigate and gather information in areas hit by disasters can greatly improve response efforts, which may save lives & help recovery processes.

4. **Economic benefits**

   - **Boosting industries:** RAVEN could help increase economic growth by offering industries like agriculture, mining, and environmental management powerful tools for exploring & analyzing data.
   - **Job creation:** Developing & rolling out RAVEN will open up job opportunities in technology, engineering, and research, boosting local and regional economies.

5. **Vision for the future**

   - **Pioneering exploration:** RAVEN aims to take the lead in exploration technology by setting new benchmarks for efficiency, reliability, & flexibility. This vision fits well with global trends toward automation and smart technologies, laying the groundwork for future innovations.

Chapter 2

LITERATURE REVIEW

Qin Zou et al., explained “SLAM is an important method used in indoor navigation for autonomous vehicles & robots. It helps create a global map of the environment. At the same time, the robot’s position & direction are determined. Recently, visual SLAM has seen improvements in its abilities. Still, it can have problems in low-texture places like warehouses with plain white walls. This makes finding locations accurately very tough. On the other hand, LiDAR SLAM is more robust. It uses 3D information from LiDAR point clouds, which is why it is often chosen for industrial uses, like AGVs. Even though several LiDAR SLAM methods have been developed over the years, it’s not always clear what their strengths & weaknesses are. This can confuse both researchers and engineers. To help with this, a comparison of different indoor navigation methods based on LiDAR SLAM is being done. There will also be extensive tests to check how they perform in the real world. The findings from this analysis will help both academic and industry researchers pick the best LiDAR SLAM system for their specific needs.” [1]

Rohit Roy et al., explained “This research introduces a motion control approach for IMRs. It uses e-SLAM techniques but has limited sensor tools—specifically, it relies only on LiDAR. The path planning starts with basic floor plans created as the IMR explores. It begins at reach points and moves through steps for both turning & straight-line motion. Eventually, this leads to calculated points that link the key spots. By using LiDAR data, the IMR learns about its position & surroundings over time. Notably, the upper sections of the LiDAR image focus on finding its location, while the lower parts deal with spotting obstacles. As it moves from one important point to another, the IMR must compile a complete LiDAR image to plan its path effectively. A major obstacle here is that LiDAR is the only reference for checking against the planned route based on the floor map. This makes it crucial to adjust for accurate distances related to that map and manage any deviations from the IMR's path to steer clear of barriers. There are important considerations around LiDAR settings too as well as controlling the speed of IMR. This study offers a thorough, step-by-step guide on how to carry out path planning & motion control using exclusively LiDAR data. Additionally, it combines various software parts while improving control strategies through trials with different proportional gains for position, direction, and speed of the LiDAR within the IMR system." [2]

Dong Shen et al., proposed a comparison of three different 2D-SLAM algorithms that use laser radar within the ROS. The algorithms under review are Gmapping, Hector-SLAM, & Cartographer. The focus is on how these algorithms help indoor mobile robots navigate in unknown environments. To make this comparison possible, a mobile robot platform was created using ROS. This setup allowed for tests in real-world conditions. Each SLAM algorithm's ability to create maps was evaluated through experiments conducted in a simple corridor and a lab with various obstacles. Moreover, ten unique points in the actual environment were chosen. We measured distances from the maps and compared them to those recorded by a laser range finder. This was done for error analysis. The results of these experiments helped to highlight the strengths and weaknesses of each SLAM algorithm. In summary, Gmapping shows the best mapping accuracy in basic, small-scene environments. On the other hand, Hector-SLAM is better suited for long corridor situations. Meanwhile, Cartographer has clear advantages when used in more complex surroundings. This analysis gives useful insights for both researchers & practitioners. It aids in choosing suitable SLAM algorithms for different robotic uses. [3]

Lili Mu et al., The system showcases contemporaneous Localization and Mapping (SLAM). It uses graph-grounded optimization. Different detectors are combined, similar to Light Detection and Ranging (LiDAR), a D camera, encoders, &

an Inertial Measurement Unit (IMU). This system is really at situating those four detectors together. It employs the UKF to reuse the 2D LiDAR and RGB-D camera point shadows. A fascinating point is how it handles 3D LiDAR points pall data generated from the RGB- D camera. This data is integrated into the SLAM process during the step called successional enrollment. By doing this, it effectively matches the 2D LiDAR information with the 3D RGB- D information. It uses CSM ways in this matching process. In addition, during circle check discovery, this system boosts delicacy for vindicating circle closures. It does so by furnishing detailed descriptions of the 3D point pall data after the original matching with 2D LiDAR. The viability and effectiveness of this multi-sensor SLAM frame have been completely tested. This was done through theoretical studies, simulation trials, & physical tests. The results from these trials show that this new SLAM approach achieves remarkable mapping issues, with great perfection & delicacy. Similar results punctuate its promising operations in advanced robotics. [4]

Misha Urooj Khan et al., provides an overview of contemporaneous Localization and Mapping (SLAM), fastening on its capability to achieve concurrent localization and chart creation through tone recognition. It highlights the rapid-fire advancements in LiDAR- grounded SLAM technology, driven by the wide relinquishment of LiDAR detectors across colourful technological sectors. The discussion begins with a relative analysis of different detector technologies, including radar, ultrawideband positioning, and Wi-Fi, emphasizing their functional significance in robotization, robotics, and other disciplines. A bracket of LiDAR detectors is also presented in irregular form for clarity. Later, the paper introduces LiDAR-grounded SLAM by outlining its general visual and fine modelling. It explores three crucial features of LiDAR SLAM — mapping, localization, and navigation — ahead concluding with a comparison of LiDAR SLAM against other SLAM technologies and addressing the challenges encountered during its perpetration. This comprehensive examination underscores the applicability and efficacity of LiDAR in advancing SLAM operations. [5]

Y. Li et al., presents a cost-effective and efficient solution for autonomous navigation robots in indoor environments, featuring a modular mobile robot platform with a divided control system to enhance stability and reduce module coupling. Utilizing Lidar and an RGB-D camera (Kinect) for environmental sensing, the robot's software is developed on the Robot Operating System (ROS), implementing a SLAM algorithm based on particle filters for accurate localization and mapping in unknown spaces. Experimental results confirm that this system can create a reliable map of the indoor environment and successfully perform autonomous navigation tasks, characterized by its low cost, high performance, short development cycle, and easy scalability. [6]

Wan Abdul Syaqur et al., emphasizes the importance of mapping in robot navigation through a project focused on Simultaneous Localization and Mapping (SLAM) using the GMapping approach. A Turtlebot equipped with a Hokuyo Laser Range Finder (LRF) URG-04LX-UG01 was employed for mapping in three different locations at UniMAP, which included both indoor and mixed indoor-outdoor environments. The findings reveal that the indoor maps generated were significantly more accurate than those created in outdoor settings due to the laser scanner's limitations in providing precise measurements outdoors, resulting in difficulties with scan matching. [7]

S. Gatesichapakorn et al., presents the implementation of an autonomous mobile robot using the Robot Operating System (ROS), featuring a 2D LiDAR and RGB-D camera integrated with the ROS 2D navigation stack, all powered by a low-cost onboard computer with minimal power consumption. Prioritizing safety for both property and humans, the system utilizes official ROS packages with slight parameter modifications, while facing challenges such as hardware limitations and system configurations. The proposed system includes two setups: one on a Raspberry Pi 3 with only 2D LiDAR and another on an Intel NUC that combines 2D LiDAR and an RGB-D camera. Usability testing across multiple experiments demonstrated the robot's ability to navigate dynamically and avoid obstacles or stop in unavoidable situations, followed by a discussion of the challenges encountered and their solutions. [8]

Yi Kiat Tee et al., provides a comprehensive review and comparison of prevalent 2D SLAM (Simultaneous Localization and Mapping) systems in indoor static environments, utilizing ROS-based SLAM libraries on an experimental mobile robot equipped with a 2D LIDAR, IMU, and wheel encoders. It examines three common algorithms—GMapping, Hector-SLAM, and Google Cartographer—which are classified as either filter-based or graph-based SLAM for metrical map generation. Results from identical robot trajectories in both simulated and real-world settings facilitate analysis under varying conditions. The paper highlights the strengths and weaknesses of each algorithm, visualizes differences in generated maps, and underscores the importance of selecting the appropriate system for specific applications while identifying potential future optimization avenues.[9]

X. Yang et al., explains the design of an indoor service robot utilizing the Robot Operating System (ROS). The robot employs a two-dimensional LiDAR as its primary sensor to gather depth information about its surroundings, while a particle filter-based SLAM algorithm is implemented for mapping the environment. Within the ROS framework, both the A* algorithm and the Dynamic Window Approach (DWA) algorithm are utilized to enable effective navigation capabilities. To validate the functionalities of path planning, local obstacle avoidance, and navigation, simulations are conducted in the Gazebo environment. [10]

X. P. Cu et al., showcases the application of accelerated testing aimed at predicting the lifespan of continuous tracks used in combat vehicles. These tracks consist of modular links that form a closed chain, with rubber bushes situated at the joints between adjacent links. Consequently, the durability of the tracks is primarily influenced by the longevity of these rubber bushes. In the experiments, modular track links equipped with rubber bushes are mounted on a specialized testing rig that enables continuous rotation of the bushes at angles that mimic actual operating conditions. The paper presents the results of these tests along with a thorough evaluation of the findings. [11]

Pedraza Yepes et al., addresses the design, simulation, and construction of a fuel storage tank-chassis coupled with a lifting system, which operates as a single unit alongside a Cummins QSK19 engine-driven HL260m pump. This system is capable of providing up to 12 continuous hours of operational autonomy and can be transported to various locations using lifting systems. The mechanical design adheres to the guidelines set by the American Institute of Steel Construction (AISC) and incorporates failure criteria for Von Mises ductile materials or Maximum Energy Distortion. The storage tank's dimensions are based on the average consumption specified by the manufacturer, and simulations were conducted using SolidWorks®. Ultimately, a functional and safe system suitable for on-site applications has been successfully developed. [12]

G. S. Wang et al., analyzes three factors contributing to the decreased shooting accuracy of a tank moving at high speeds, focusing on the linear vibration of its chassis. By examining real test data, the study reveals that the lateral shooting deviation caused by the chassis's linear vibration is minimal and does not significantly impair shooting accuracy. While this vibration has some effect on the imaging quality of the sighting telescope, it generally does not impact the sighting effectiveness. However, the more pronounced linear vibration of the crew seat results in poor ride comfort, making it challenging for the crew to accurately manipulate the sighting telescope, thereby affecting the overall sighting performance. Consequently, the primary influence of the linear vibration of the tank chassis on shooting accuracy is linked to its effect on ride comfort, which emerges as a critical factor in determining shooting accuracy while on the move. [13]

