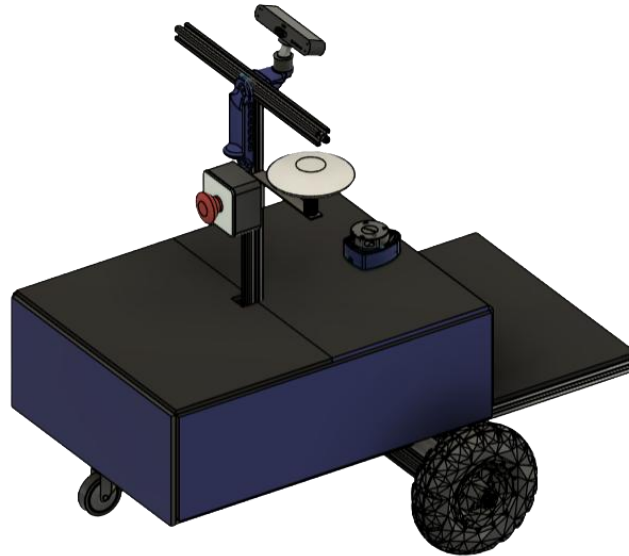


Vehicle Name: Vega
Competition: AutoNav



Date Submitted: 14th May 2026

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I, Dr. Avinash More & Dr. Sumita Nainan, hereby declare that the work done by Team DARVIN under our guidance for the IGVC competition 2026 has been significant and equivalent to what might be awarded credit in a senior design course.

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1. Introduction

1.1 Overview

With the ambition to break past our limitations, Team DARVIN underwent a reboot with a new roster and new plans for IGVC 2026. This brought about the creation of Vega, our vehicle that aims to go beyond the challenges faced by Kaizen V2. The team introduced several major additions to the vehicle like integration of LiDAR sensor and computer vision through camera-based tracking allowing more accurate obstacle detection. Along with this, an onboard computing system is incorporated to efficiently handle the increased computational requirements.

1.2 Organization

Team Darwin is the robotics club of NMIMS MPSTME, composed of -- team members that have been involved in the 4 departments of the team: Manufacturing, Electronics, Software and Documentation. The roles of individual members and brief information about them are as follows:

Table 1. Team Constitution

Name	Graduation Year	Major	Role
Pranav Lavande	2026	Electronics and Telecommunication	Student Mentor
Veer Bafna	2027	Electronics and Telecommunication	Captain
Vishal Iyer	2027	Electronics and Telecommunication	Co-Captain
Rishabh Bhangale	2026	Computer Science	Software Core
Aadidev Raizada	2029	Computer Engineering	Software Core
Chinmay Pai	2028	Mechatronics	Manufacturing Core
Div Vora	2029	Computer Engineering	Electronics Core
Yash Kalbhor	2027	Information Technology	Software Core
Kush Modi	2029	Computer Science	Design Core
Pinak Jivarajani	2029	Computer Engineering	Electronics Executive
Kathan Dodia	2029	Computer Engineering	Electronics Executive
Bhavya Yagnik	2027	Computer Engineering	Electronics Executive
Kaveri Ahirrao	2029	Electronics and Telecommunication	Documentation Core

1.3 Design Process

For the development of our vehicle, we adopted a Rapid Application Development (RAD) strategy (refer to Figure 1 for an overview of this approach). Instead of following traditional methodologies such as the waterfall model, which often delay error detection until the final testing phase, RAD allowed us to embrace iterative development. This provided flexibility to identify and address issues early in the process rather than encountering them all at the end. Additionally, RAD enabled us to concentrate on refining individual functionalities step by step, rather than focusing solely on the outcome, which significantly enhanced our ideation and improvement process.

Our implementation of RAD consisted of the following stages:

- **Requirements:** We began by thoroughly reviewing the constraints and guidelines outlined for the current edition of the IGVC competition. This involved carefully reassessing all conditions and reevaluating previous assumptions to determine necessary modifications.
- **Analysis:** To overcome earlier limitations and integrate innovative solutions, we defined measurable parameters to evaluate the performance and effectiveness of each implemented component. This analytical stage played a key role in identifying weaknesses and guiding improvements in our design strategy.
- **Prototyping:** To validate the feasibility and functionality of our concepts, we developed detailed 3D CAD models, simulated the behavior of physical components, and conducted controlled experimental tests. Prototyping allowed us to visualize our ideas and assess their practicality before full-scale implementation.
- **Integration:** After verifying that each individual component met predefined standards, we integrated them into a unified system. This included subsystems such as boundary detection and manipulation, camera input/output processing, and power distribution. During this phase, previously unnoticed issues emerged, enabling us to further refine and enhance the vehicle’s overall performance.

