Visual Navigation in Autonomous Vehicles

Team Members
1906A033 Dilruba CANKURT
2006A022 Ceyda BİBER

Advisor: Asst. Prof. Ertuğrul BAYRAKTAR

INTRODUCTION

- 4-wheeled, multi-purpose autonomous mobile robot.
- Explores unknown places and monitors its environment.
- Navigates autonomously.
- Avoids obstacles.
- Maps surroundings accurately.

system introduction video

PROJECT TIMELINE

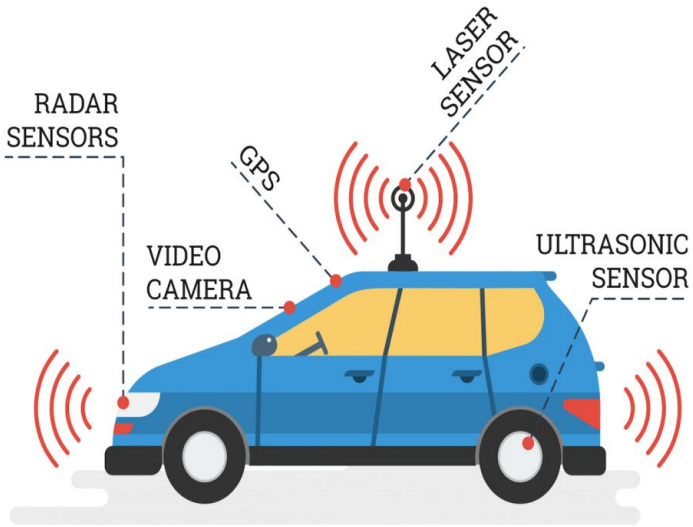
Team

Dilruba Cankurt

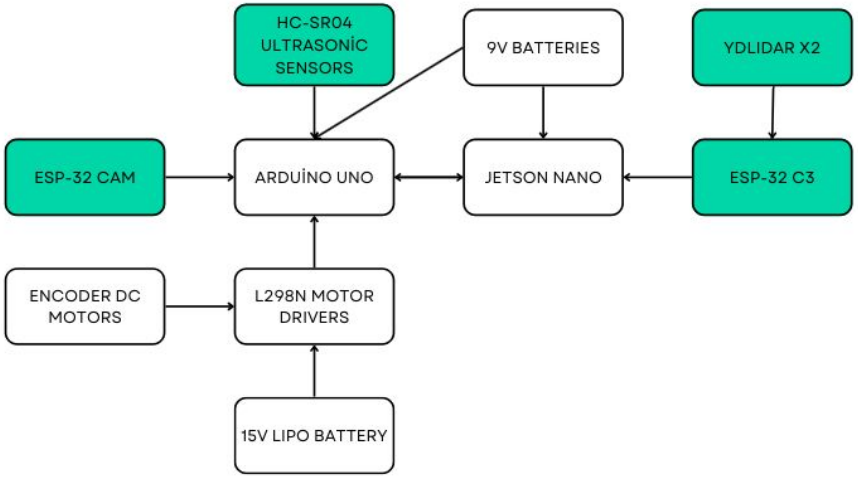
Ceyda Biber

OBJECTIVE

The initial objective of our project was to develop a robust SLAM (Simultaneous Localization and Mapping) system using data from various sensors, including camera, radar, LiDAR, and IMU, to ensure reliable operation under adverse weather conditions. However, due to budget constraints, we were unable to procure the necessary radar equipment. Consequently, we adapted our approach to implement a LiDAR-based SLAM system with obstacle avoidance using ultrasonic radar sensors. This adjustment allowed us to achieve reliable environmental mapping and navigation while utilizing available resources effectively.