Lonare et al., explains that the chassis is fundamentally the base frame for various vehicles, such as automobiles, motorcycles, and carriages. Imagine it as a structural skeleton where multiple components of the vehicle are installed. When designing a chassis, several factors need to be taken into account, including material choice, strength, stiffness, and weight. For electric vehicles specifically, the most important criteria revolve around rigidity, strength, and cost-effectiveness. To meet the performance needs of the electric vehicle market, the chassis must be lightweight yet robust and durable. Given that the chassis supports a substantial amount of weight, it is regarded as one of the most vital elements of any vehicle, as it holds all the components and systems together. [14]

Chapter 3

PROJECT DESCRIPTION

3.1 Working Principle

The RAVEN's working principle is a combination of particulate processes which involves:

- **Data Acquisition:** The UGV improves situational awareness by using depth cameras and LiDAR to collect environmental data, ensuring precise navigation and effective obstacle detection through continuous sensor data acquisition.
- **Data Transmission:** Utilize the DDS provided by ROS2 for reliable and efficient data sharing, while establishing strong wireless connections to enable remote control and real-time tracking.
- **Localization:** Integrate depth camera and LiDAR data to enhance the robot's perception of its surroundings, and employ SLAM to create dynamic maps and localize the robot within them.
- **Data Storage:** While navigating, temporarily store data for quick processing, and keep sensor data and maps for future use and analysis.
- **Analysis and Visualization:** Utilize programs like rViz2 to visualize the robot's current state, surroundings, and mapping progress, while analyzing sensor data to identify and classify obstacles for informed navigation.
- **Path Planning:** Use Nav2 for dynamic path planning, enabling real-time navigation around obstacles, and implementing decision-making algorithms to adapt to complex environments and meet operational goals.

- **Feedback and Control:** Implement feedback systems to refine navigation for seamless operation, utilizing real-time sensor data to prevent collisions with both static and dynamic obstacles.

- **User Interaction:** Provide operators with a user interface to monitor environmental data and the robot's status, while allowing manual control when necessary to enhance flexibility and manage challenging tasks.

- **Safety Mechanisms:** Implement immediate stop features for safety in the event of detected anomalies, and use real-time sensor data to proactively avoid collisions during navigation.

To function, the UGV gathers real-time data from depth and LiDAR cameras, which are then relayed and analyzed to provide quick insights. GPS and odometry improve localization, and SLAM creates dynamic maps. Effective path planning is supported by NAV2, and real-time modifications are possible thanks to feedback systems. Through emergency procedures and power management, user features provide safety while enabling manual control and monitoring.

3.1.1 Block Diagrams

3.1.1.1 Hardware

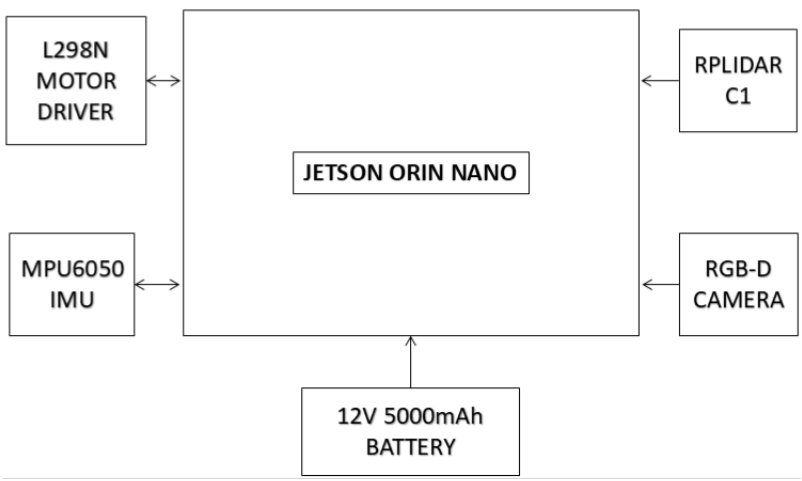


Figure 3.1: Hardware block diagram

3.1.1.2 System

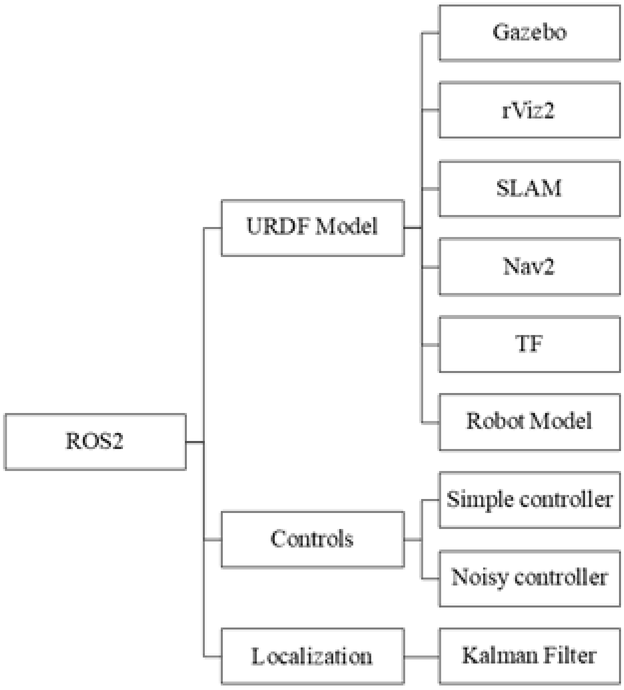


Figure 3.2: ROS2 system block diagram

3.1.1.3 URDF

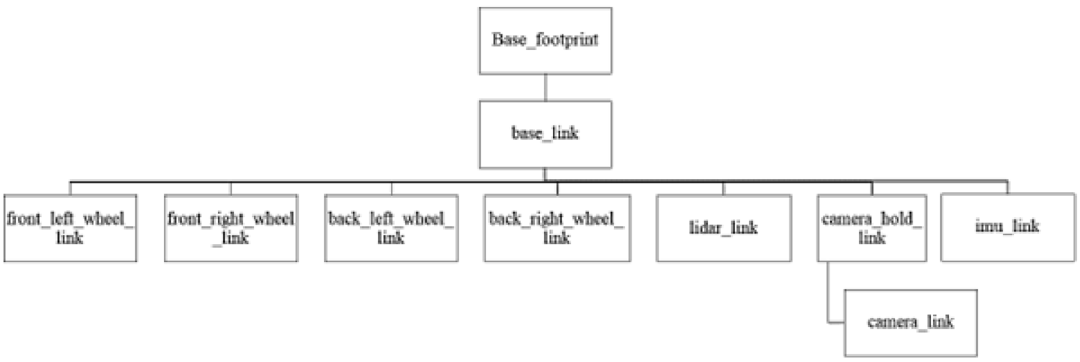


Figure 3.3: URDF system block diagram

3.1.2 Flow Chart

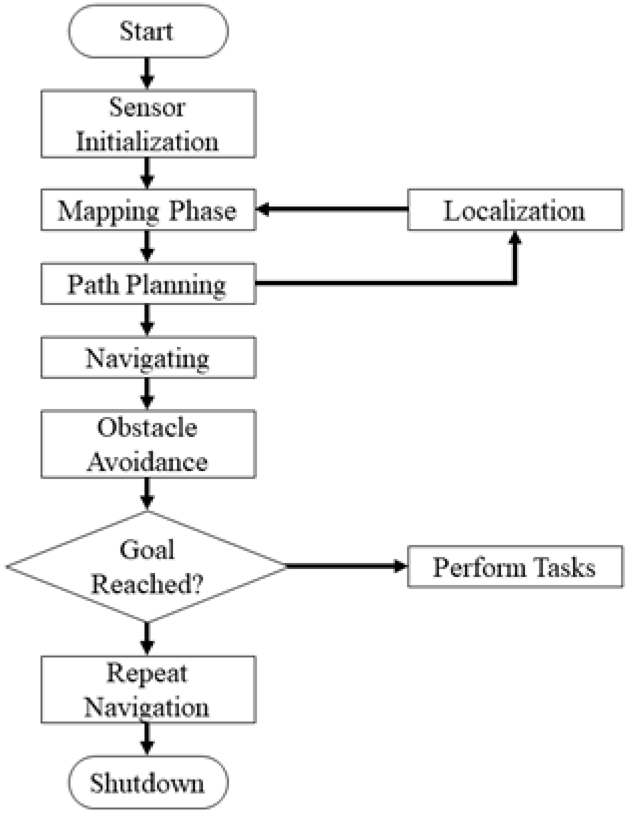


Figure 3.4: Flow chart representation

3.2 Hardware Requirements

The RAVEN robot is designed for advanced navigation and obstacle detection, making it an excellent platform for various applications in robotics and automation. To achieve its capabilities, RAVEN integrates a combination of cutting-edge hardware components that work together seamlessly. These components include powerful processing units, sophisticated sensors, and efficient power management systems, enabling RAVEN to perform complex tasks in real-time. The following list outlines the essential hardware that forms the backbone of this impressive robotic system. A list of the key hardware required are:

- Jetson Orin Nano

- Arduino Nano V3.0
- RPLIDAR C1
- Astra Pro Plus Depth Camera
- MPU6050 IMU
- L298N Motor Driver
- CHR-GM37-545 112RPM Geared Motor
- 7 Output USB 3.0 Hub
- 12V 5000mAh Battery

3.3 Hardware Design

The hardware design of RAVEN is meticulously crafted to ensure optimal performance, reliability, and versatility in various environments. The design encompasses several key elements:

1. **Structural Framework**
   - The robust chassis provides stability and maneuverability, allowing RAVEN to traverse diverse terrains effortlessly.
2. **Processing Unit**
   - Jetson Orin Nano, a powerful computing platform acts as the brain of RAVEN, enabling real-time data processing and complex decision-making for navigation and control.
3. **Sensing Capabilities**
   - A LiDAR is used for mapping and obstacle detection, the lidar sensor offers precise distance measurements to navigate surroundings.

- Depth Camera enhances the robot's vision capabilities, allowing for depth perception and object recognition.
- The Inertial Measurement Unit ensures that RAVEN maintains stability and orientation, crucial for smooth navigation.

4. **Power Management**

- A high-capacity battery is required to provide sufficient power for extended operation, ensuring that RAVEN can perform its tasks without interruptions.