System Overview

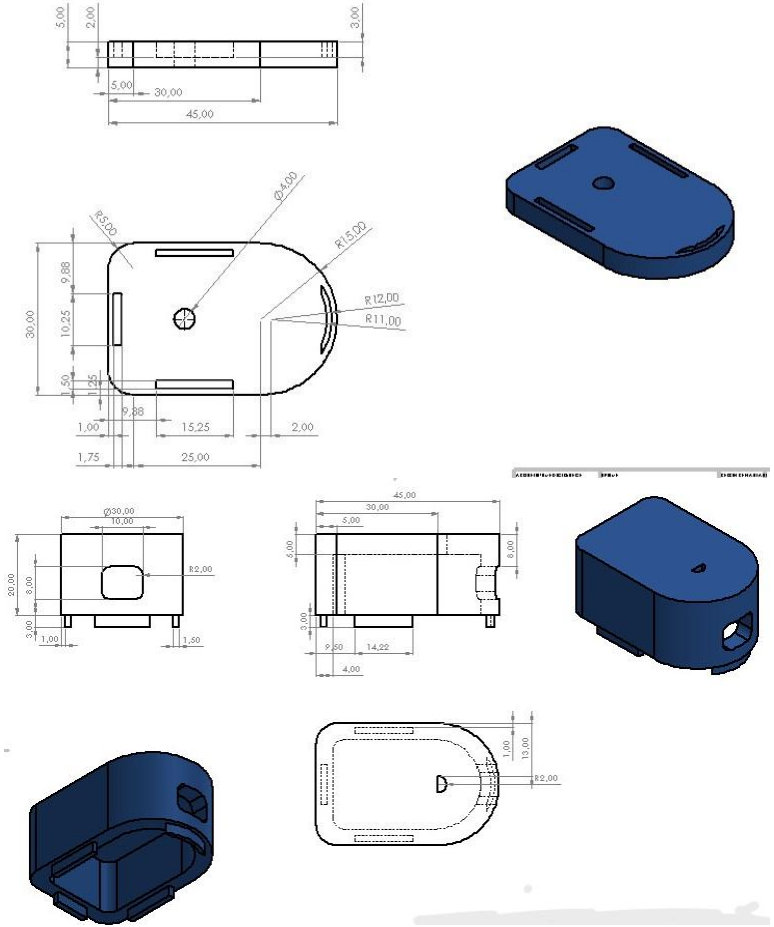


Our 4-wheeled autonomous robot explores unknown places and monitors its environment. It features the YDLidar X2 for mapping, HC-SR04 Ultrasonic Sensors for obstacle avoidance, and the ESP-32 CAM for image capture. Controlled by an Arduino Uno and a Jetson Nano, it uses 9V batteries for sensors and a 15V LiPo battery for motors. This setup allows the robot to navigate, avoid obstacles, and map surroundings efficiently.

MECHANICAL DESIGN

TECHNICAL DRAWING

Our design comprises two main parts: the body and the chassis. We've adopted a plug-and-play approach for easy and flexible installation. The body seamlessly mounts onto the chassis, ensuring a perfect fit. The body features holes on each side for wheel connection to the internal motors. Additionally, there's a discrete hole at the top for lidar connection to the main circuitry. For camera and ultrasonic radar views, there's a window opening at the front.

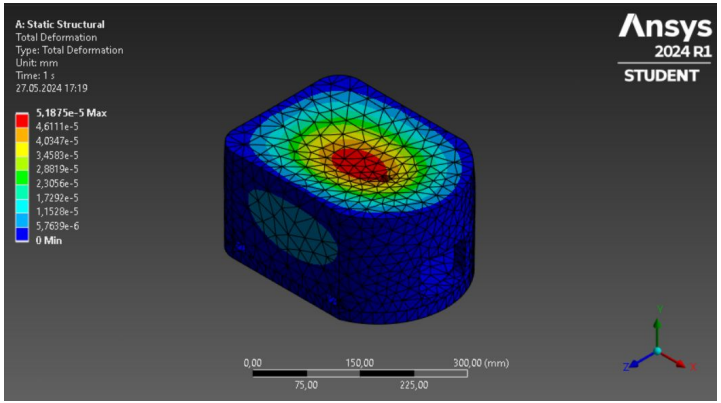


MECHANIC TEST

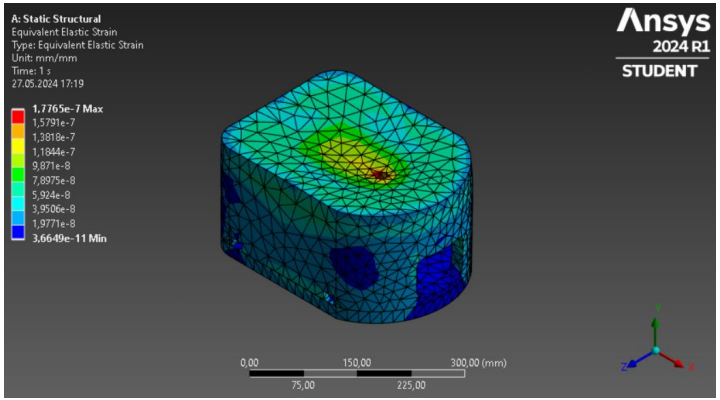
Using ANSYS software, we evaluated the robot's structural behavior under various forces from falling objects. The analysis parameters included force ranges for different objects: bricks (20-80 N), wood beams (50-200 N), door beams (130-350 N), stones (40-150 N), and tree branches (30-120 N). A 3D model from SolidWorks was imported into ANSYS, where material properties were defined, the model was meshed, and the forces were applied.

The analysis showed that maximum deformation occurred at force application points but remained within acceptable limits. The von Mises stress distribution identified critical regions, with material properties staying within safe limits. These results confirm that the robot body can safely operate under the specified force ranges, maintaining structural integrity even under the highest expected forces.