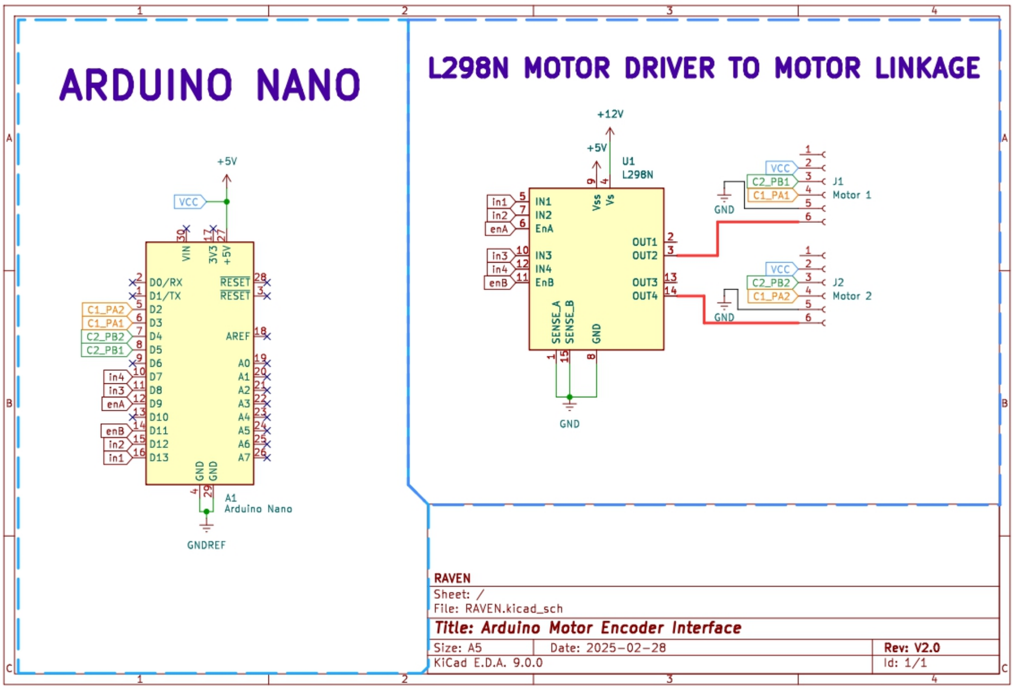


Figure 3.5: Circuit Diagram

3.4 Hardware Description

3.4.1 NVIDIA Jetson Orin Nano

The Jetson Orin Nano is a powerful and compact computing platform developed by NVIDIA, designed specifically for edge AI applications. It is part of the Jetson

Orin series, which is known for its advanced capabilities in processing AI workloads efficiently. Below are the specifications and key components of the Jetson Orin Nano:

1. **CPU**
   - Architecture: 6-core *Arm® Cortex®-A78AE* v8.2
   - Max Frequency: Up to 1.5 GHz
2. **GPU**
   - Architecture: 512-core *NVIDIA Ampere architecture GPU*
   - Tensor Cores: 16 tensor cores for enhanced AI performance
3. **Memory**
   - Size: 4GB 64-bit *LPDDR5*
   - Bandwidth: 34 GB/s
4. **Storage**
   - Internal Storage: 64GB eMMC 5.1
   - External Storage: Supports NVMe for additional storage options
5. **Power Consumption**
   - Power Range: 5W to 10W, allowing for flexible power management
6. **Connectivity**
   - PCIe: 1 x4 + 3 x1 (PCIe Gen3, Root Port, & Endpoint)
   - USB Ports: Includes a USB-C port for data transfer
   - Ethernet: Gigabit Ethernet Port for network connectivity
7. **Expansion**
   - 40-pin Expansion Header: For connecting additional peripherals and sensors
   - microSD Card Slot: For expandable storage options

8. **Video Encode/Decode**
    - Video Encode: Supports up to 2x 4K60 (H.265) and 4x 4K30 (H.265)
    - Video Decode: Capable of handling multiple high-definition streams
9. **Operating Temperature**
    - Range: Designed to operate in a wide temperature range
10. **Form Factor**
    - Compact design, suitable for embedded applications and robotics

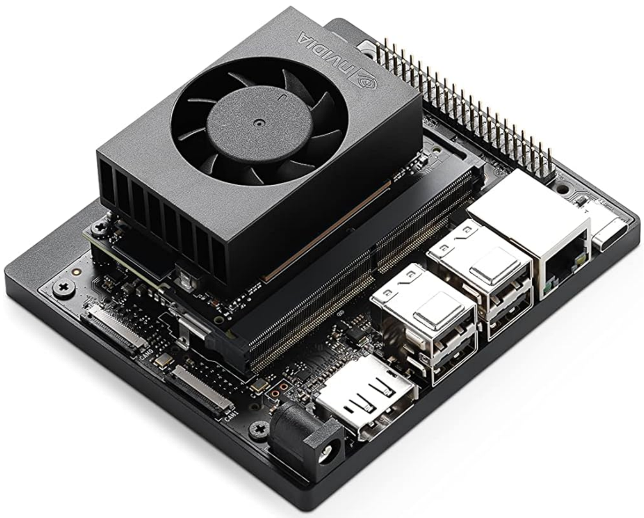


Figure 3.6: NVIDIA Jetson Orin Nano

3.4.2 Arduino Nano V3.0

The Arduino Nano is a compact and versatile microcontroller board based on the ATmega328 microcontroller. It is part of the Arduino family, which is widely used for building digital devices and interactive objects that can sense and control the physical world. The Nano is particularly popular among hobbyists and professionals for its small size and ease of use.

1. **Microcontroller**: ATmega328 (8-bit)
2. **Clock Speed**: 16 MHz

3. **Operating Voltage**: 5 V
4. **Input Voltage**:
   - Recommended: 7-12 V
   - Absolute Maximum: 6-20 V
5. **Digital I/O Pins**: 22 (of which 6 can be used for PWM output)
6. **Analog Input Pins**: 8 (10-bit resolution)
7. **Flash Memory**: 32 KB (of which 2 KB is used by the bootloader)
8. **SRAM**: 2 KB
9. **EEPROM**: 1 KB
10. **Power Consumption**: 19 mA (typical)
11. **PCB Size**: 18 x 45 mm
12. **Weight**: Approximately 7 grams
13. **USB Connection**: Mini-B USB connector for programming and power.

Figure 3.7: Arduino Nano V3.0

3.4.3 RPLIDAR C1

The RPLIDAR C1 is a next-generation, low-cost 360-degree 2D laser scanner developed by SLAMTEC. It is designed for various applications, including robotics, mapping, and navigation, providing high-resolution data with a compact and agile design. This device is particularly valued for its ability to perform accurate distance measurements and create detailed environmental maps.

1. **Measuring Distance**:
   - Maximum Range: Up to 12 meters
   - Minimum Range: Low blind range of only 0.05 meters
2. **Measuring Accuracy**: Approximately 30 mm
3. **Sampling Frequency**: 5,000 samples per second
4. **Scanning Frequency**: 10 Hz (10 scans per second)
5. **Field of View**: Full 360 degrees for omnidirectional scanning
6. **Power Supply**: Typical Operation is 5 V with low power consumption
7. **Dimensions**: Compact design suitable for integration
8. **Weight**: Lightweight for portability and ease of use

Figure 3.8: RPLIDAR C1

3.4.4 Astra Pro Plus Depth Camera

The Astra Pro Plus Depth Camera is a sophisticated device designed for 3D vision applications, making it ideal for robotics, augmented reality, and various computer vision tasks. This camera combines multiple technologies to capture depth information and RGB images, providing a comprehensive view of the environment.

1. **Depth Range**: From 0.6 to 8 meters (with a short range of 0.4 to 2 meters)
2. **Depth Resolution and Frame Rate**: 640 x 480 pixels at 30 frames per second (fps)
3. **Field of View (FOV)**:
   - Horizontal: 60°
   - Vertical: 49.5°
   - Diagonal: 73°
4. **RGB Resolution and Frame Rate**: 1920 x 1080 pixels at 30 fps
5. **Size**: 165 mm x 30 mm x 40 mm

6. **Components**: Color camera (RGB), infrared (IR) camera, infrared projector, and depth processor.

Figure 3.9: Astra Pro Plus Depth Camera

3.4.5 MPU6050 IMU

The MPU6050 is a popular 6-axis motion tracking device that combines a 3-axis gyroscope and a 3-axis accelerometer on a single chip. It is widely used in various applications, including robotics, drones, smartphones, and other devices that require motion sensing. The MPU6050 is known for its accuracy, compact size, and ease of integration with microcontrollers.

1. **Sensor Type**:
   - 3-axis Accelerometer: Measures acceleration in the X, Y, and Z axes.
   - 3-axis Gyroscope: Measures angular velocity in the X, Y, and Z axes.
2. **Accelerometer Specifications**:
   - Full Scale Range: ±2g, ±4g, ±8g, ±16g (configurable)
   - Sensitivity:
     - ±2g: 16384 LSB/g

- ±4g: 8192 LSB/g
- ±8g: 4096 LSB/g
- ±16g: 2048 LSB/g

3. **Gyroscope Specifications**:

   - Full Scale Range: ±250°/s, ±500°/s, ±1000°/s, ±2000°/s (configurable)
   - Sensitivity:
     - ±250°/s: 131 LSB/(°/s)
     - ±500°/s: 65.5 LSB/(°/s)
     - ±1000°/s: 32.8 LSB/(°/s)
     - ±2000°/s: 16.4 LSB/(°/s)

4. **Communication Interface**: I2C (Inter-Integrated Circuit) interface for easy communication with microcontrollers.
5. **Operating Voltage**: 3.3V to 5V (typically powered at 5V)
6. **Power Consumption**: Low-power operation: Approximately 5 mA in normal mode.
7. **Temperature Range**: -40°C to +85°C

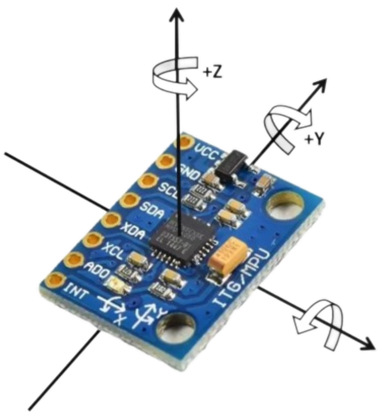


Figure 3.10: MPU6050 IMU

3.4.6 L298N

The L298N is a dual H-bridge motor driver that allows for the control of DC motors and stepper motors. It is widely used in robotics and automation projects to drive motors in both directions and control their speed. The L298N is popular due to its simplicity, flexibility, and ability to handle moderate power levels.

1. **Driver Type**: Dual H-Bridge (controls two DC motors or one stepper motor).
2. **Operating Voltage**: 5V to 35V (supply voltage for motors).
3. **Current Rating**:
   - Continuous Output Current: Up to **2A** per channel.
   - Peak Output Current: Up to 4A per channel (for short durations).
4. **Control Signals**:
   - Four input pins (IN1, IN2, IN3, IN4) to control the direction of the motors.
   - Two enable pins (ENA and ENB) to control speed using PWM (Pulse Width Modulation).
5. **Thermal Protection**: Built-in thermal shutdown protection to prevent overheating.
6. **Logical Voltage**: Typically 2.5V to 5V for control signals.
7. **Package Type**: Available in a 15-pin Multiwatt package or DIP package.

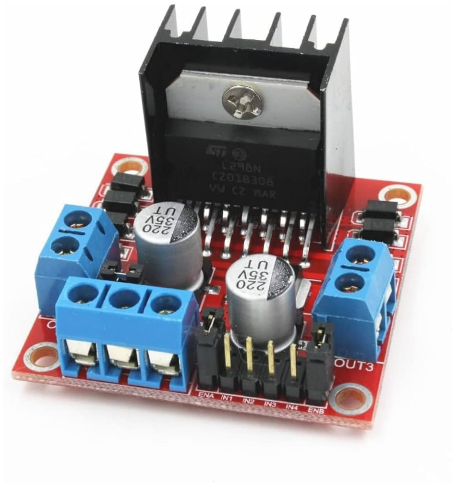


Figure 3.11: L298N

3.4.7 CHR-GM37-545 112RPM Geared Motor with encoder

The CHR-GM37-545 is a DC geared motor that features an integrated encoder, making it ideal for applications requiring precise speed and position control. This motor is particularly popular in robotics, automation, and various DIY projects due to its reliability and performance.

1. **Type**: DC Geared Motor with Encoder
2. **Speed**: 112 RPM at 12V
3. **Voltage Range**: Operates typically between 6V to 24V
4. **Output Shaft**:
    - Length: 21mm
    - Diameter: 6mm (D-type shaft)
5. **Torque**: Rated torque can vary, typically around 0.05N.m to 3.4N.m
6. **No Load Current**: lesser than equal to 0.2A to 0.4A
7. **Power**: Power ratings can be around 19W to 80W depending on the specific model and load conditions.

8. **Encoder Type**: Biphase Encoder with a basic signal voltage of 3.3V or 5.0V

9. **Weight**: Approximately 0.5 kg (varies by manufacturer)

3.4.8 7-port USB 3.0 hub

A 7-port USB 3.0 hub is a versatile device that allows you to expand the number of USB ports available on your computer or laptop, enabling you to connect multiple USB devices simultaneously

Figure 3.12: 7-port USB 3.0 hub

3.5 Software Requirements

A Jetson-based robot involves the integration of various software components and frameworks that facilitate the development, testing, and deployment of the robotics application. A list of the key software required are:

- NVIDIA JetPack SDK
- ROS2 Humble Hawksbill
- rViz2
- Joint State Publisher
- Gazebo

- PlotJuggler
- SLAM
- Nav2
- CMake
- VS Code

3.6 Software Design

The integration of URDF, RViz2, and Gazebo provides a comprehensive framework for designing, visualizing, and simulating robotic system.

1. **URDF structure**

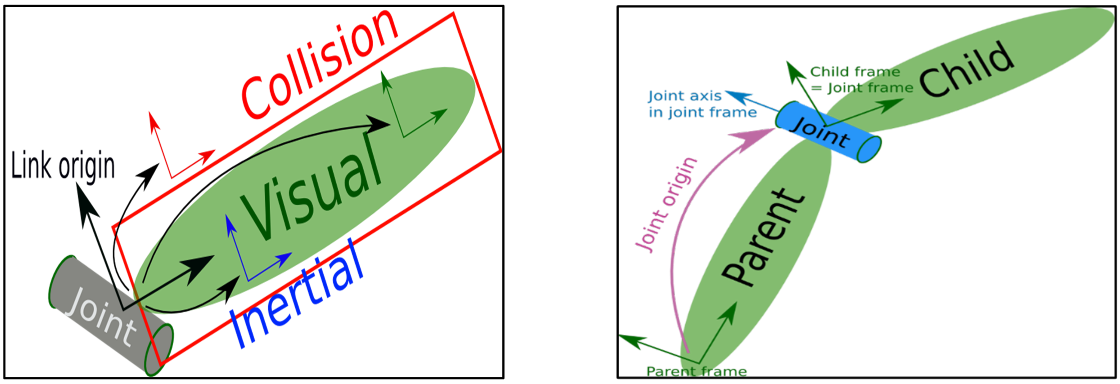
   It provides a clear and concise way to describe the various components of a robot, including its links and joints.

   - **Links:**
     - Each link represents a rigid body in the robot.
     - Links can have properties such as:
       * **Inertial properties:** Mass, center of mass, and inertia matrix.
       * **Visual properties:** Geometry (shapes like boxes, spheres, and meshes), colors, and textures.
       * **Collision properties:** Shapes used for collision detection.
   - **Joints:**
     - Joints define the relationship between two links and the type of movement allowed.
     - Types of joints include:
       * **Revolute:** A hinge joint that rotates around an axis with specified upper and lower limits.

- * **Continuous:** A hinge joint that rotates around an axis without limits.
- * **Prismatic:** A sliding joint that moves along an axis with specified upper and lower limits.
- * **Fixed:** A non-moving joint that locks all degrees of freedom, requiring no additional specifications.
- * **Floating:** A joint that allows motion in all six degrees of freedom.
- * **Planar:** A joint that permits movement within a plane perpendicular to the axis.

– Each joint should specify:

- * **Parent and child links:** Which links the joint connects.
- * **Axis of movement:** Direction in which the joint can move.
- * **Limits:** Maximum and minimum positions for joints that allow movement.



(a) Links Element **(b)** Joints Element

Figure 3.13: Links and Joints [15] [16]

2. **RViz2 visualization of the movement of links**

The RViz2 configuration include:

- Loading the URDF model to visualize the robot structure.
- Setting up appropriate displays for joint states and sensor data.

  - Configuring the frame of reference for accurate visualization.

3. **Gazebo (Simulation and Navigation)**

   - **SLAM (Simultaneous Localization and Mapping)**

     Gazebo is a robust simulation environment that allows for realistic robot modeling and testing. It integrates with ROS for powerful simulation features, including SLAM capabilities.

     – Supports various SLAM algorithms for mapping and localization.

     – Uses sensor data (e.g., LiDAR, camera) to create a map of the environment while keeping track of the robot's position within that map.

   - **Nav2 (Navigation Stack)**

     Nav2 is the navigation framework for ROS 2, enabling autonomous navigation for mobile robots. It includes several components for path planning, obstacle avoidance, and goal reaching.

     – **Global Planner:** Calculates an optimal path from the robot's current position to the desired goal.

     – **Local Planner:** Adjusts the robot's path in real-time, considering dynamic obstacles and the robot's kinematics.

     – **Costmaps:** Maintains a representation of the environment, including static and dynamic obstacles, to inform the planning process.

3.7 Software Description

3.7.1 NVIDIA JetPack SDK

The NVIDIA JetPack SDK is an essential software development kit for NVIDIA Jetson devices, providing the necessary tools and libraries to develop AI-based applications. Below are the specifications and key components of the JetPack SDK:

- **CUDA Toolkit:** Parallel computing platform and API model for GPU computing.

- **cuDNN:** GPU-accelerated library for deep neural networks, optimizing performance for training and inference.
- **TensorRT:** High-performance deep learning inference optimizer and runtime, enabling fast deployment of AI models.
- **VisionWorks:** A development package for computer vision applications, providing GPU-accelerated image processing.
- **OpenCV:** Library of programming functions for real-time computer vision, included in the JetPack SDK.
- **L4T:** An operating system that includes the necessary drivers and libraries for Jetson hardware.

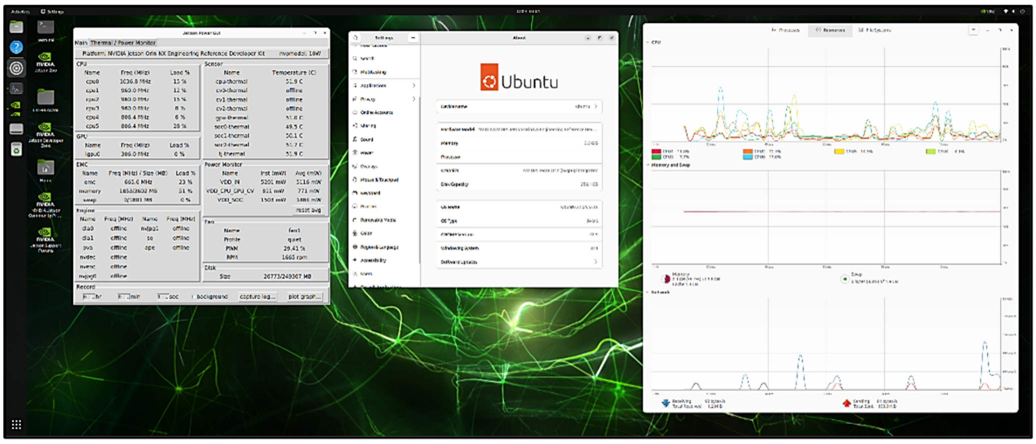


Figure 3.14: Ubuntu 22.04 with NVIDIA JetPack SDK

3.7.2 ROS2 Humble Hawksbill

ROS 2 Humble Hawksbill is the eighth release of ROS 2 and is notable for several key features and improvements. Below is an overview of its specifications and highlights:

- **LTS:** Supported until May 2027.
- **Ubuntu Compatibility:** Officially supports Ubuntu 22.04 (Jammy Jellyfish).

- **Enhanced Performance:** Improvements in real-time capabilities and inter-process communication.
- **New Packages:** Updates in navigation, perception, and robot control.
- **Documentation & Community:** Robust resources and support available.

Figure 3.15: ROS2 Humble [17]

3.7.3 rViz2

rViz2 is a powerful visualization tool designed for ROS 2. It allows users to visualize various types of data related to their robotic systems, making it easier to understand and debug complex interactions. Below are the key specifications and features of rViz2:

- **Graphical Interface:** Provides a user-friendly graphical interface to visualize robot models, sensor data, maps, and more.
- **Plugin Architecture:** Supports a wide range of plugins, enabling users to visualize different types of data and customize their workspace according to their needs.
- **3D Visualization:** Offers 3D visualization capabilities, allowing users to see their robot and environment more intuitively.
- **Frame Transformation:** The frame transformation library is pluggable, meaning users can load and change different transformation library plugins as needed.
- **Data Display:** Capable of displaying various data types, including point clouds, images, and robot states, which helps in monitoring and debugging.