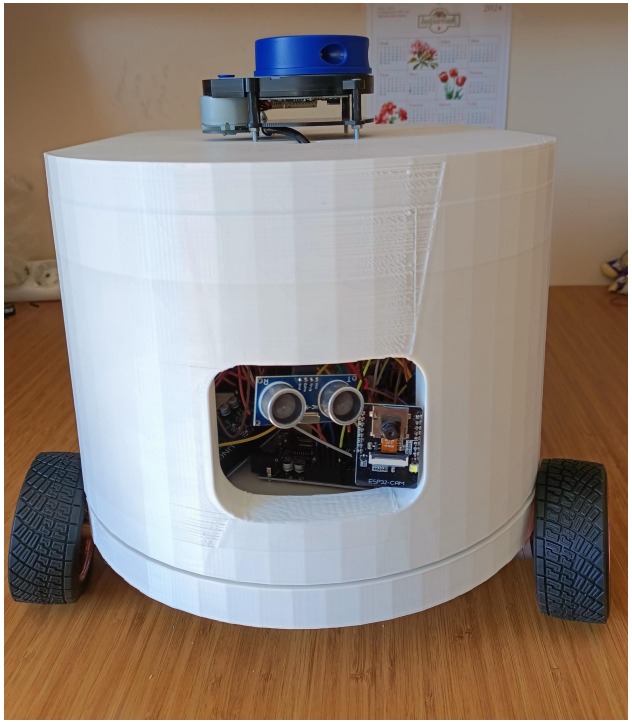
total deformation under 65N

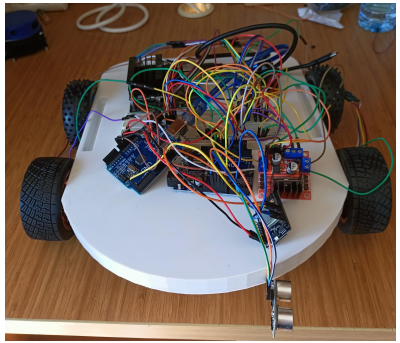


total strain under 65N



ASSEMBLY

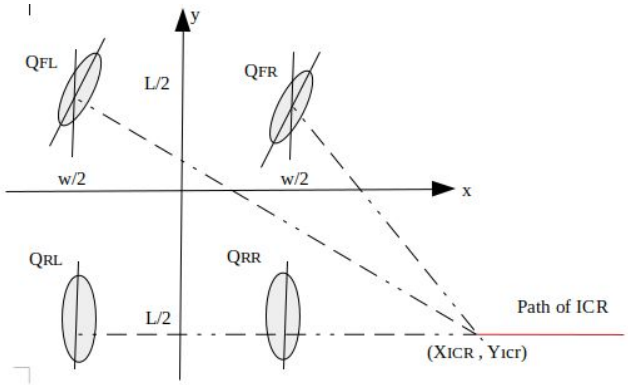




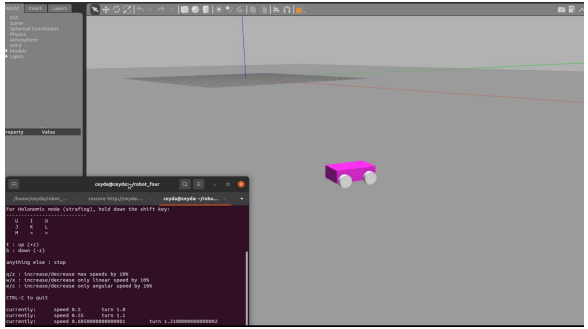
We used 3D printing services to manufacture our prototype. After the printing process, the necessary leveling and cleaning were done. We applied machine oil for easy installation. Next, we completed the sensor integration of the mobile vehicle in a specific order and mounted the electronic circuits inside the vehicle. Once the mechanical assembly was finished, the robot was ready for real-life testing.

DIFFERENTIAL DRIVE

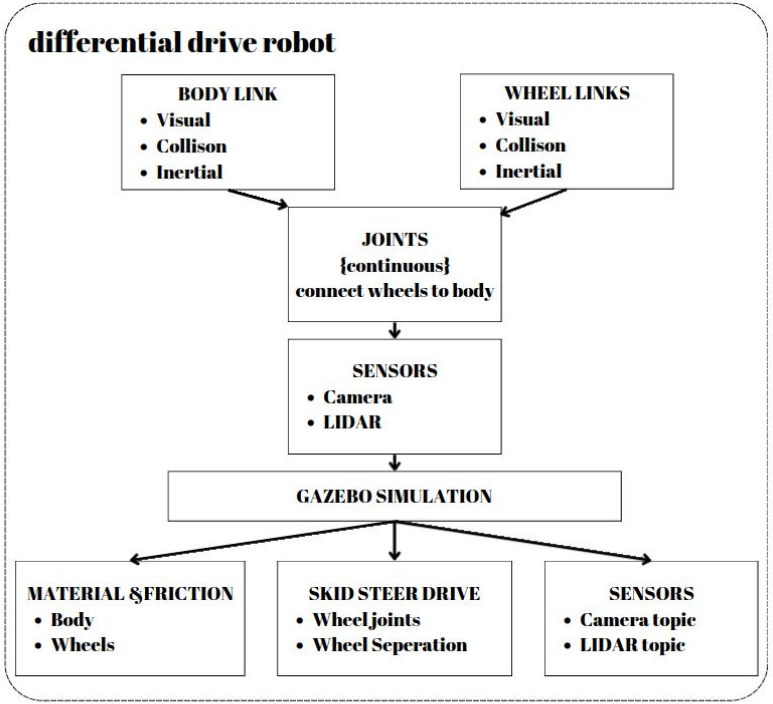
Our autonomous mobile robot uses a differential drive system for precise and flexible movement control. This system allows the robot to move straight, turn smoothly, and rotate in place. We have four independent motors, each connected to a drive wheel. By adjusting the speeds and directions of these motors, the robot can perform different movements. For example, it moves straight when both motors run at the same speed and direction. To turn, we vary the speeds of the motors accordingly. Rotation in place is achieved by running the motors at the same speed but in opposite directions. The differential drive system is advantageous due to its maneuverability, simplicity, and precision. It requires fewer mechanical components and provides precise control, making it reliable for various tasks. With precise sensor integration and reliable motor control, our robot can navigate environments and perform tasks independently.



DIFFERENTIAL DRIVE



We tested our differential drive system using ROS and Gazebo simulation. First, we made a simple model of a four-wheel robot using URDF files. The robot has a rectangular body and four wheels. It also has a camera and a 2D LiDAR sensor. In the simulation, the robot can move forward, backward, and turn by adjusting the speeds of its wheels. We used plugins in Gazebo to control the robot's movement and simulate sensors. This setup helps us test navigation and control algorithms in a realistic environment.



ELECTRICAL DESIGN

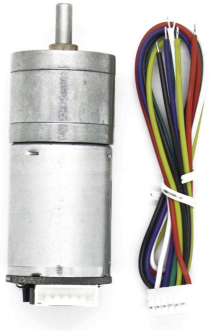
COMPONENTS

YDLIDAR X2

- **Data Collection: Fast and precise with a variable frequency up to 3kHz.**
- **Measurement Range: At least 8 meters.**
- **Scanning Capability: 360-degree omnidirectional scanning.**
- **Motor Speed: Adjustable, recommended speed is 6kHz.**
- **Strong resistance to ambient light interference.**

MP5BFN

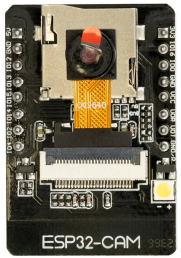
	MP5BFN 12V EncoderDC Motor	12V 350 RPM Encoder DC Motor
Voltage (V)	12 V DC	12V DC
No-Load Speed (RPM)	1500 RPM	350 RPM
No-Load Current (A)	Approximately 0.2 A	Approximately 0.3 A
Encoder Resolution (PPR)	11 PPR	11 PPR or higher
Torque (kg.cm)		2.0 kg.cm



12V 350 RPM

COMPONENTS

ESP32-CAM

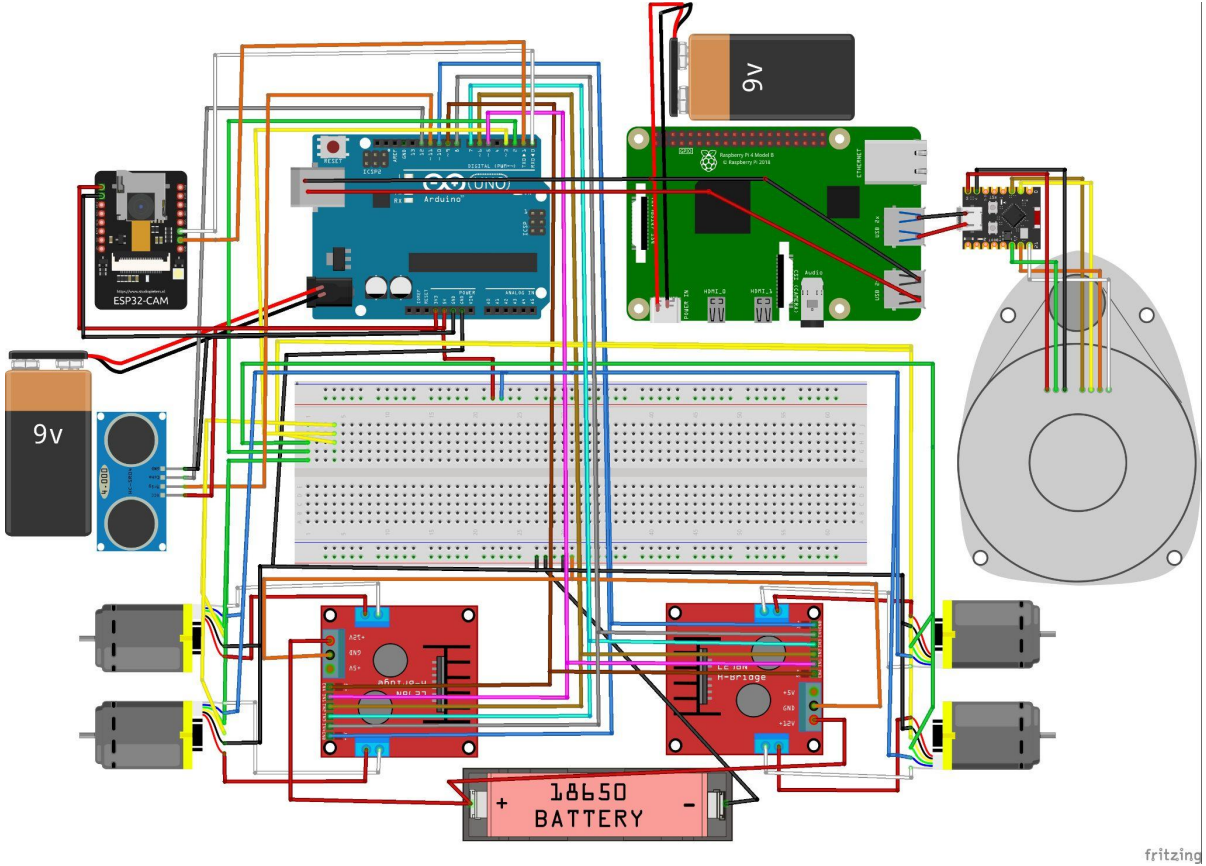


- Resolution: 2 MP.
- Field of View: 66.5 degrees.
- Wireless Communication: Built-in Wi-Fi and Bluetooth.
- Storage: MicroSD card slot supports up to 4 GB.
- LED Flash: Built-in, controllable with Python scripts.
- Image Processing: Utilizes ESP32's processing capabilities.
- Video Streaming: Up to 1600x1200 pixels (UXGA) at 15 FPS.