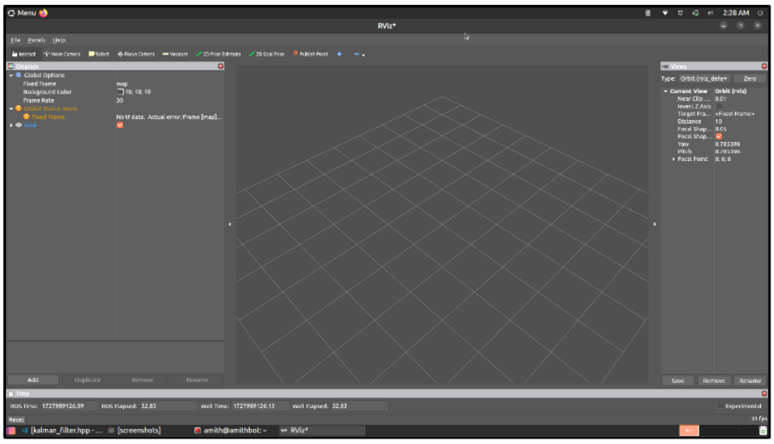


Figure 3.16: rViz2

3.7.4 Joint State Publisher

Joint State Publisher is a ROS 2 package that allows users to publish the state of a robot's joints. This tool is particularly useful in robotic applications for simulating and visualizing joint states. Below are the key specifications and features of the Joint State Publisher:

- **Joint State Publishing:** Publishes the state of all joints in a robot model, allowing for real-time monitoring and control.
- **GUI:** Includes a simple GUI that enables users to manually adjust the positions of the joints, facilitating interactive testing and visualization.
- **Integration with URDF:** Works seamlessly with URDF models, making it easy to visualize joint states based on the robot's configuration.

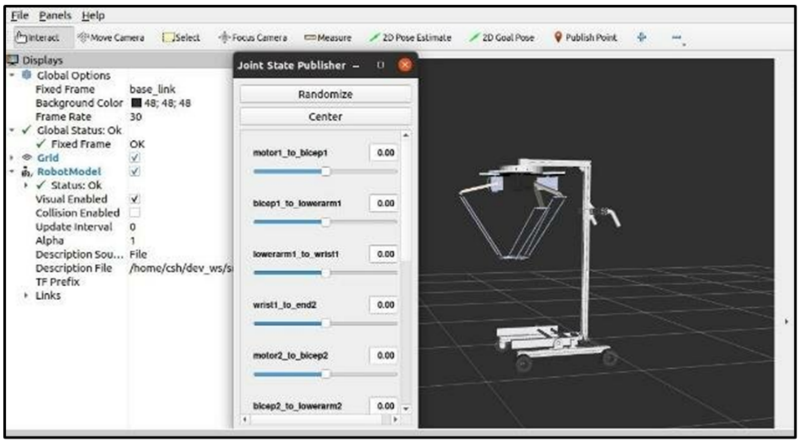


Figure 3.17: Joint State Publisher GUI [18]

3.7.5 Gazebo

Gazebo is a powerful simulation tool designed for testing robot models in complex environments. It provides advanced physics simulation, rendering capabilities, and a user- friendly interface. Below are the key specifications and features of Gazebo:

- **3D Simulation:** Offers high-fidelity 3D simulation of robots and their environments, allowing users to visualize interactions in real-time.
- **Physics Engines:** Supports multiple physics engines enabling accurate modeling of physical interactions such as collisions and gravity.
- **Sensor Simulation:** Simulates a variety of sensors including cameras, LIDAR, and IMUs, allowing for realistic testing of robotic perception and navigation.
- **Integration with ROS:** Fully compatible with ROS and ROS 2, facilitating easy integration of robotic algorithms with simulated environments.
- **World Building:** Provides tools for creating and editing complex environments with customizable terrains, obstacles, and lighting.

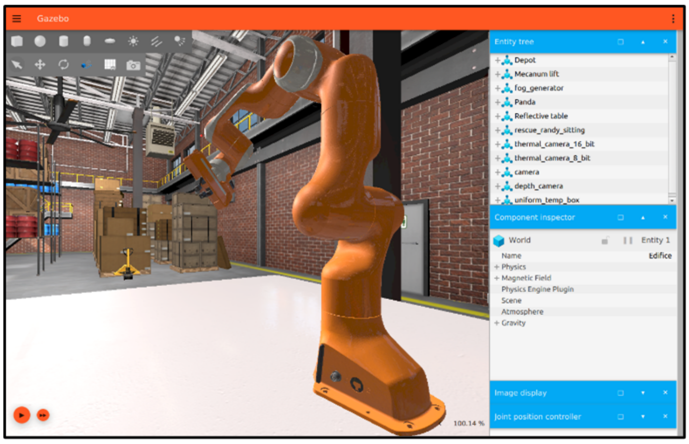


Figure 3.18: Gazebo interface [19]

3.7.6 PlotJuggler

PlotJuggler is a versatile tool designed for visualizing time-series data, particularly in robotics and simulation contexts. It allows users to plot, analyze, and interact with data streams in real time. Below are the key specifications and features of PlotJuggler:

- **Real-Time Data Visualization:** Supports real-time plotting of time-series data, making it ideal for monitoring robot states, sensor outputs, and other dynamic data.
- **Flexible Data Import:** Capable of importing data from various sources, including ROS topics, CSV files, and custom data streams.
- **Multi-Plot Capability:** Allows for multiple plots to be displayed simultaneously, enabling comparative analysis of different data streams.

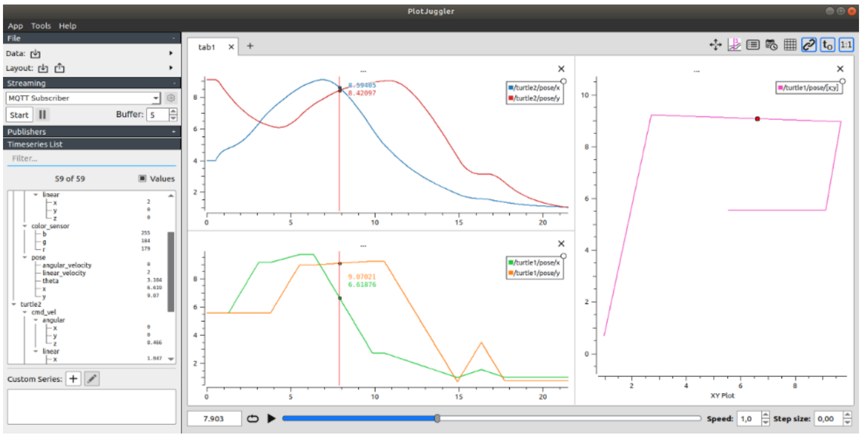


Figure 3.19: PlotJuggler [20]

3.7.7 SLAM

SLAM is a technology used in robotics and computer vision that allows a device to create a map of an unknown environment while simultaneously determining its location within that map. Here are the key specifications of SLAM systems:

- **Real-Time Processing:** Ability to process data and update maps in real-time, enabling immediate feedback and navigation.
- **Loop Closure Detection:** Recognizing previously visited locations to correct drift and improve map accuracy.
- **Data Association:** Matching measurements from sensors to features in the map to maintain consistency.
- **Scalability:** Effective performance in both small and large environments without significant loss of accuracy.

3.7.8 Nav2

Nav2 is a powerful navigation framework designed to enable mobile robots to navigate autonomously. Below are the key specifications and features of the Nav2 framework.

- **Global Planner:** Responsible for generating a global path from the robot's start position to the goal position and utilizes algorithms like A* or Dijkstra's for pathfinding.

- **Local Planner:** Handles real-time adjustments to the path based on dynamic obstacles and changes in the environment and works closely with the robot's sensors to ensure safe navigation.

- **Lifecycle Management:** Each component of Nav2 can be managed through a lifecycle interface, allowing for better control over the state of the navigation stack.

- **Sensor Integration:** Supports various sensor inputs, including LIDAR, cameras, and IMUs, for effective navigation in diverse environments.

- **Dynamic Reconfiguration:** Parameters can be adjusted at runtime without stopping the navigation process.

- **Behavior Trees:** Uses behavior trees for managing high-level navigation tasks, providing a clear structure for managing complex behaviors.

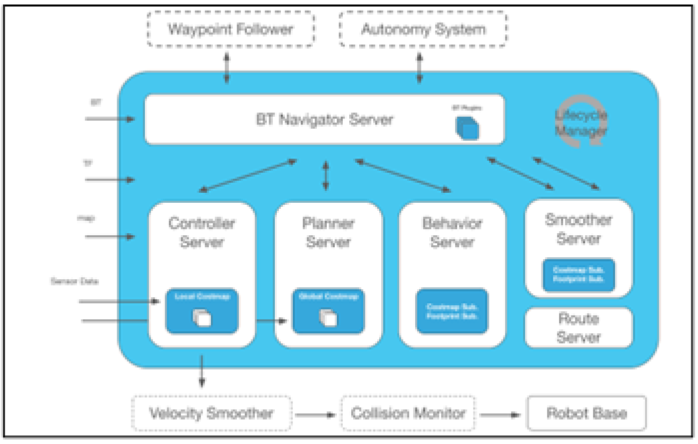


Figure 3.20: Nav2 architecture [21]

3.7.9 CMake

CMake is an open-source build system generator that uses a simple configuration file to manage the build process of software projects across different platforms. It is widely used in the C++ community for managing project dependencies and building applications. Below are the key features of CMake.

- **Cross-Platform Support:** CMake can generate build files for various platforms, including Windows, Linux, and macOS, allowing for consistent builds across different environments.
- **Build System Generation:** Supports multiple build systems, such as Makefiles, Ninja, Visual Studio, and Xcode, enabling developers to choose their preferred environment.
- **Dependency Management:** Facilitates the management of project dependencies, allowing for easy inclusion of external libraries and packages.
- **Modularization:** Supports the creation of modular projects with subdirectories and separate *CMakeLists.txt* files for each module.

3.7.10 VS Code

VS Code is a popular, open-source code editor developed by Microsoft. It is designed to be lightweight yet powerful, providing developers with a variety of features to enhance productivity. Below are the key specifications and features of Visual Studio Code.

- **IntelliSense:** Provides intelligent code completion, parameter info, quick info, and member lists, enhancing coding efficiency.
- **Debugging:** Built-in debugging support for various programming languages, allowing developers to set breakpoints, inspect variables, and navigate through code.
- **Extensions and Customization:** A rich ecosystem of extensions available through the Visual Studio Code Marketplace to add functionality, including support for additional languages, themes, and tools.

- **Integrated Terminal:** Built-in terminal support that allows users to run command-line tools directly within the editor, streamlining the development workflow.

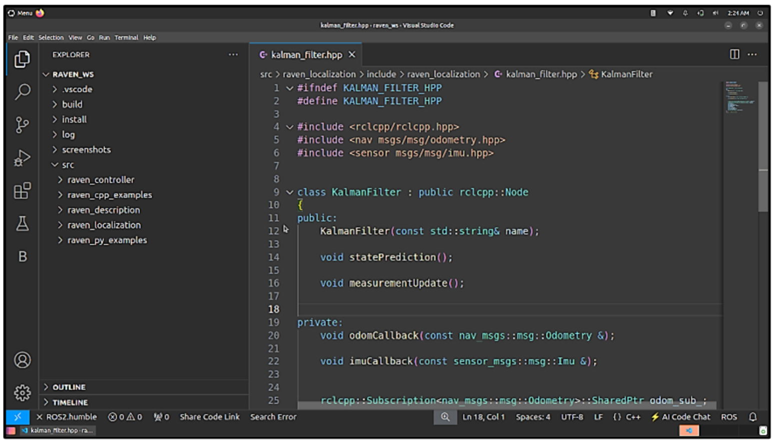


Figure 3.21: VS Code user interface

Chapter 4

RESULTS AND DISCUSSIONS

1. **URDF created:** URDF (Unified Robot Description Format) is an XML format used to describe the physical configuration of a robot, including its joints, links and visual representations.