HC-SR04

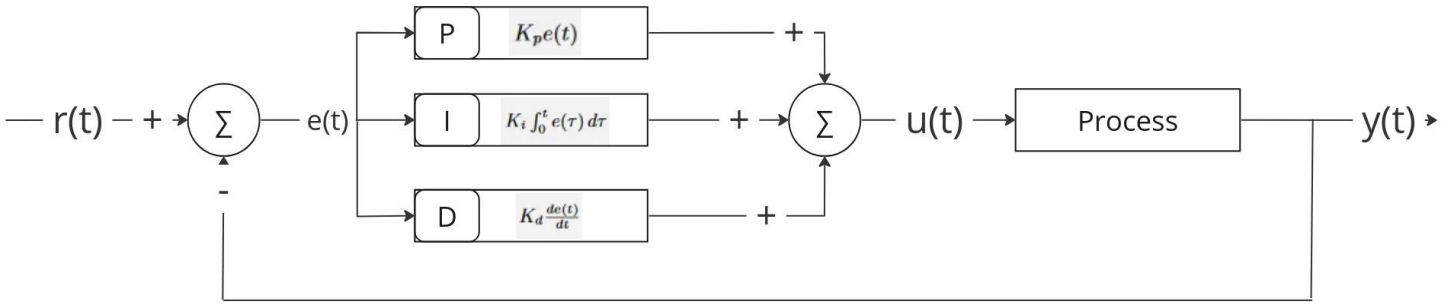
- Measurement Range: 2 cm to 4 meters.
- Accuracy: ±3 mm.
- Operating Frequency: 40 kHz.
- Working Voltage: 5V DC.
- Integration: Easily controlled via microcontroller using trig and echo pins.
- Environmental Conditions: Works effectively under various conditions.

CIRCUIT DESIGN



CONTROL DESIGN

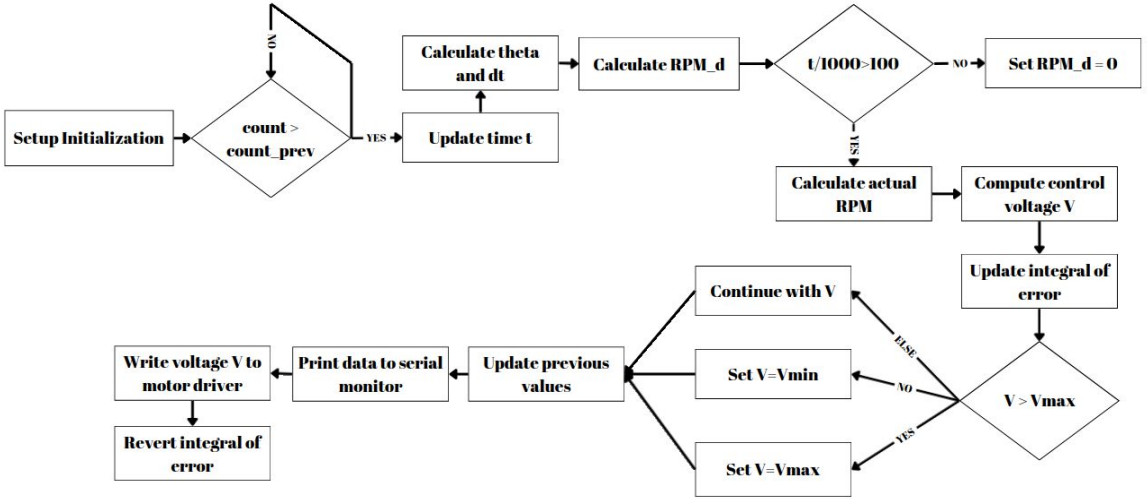
PID CONTROL



Proportional-Integral-Derivative (PID) control is a commonly used feedback control technique in engineering and industry. It regulates dynamic systems by minimizing errors between a desired setpoint and the actual process variable. While simple to implement and tune, PID control can be time-consuming to optimize and sensitive to changes and noise.

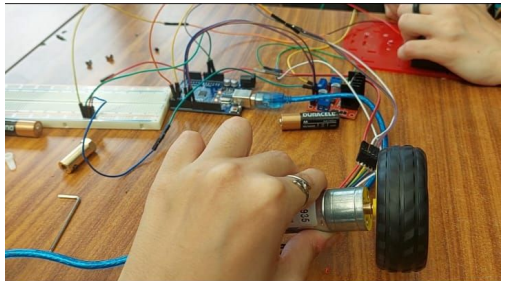
PID CONTROL LOGIC

We implemented PID control using Arduino code to regulate motor speed. An encoder reads the motor's position, with interrupt service routines updating the encoder count. The main loop calculates motor speed (RPM) and adjusts it to a desired sinusoidal pattern (RPM_d) over time. A PID controller minimizes the difference between desired and actual RPM, generating a control voltage applied to the motor driver. Relevant data is printed to the serial monitor for monitoring and debugging. A hardware timer ensures consistent loop intervals.