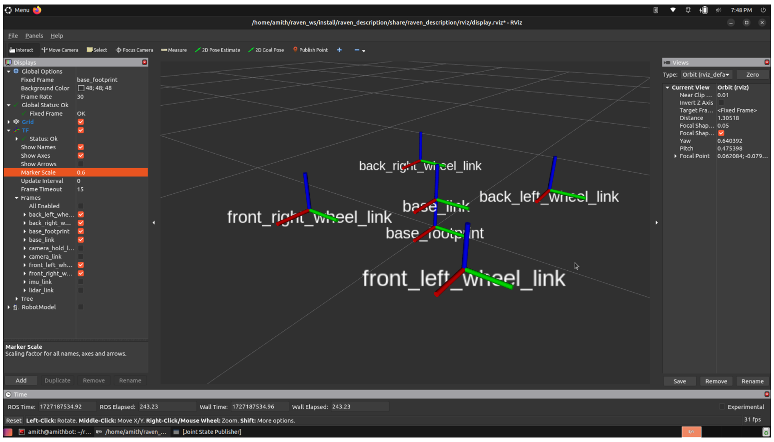


Figure 4.1: Transform links of the URDF

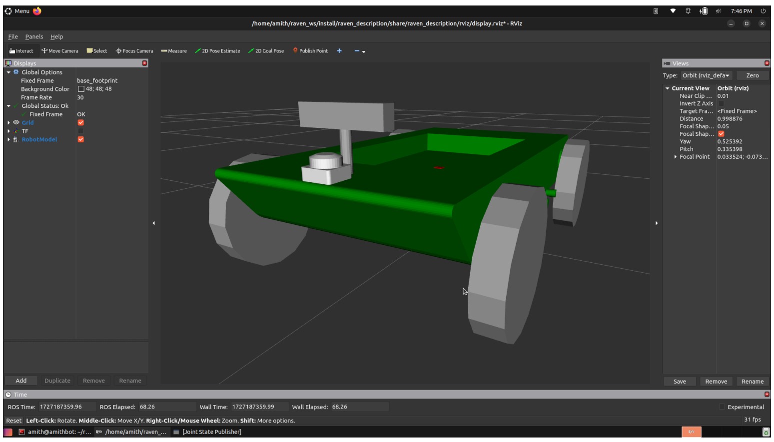


Figure 4.2: Robot model of the URDF

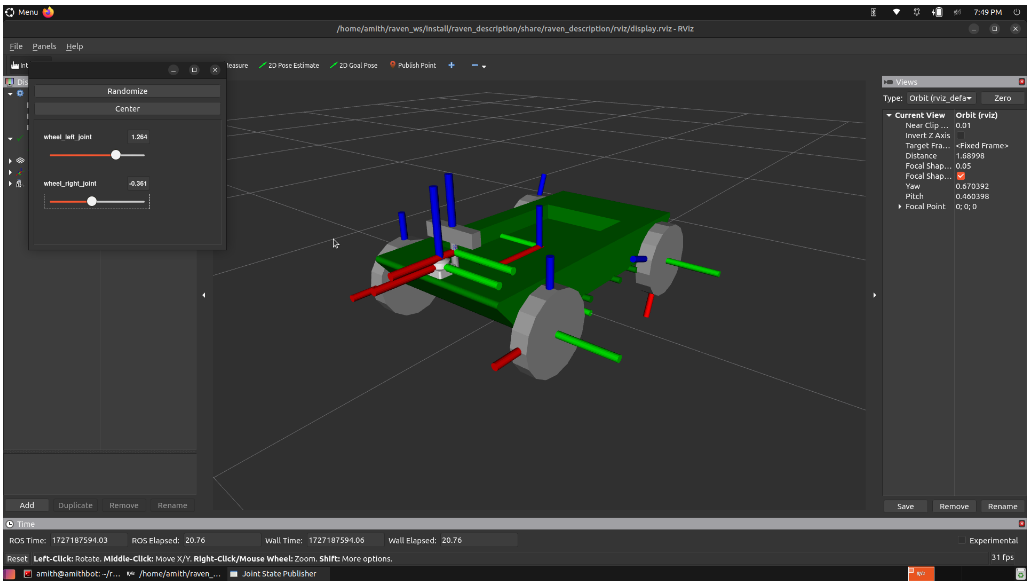


Figure 4.3: Joint State Publisher GUI

2. **Robot visualization launch file created:** This is a configuration file used to start a visualization environment, allowing users to see the robot model in a graphical interface, typically using tools like Rviz.

3. **GAZEBO simulation launch file created:** A launch file for Gazebo, a robotics simulator that enables the testing of robotic algorithms in a 3D environment, providing realistic physics and sensor feedback.

4. **Simple controller:** A basic control algorithm that manages the robot's movements, typically involving direct input-output relationships without complex decision-making processes.

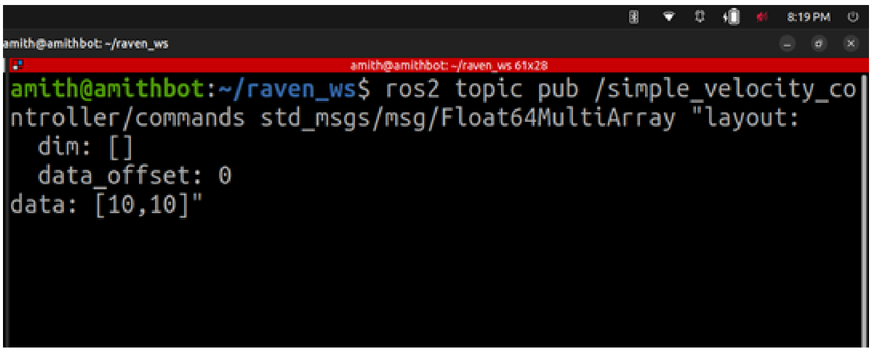


Figure 4.4: Simple controller command

5. **Differential drive controller:** A control system specifically designed for robots with a differential drive mechanism, allowing them to navigate by varying the speed of each wheel independently.

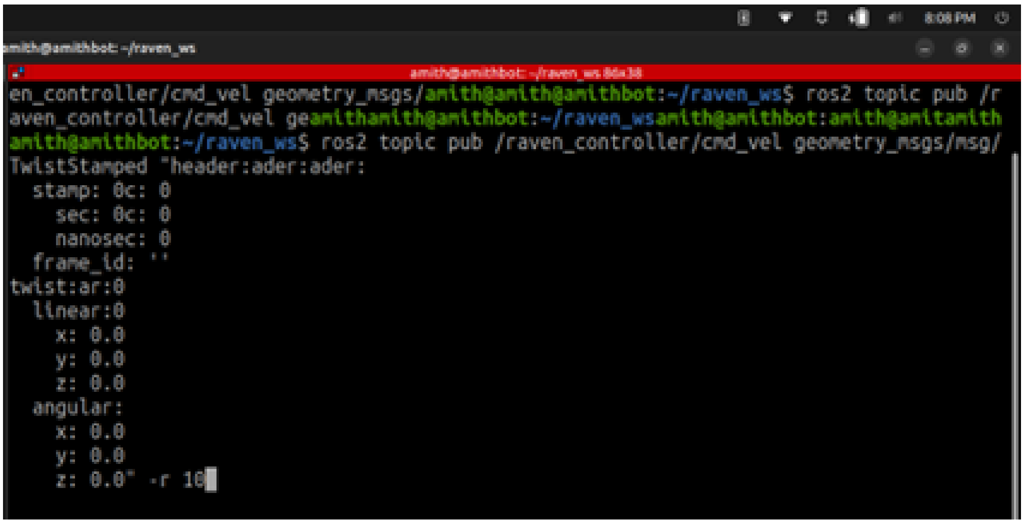


Figure 4.5: Differential drive controller command

6. **Noisy controller:** A controller designed to handle and compensate for noise in sensor data or actuator performance, ensuring more stable and reliable robot behavior during operation.

7. **Kalman Filter:** An algorithm used for estimating the state of a dynamic system from a series of incomplete and noisy measurements, commonly used for sensor fusion in robotics.

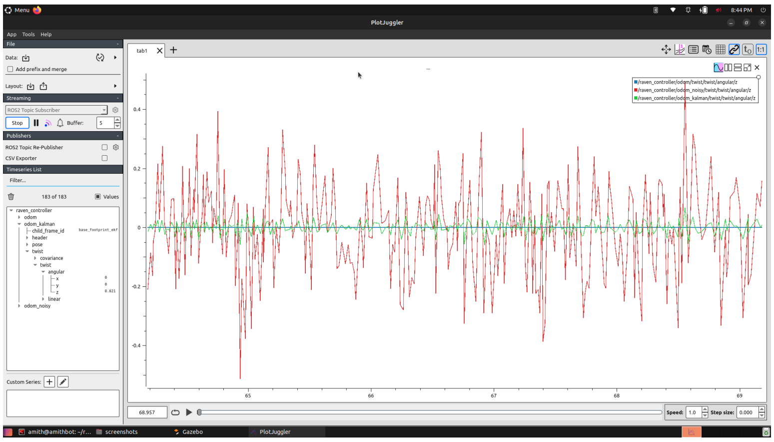


Figure 4.6: Kalman filtering the odometry values

8. **Sensor integration:** The process of combining data from various sensors (e.g., LiDAR, cameras) to provide a comprehensive understanding of the robot's environment and enhance its decision-making capabilities.