PID CONTROL TEST

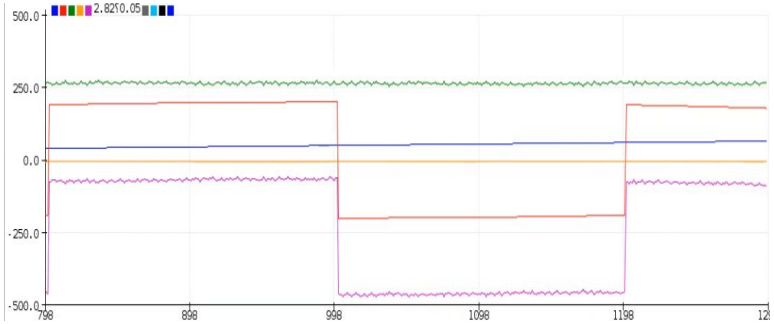
We tested the each motor individually. Connecting each encoder DC motor to a simple control circuit, we monitored the plot generated when applying PID. We adjusted the variables until achieving satisfactory results.



testing setup

Wiring Information:

- Pin 2 and 3: External ISR pins for rotary encoder pulses.
- Pin 6: PWM pin for motor speed control.
- Pins 7 and 8: Change motor direction by altering polarity.
- Common ground between motor driver, Arduino, and power supply is crucial for stability.



test results

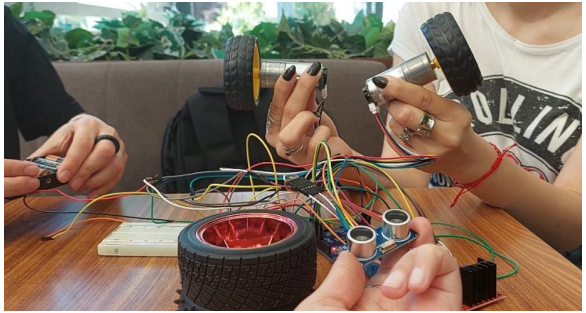
SOFTWARE DESIGN

OBSTACLE AVOIDANCE

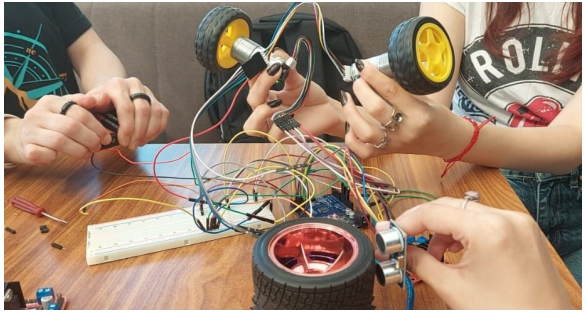
Obstacle avoidance is vital for our robot's navigation in unknown environments. We use an ultrasonic sensor to ensure reliability.

The algorithm autonomously guides the robot by detecting obstacles with the ultrasonic sensor. If an obstacle is within 16 inches, the robot moves backward for two seconds, then randomly turns left or right for three seconds before resuming forward motion.

This allows our robot to navigate autonomously, avoiding collisions and freely exploring its surroundings.



clear path

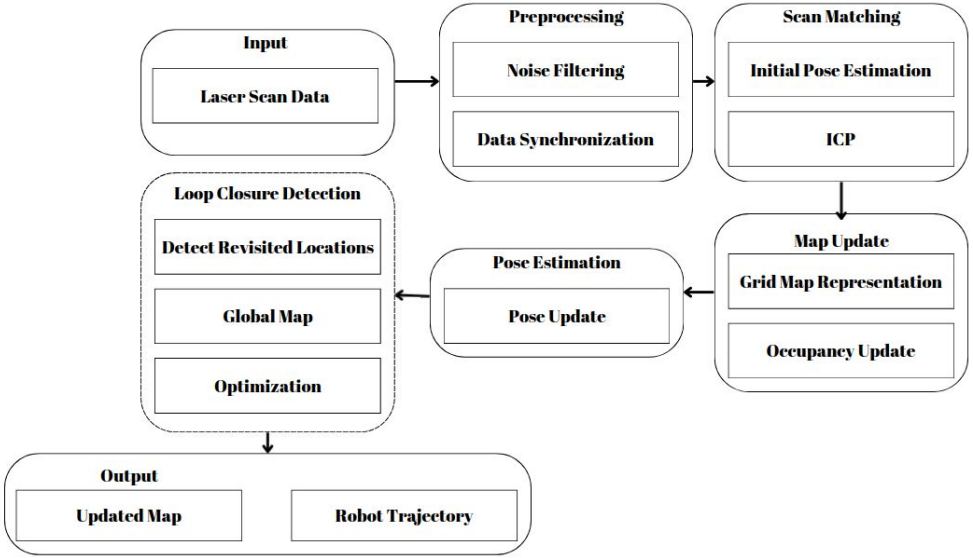


detection

testing setup

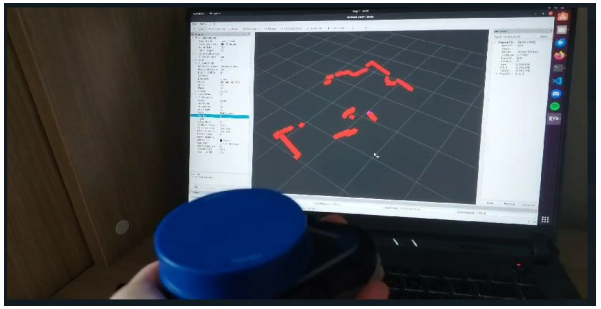
LIDAR SLAM

Our SLAM application uses a 2D LiDAR algorithm known for its high accuracy and efficiency, ideal for real-time applications like rescue robots and autonomous vehicles. This algorithm creates detailed maps from 2D LiDAR sensors while localizing the sensor within the map. The LiDAR emits laser beams in multiple directions, measuring return times to construct a precise 2D grid map. Not requiring odometry or IMU data, it is well-suited for our project.



LIDAR SLAM

Using the YDLidar X2 with its high-precision distance measurement and 360-degree scanning capability, the sensor is mounted on the robot to continuously scan and collect data processed by the algorithm. This setup is effective in dynamic environments with low drift and requires no odometry information.



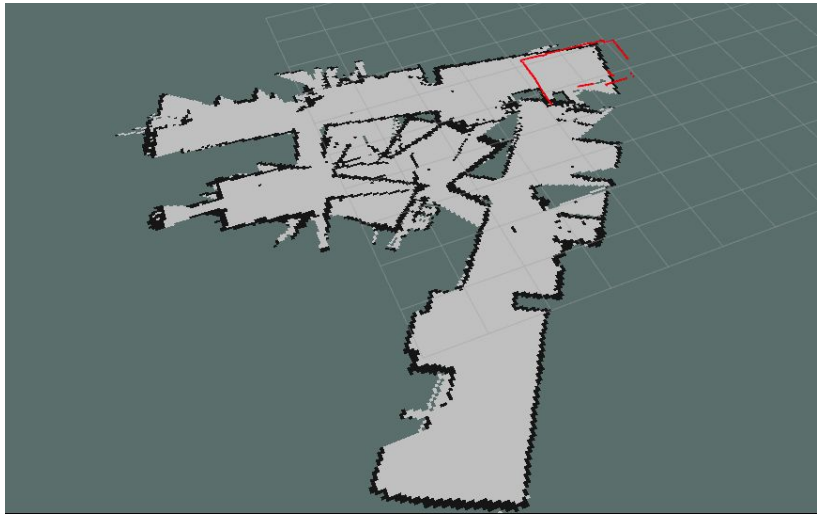
lidar data

We conducted mapping tests in various environments, both indoor and outdoor spaces. These tests demonstrated the SLAM system's performance in both confined indoor spaces and larger outdoor areas.