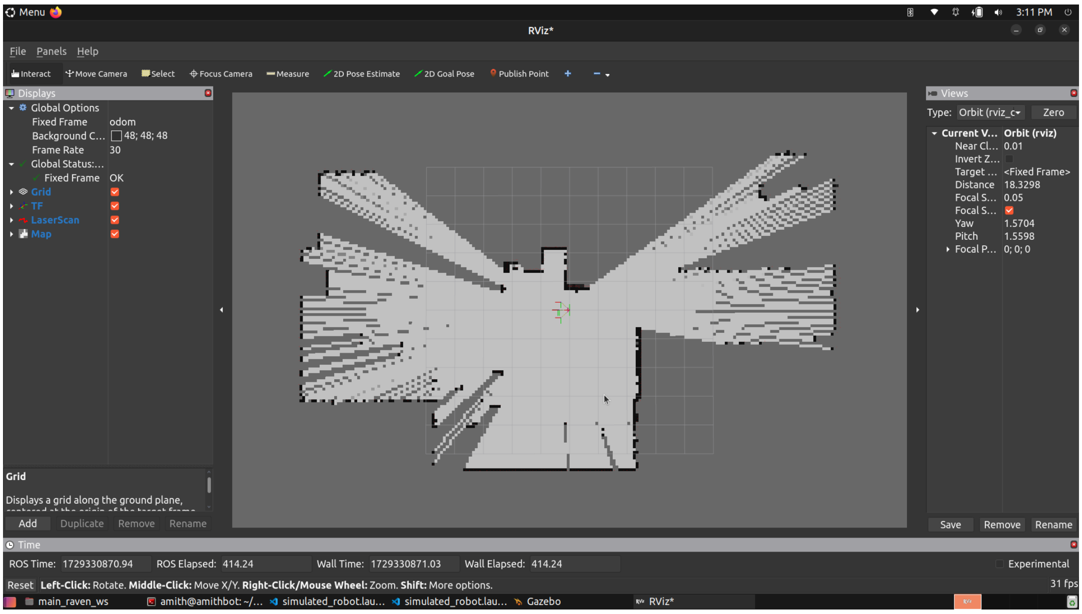


Figure 4.7: LiDAR mapping

9. **Joystick Teleoperation:** A method for controlling the robot remotely using a joystick. Enables manual control of the robot's movements and actions.

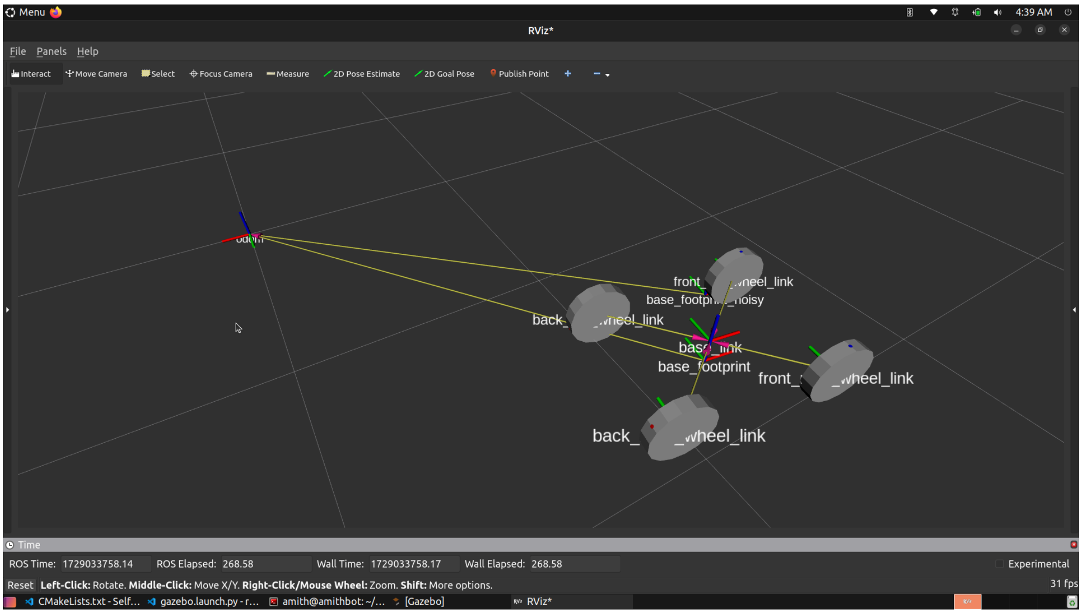
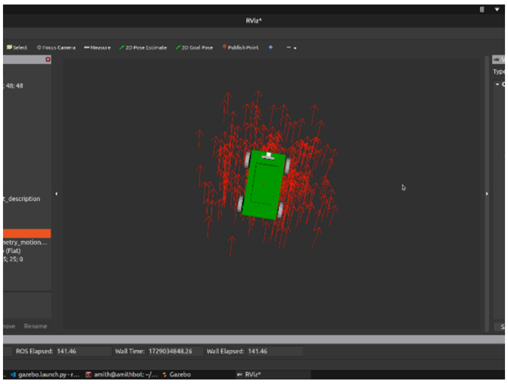
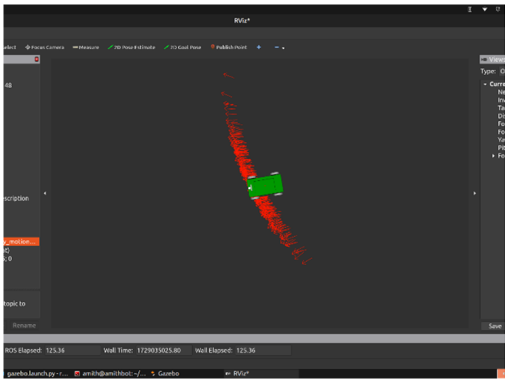


Figure 4.8: Joystick teleoperation

10. **NAV2 based simulation:** Utilizing the Navigation 2 framework for simulating robot navigation tasks, including path planning, obstacle avoidance, and goal reaching, typically in a simulated environment.



(a) Linear pose estimation



(b) Angular pose estimation

Figure 4.9: Pose estimation

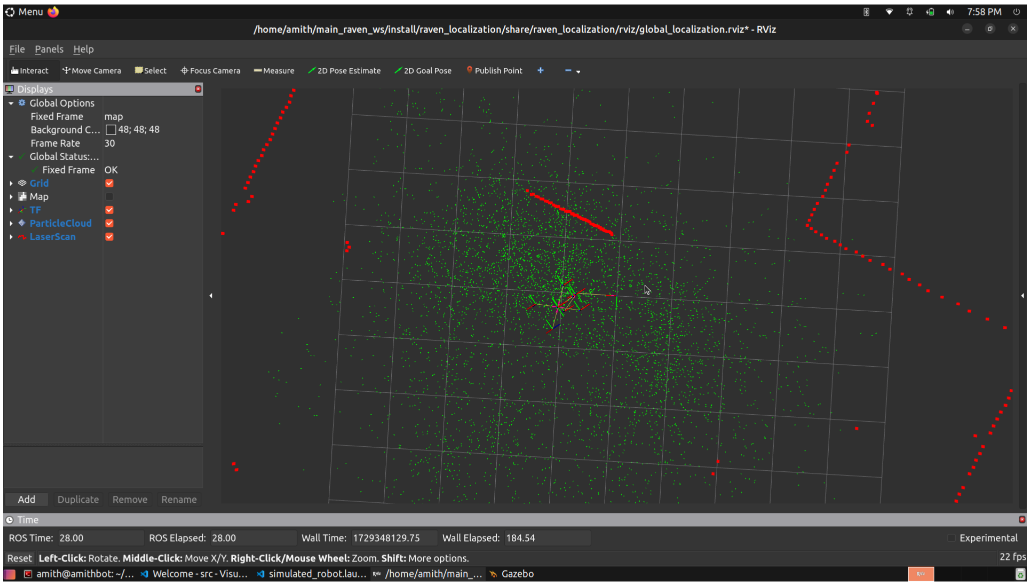
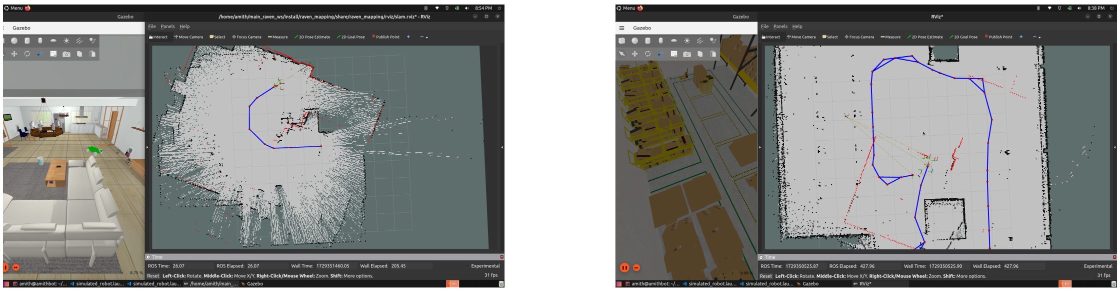


Figure 4.10: Nav2 AMCL

11. **SLAM simulation:** SLAM (Simultaneous Localization and Mapping) involves creating a map of an unknown environment while simultaneously keeping track of the robot's location within that environment, typically simulated in a controlled setting.



(a) Low accuracy SLAM **(b)** High accuracy SLAM

Figure 4.11: SLAM

12. **Final Robot firmware launch file created:** A launch file that initializes and executes the final firmware code on the robot, encompassing all necessary configurations and parameters for the robot to operate effectively in real-world scenarios. These components collectively contribute to the overall functionality and performance of the robotic system under development. *"simulated_robot.launch.py"*.

13. **IMU Simulation in WOKWI:** A simulation environment for testing and validating IMU (Inertial Measurement Unit) functionality using WOKWI. This setup allows for real-time testing of IMU data processing and integration before hardware deployment.

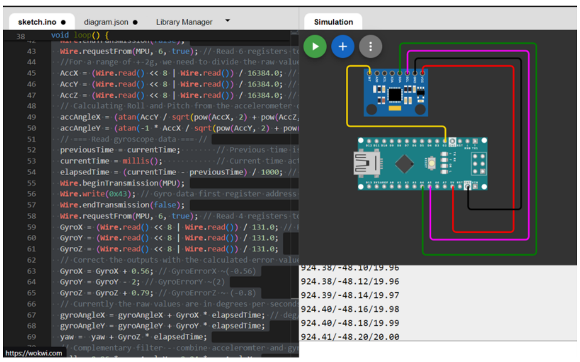


Figure 4.12: IMU Simulation in WOKWI

14. **IMU Interfacing with Arduino Nano:** A demonstration of IMU integration with an Arduino Nano microcontroller. This setup enables the collection and processing of IMU data for motion tracking and orientation estimation in small-scale robotics applications.

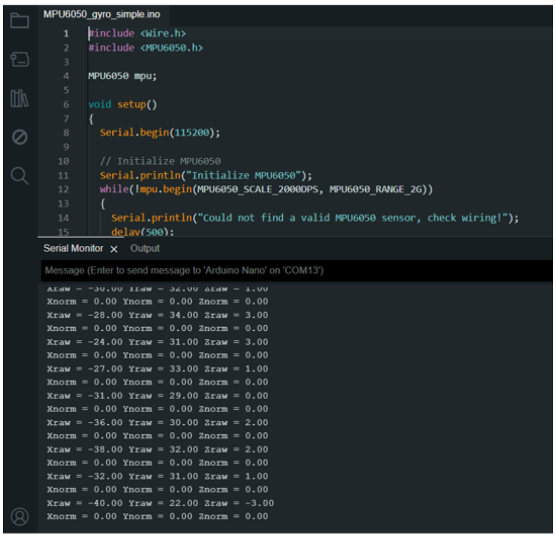


Figure 4.13: IMU Interfacing with Arduino Nano

15. **IMU Interfacing with Jetson Orin Nano:** A high-performance IMU integration with the Jetson Orin Nano platform. This configuration supports advanced data processing and real-time analytics for robotics applications requiring high computational power.

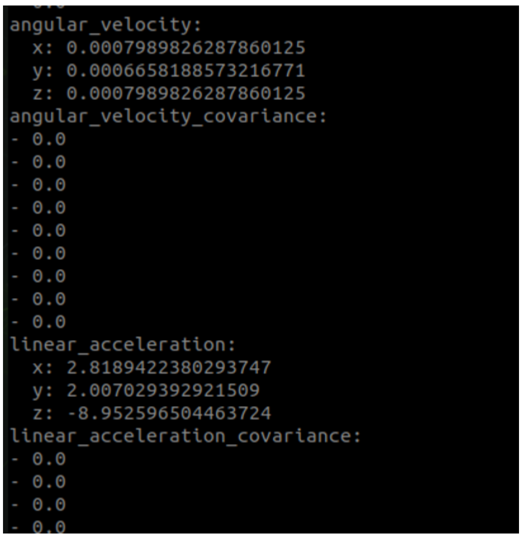


Figure 4.14: IMU Interfacing with Jetson Orin Nano

16. **IMU Interfacing and Visualization:** A visualization of IMU data using RVIZ, a robotics visualization tool. This setup provides real-time feedback on IMU orientation and motion, aiding in system calibration and performance monitoring.

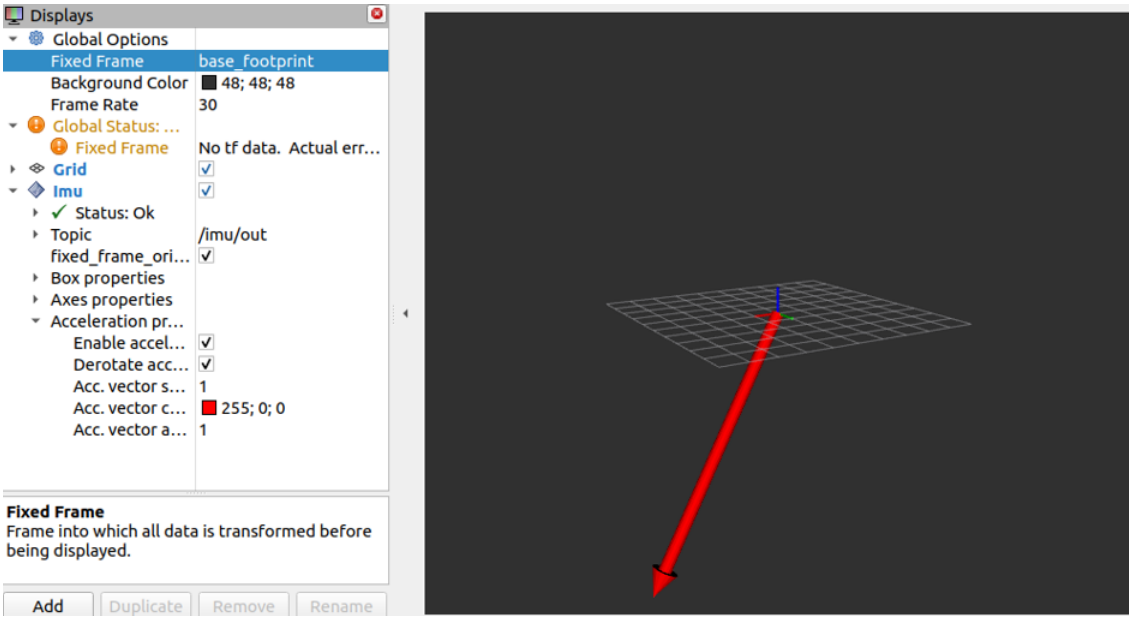
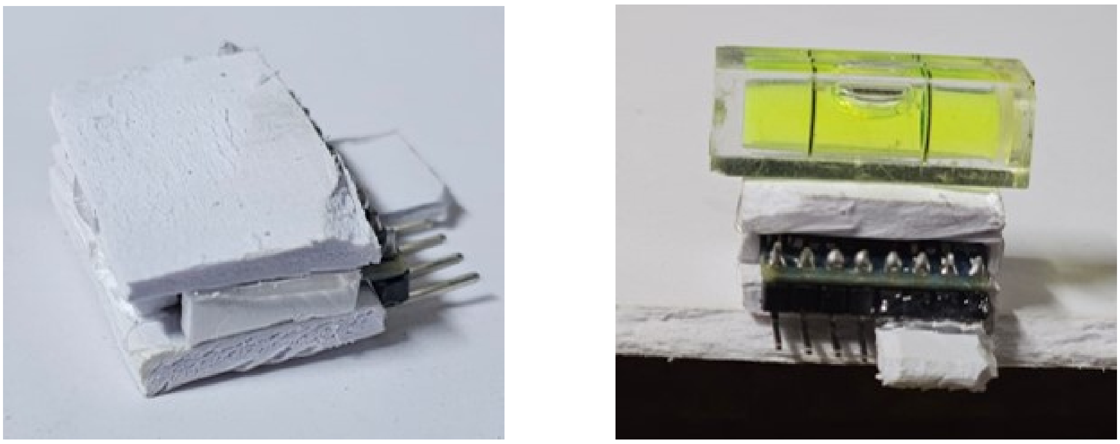


Figure 4.15: IMU Interfacing and Visualization

17. **IMU Structure Calibration:** A detailed process of calibrating the IMU holder to ensure accurate sensor alignment and leveling. Proper calibration is critical for precise motion tracking and orientation estimation in robotics applications.



(a) IMU holder **(b)** IMU holder leveling

Figure 4.16: IMU Structure Calibration

18. **Internal System Wiring:** Internal system wiring organizes electrical connections for reliable communication between components, enhancing reliability and simplifying troubleshooting. Clear documentation supports integration, maintenance, and performance monitoring.

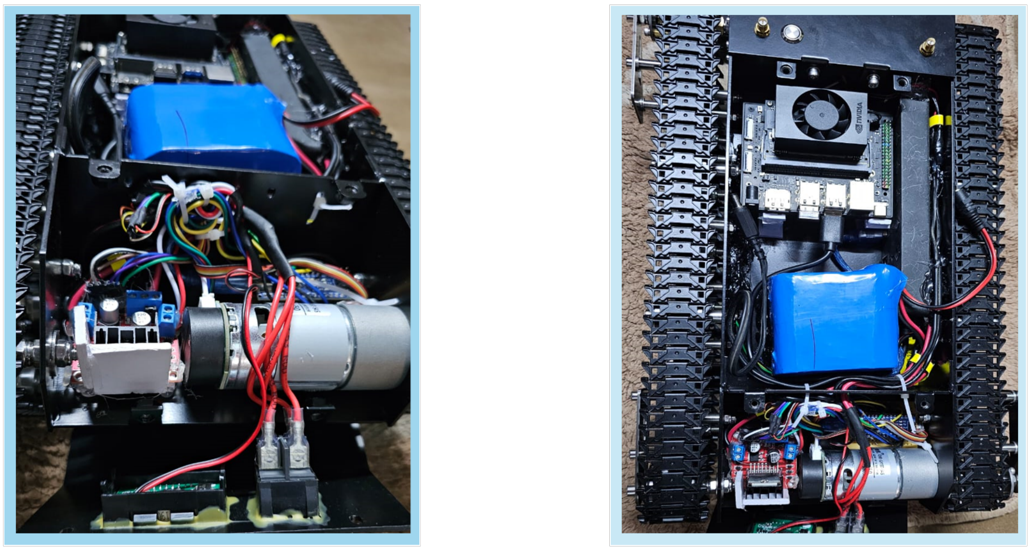


Figure 4.17: Internal System Wiring

19. **RPLIDAR Placement:** Strategic RPLIDAR placement ensures optimal scanning, minimizes obstructions, and enhances mapping and navigation. Key considerations include height, angle, and stable mounting to maximize performance and ensure consistent data collection.

Figure 4.18: RPLIDAR Placement

Chapter 5

FUTURE SCOPE

The RAVEN holds substantial potential for growth and innovation across various sectors. By leveraging advanced technologies and integrating cutting-edge solutions, RAVEN can significantly enhance its capabilities and expand its impact. This project not only addresses immediate needs in areas such as search and rescue operations but also opens avenues for applications in agriculture, environmental monitoring, and community engagement. Here are some key areas where RAVEN could evolve and expand its impact:

1. Advanced Technologies Integration

- **AI and Machine Learning:** Incorporating AI algorithms for better data analysis and decision-making in search and rescue missions.
- **Enhanced Sensors:** Development of more sophisticated sensors that can detect a wider range of environmental variables and hazards.

2. Autonomous Operations

- **Improved Autonomy:** Enhancing RAVEN's ability to navigate complex and hazardous environments without human intervention, increasing safety for rescue teams.
- **Swarm Robotics:** Utilizing multiple RAVEN units working collaboratively to cover larger areas more effectively.

3. Cross-Sector Applications

- **Agricultural Monitoring:** Expanding RAVEN's capabilities to assist in precision agriculture by monitoring crop health and optimizing resource use.

- **Environmental Conservation:** Using RAVEN technology for monitoring ecosystems, wildlife tracking, and supporting conservation efforts.

4. **Community Engagement and Empowerment**

   - **Local Training Programs:** Developing training programs for local communities to effectively use RAVEN technology in emergencies.
   - **Public Awareness:** Initiatives to raise awareness about RAVEN's capabilities and benefits, fostering community support and trust.

5. **Global Collaboration**

   - **Partnerships with Organizations:** Collaborating with NGOs, government agencies, and private sectors to enhance RAVEN's applications and reach in various regions.
   - **International Deployments:** Expanding RAVEN's use in international disaster relief efforts, especially in areas prone to natural disasters.

6. **Sustainability Focus**

   - **Eco-Friendly Operations:** Developing RAVEN to operate with minimal environmental impact, using renewable energy sources for power.
   - **Resource Management:** Utilizing RAVEN for monitoring and managing natural resources sustainably, contributing to long-term ecosystem health.

7. **Innovation in Data Utilization**

   - **Real-Time Data Sharing:** Implementing platforms for real-time data sharing among rescue teams, agencies, and communities.
   - **Predictive Analytics:** Leveraging gathered data to predict potential natural disasters or emergencies, enabling proactive measures.

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