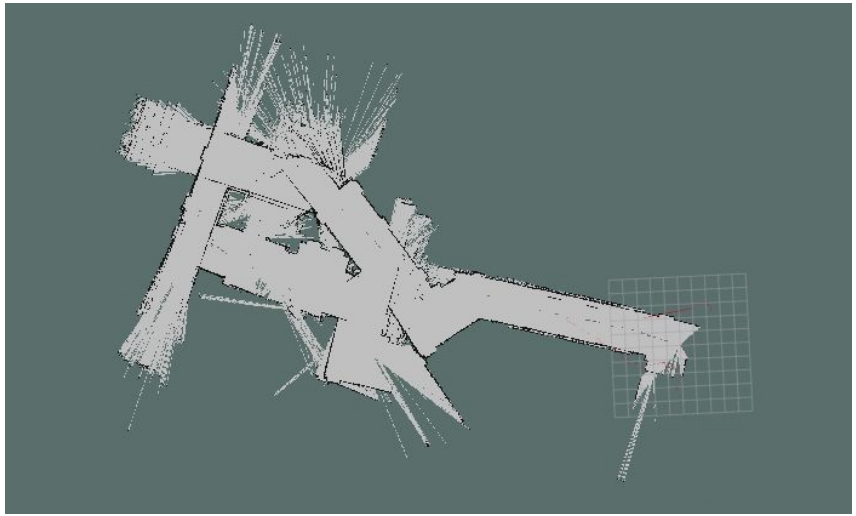
mapping tests

MAPPING DEMONSTRATION

MAPPING RESULTS

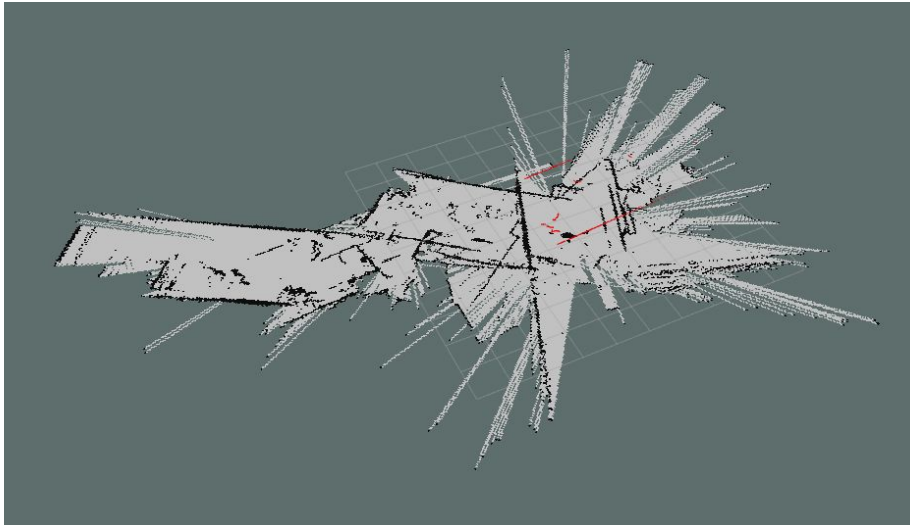


DORM ROOM

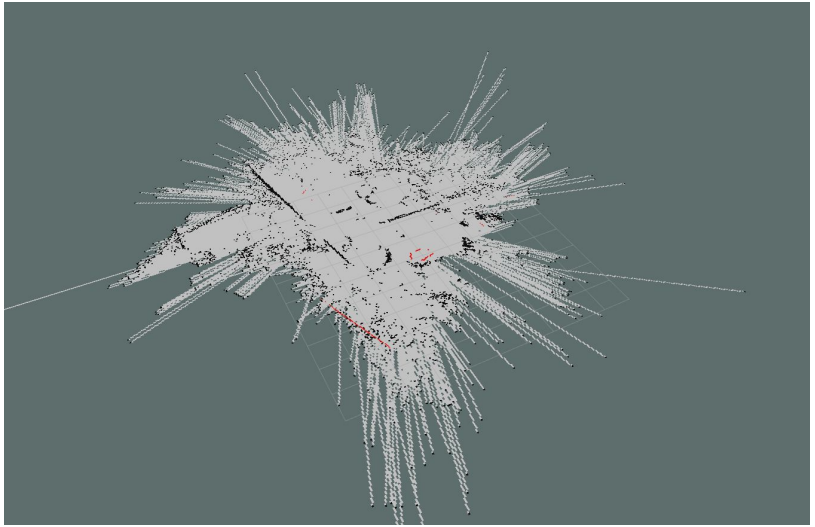


FLOOR PLAN

MAPPING RESULTS



WALKWAY



OPEN FIELD TEST

REFERENCES

- Hong, Z. *et al.* (2021) *Radar SLAM: A Robust SLAM System for All Weather Conditions* [Preprint]. doi: https://doi.org/10.48550/arXiv.2104.05347.
- Cadena, C. *et al.* (2016) 'Past, present, and future of simultaneous localization and mapping: Toward the robust-perception age', *IEEE Transactions on Robotics*, 32(6), pp. 1309–1332. doi:10.1109/tro.2016.2624754.
- Debeunne, C. and Vivet, D. (2020) 'A review of visual-lidar fusion based simultaneous localization and mapping', *Sensors*, 20(7), p. 2068. doi:10.3390/s20072068.
- Mielle, M., Magnusson, M. and Lilienthal, A.J. (2019) 'A comparative analysis of radar and Lidar Sensing for localization and mapping', *2019 European Conference on Mobile Robots (ECMR)* [Preprint]. doi:10.1109/ecmr.2019.8870345.
- R. Mur-Artal and J. D. Tard´os, "ORB-SLAM2: an open-source SLAM system for monocular, stereo and RGB-D cameras," IEEE Transactions on Robotics, vol. 33, no. 5, pp. 1255–1262, 2017.
- Hong, Z., Petillot, Y. and Wang, S. (2020) 'RadarSLAM: Radar based large-scale slam in all Weathers', 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) [Preprint]. doi:10.1109/iros45743.2020.9341287.
- Behley, J. and Stachniss, C. (2018) 'Efficient surfel-based slam using 3D laser range data in urban environments', Robotics: Science and Systems XIV [Preprint]. doi:10.15607/rss.2018.xiv.016.
- S. Nagla, "2D Hector SLAM of Indoor Mobile Robot using 2D Lidar," 2020 International Conference on Power, Energy, Control and Transmission Systems (ICPECTS), Chennai, India, 2020, pp. 1-4, doi: 10.1109/ICPECTS49113.2020.9336995. keywords: {Simultaneous localization and mapping;Laser radar;Service robots;Operating systems;Two dimensional displays;Real-time systems;Mobile robots;Robot Operating System (ROS);Simultaneous Localization and Mapping (SLAM);Hector-SLAM;Light Detection and Ranging (LiDAR)}
- Harik EHC, Korsaeth A. Combining Hector SLAM and Artificial Potential Field for Autonomous Navigation Inside a Greenhouse. *Robotics*. 2018; 7(2):22. https://doi.org/10.3390/robotics7020022
- N. Yu and B. Zhang, "An Improved Hector SLAM Algorithm based on Information Fusion for Mobile Robot," 2018 5th IEEE International Conference on Cloud Computing and Intelligence Systems (CCIS), Nanjing, China, 2018, pp. 279-284, doi: 10.1109/CCIS.2018.8691198. keywords: {mobile robot;information fusion;EKF;simultaneous localization and mapping}

Thank you for listening