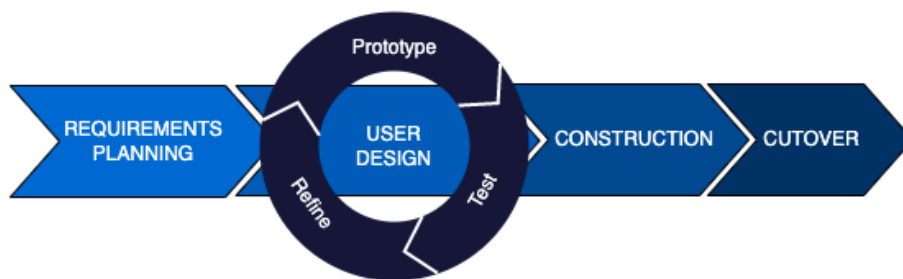


Figure 1. Development process utilized for Vega

Overall, the design process was driven by the goal of building a vehicle specifically optimized for the IGVC. Emphasis was placed on innovation, reliability, and performance optimization. Through continuous iteration, testing, and refinement, the team has been working towards achieving a highly capable and competitive final design.

2. Vehicular Requirements

2.1 Assumptions

The primary objective for this year’s design was to enhance both mechanical as well as software efficiency of the vehicle, focusing on improved weight distribution and more optimized navigation performance, particularly for handling steeper slopes and ramp conditions. See Section 4.3 and Table 5, for results obtained. Another goal was to make software less computationally heavy to ensure improved auto-navigation and a higher capacity battery is used to considerably increase the vehicle’s range.

2.2 Costing

The overall cost of the vehicle was distributed across various components, with most of the budget being allocated to a selective few top-of-the-line standard components which included the LIDAR and the camera module. The rest of the budget was used on the mechanical aspects of the vehicle. The PCBs were custom designed to ensure better quality and reliability. The table below presents a breakdown of major components along with their cost and sources.

Table 2. Expenses for Major Components

Sr No.	Item	Cost (In INR)	Source
1	DC Planetary Motors	8,500 per motor	University
2	Motor Driver	4,500	University
3	ZED 2i	75,800	University
5	LIDAR	9,000	University
6	All Terrain Wheels	4,500 per wheel	University

2.3 Structure Quality

To ensure the quality of the chassis, it was purely built via aluminum extrusions, fastened together with stainless steel bolts and brackets to form single integrated structure instead of multiple assembled sections. The bottom side of the vehicle is reinforced with 1.5mm thick stainless-steel plate which serves as the mounting base for all the electronics in the vehicle. This stainless steel provides mechanical protection to the underbody of the vehicle against debris that could potentially be displaced from the ground while the vehicle is in motion. The sides of the vehicle are enclosed with acrylic plates. The top half serves as the only access point to the vehicle which is protected by an acrylic layer. **See Figure 2.**

2.4 Safety Mechanisms

To ensure safe operation of the vehicle, several safety features were added to reduce risks and improve control. A remote e-kill is used to safely stop the vehicle when required without shutting down the whole vehicle, allowing quick restarts. E-kill system is implemented directly

through the controller using radio frequency communication allowing the vehicle to be stopped instantly which has a range of more than 100 feet. **See Section 5.5**

3. Innovations

3.1 Mechanical Innovations

1. Precision-fit structural components: Vega's use of precision engineered mechanical parts helps to ensure chassis alignment, increased structural strength and a cleaner overall vehicle assembly, leading to a more stable, reliable vehicle platform. We have used processes like laser cutting, 3D printing and CNC to achieve this mechanical precision.
2. Improved camera placement: Camera is placed at the exact center of the vehicle, which ensures symmetric vision, better spatial awareness, lane tracking and navigation accuracy.
3. Refined body architecture: The chassis has been redesigned with a reduced overall width resulting in a sleeker appearance of Vega while improving adaptability and navigation in constrained environments.

3.2 Electronic Innovations

1. LiDAR integration: Vega introduces a dedicated LiDAR sensor for accurate distance measurement and real-time obstacle sensing during autonomous navigation into the electronic system. Consistent spatial data for safer and more reliable movement of the vehicle is provided by the sensor.
2. Brighter omnidirectional indicator: A brighter omnidirectional light indicator is used to improve visibility and provide clearer vehicle status indication from all directions. This helps ensure that the vehicle can be easily seen, even when driving outside or in low-light conditions.
3. Updated IMU configuration: The previous integrated IMU has been changed to a dedicated 9-axis IMU with a built-in magnetometer that provides better motion tracking and orientation accuracy. The new module provides more stable heading and movement data during the navigation process.

3.3 Software Innovations

1. LiDAR-based obstacle detection: Vega replaces the earlier vision-based obstacle detection approach with a dedicated LiDAR system capable of detecting objects using real-world distance measurements. Instead of relying only on image coordinates, the system identifies safe and passable gaps based on the actual width of the rover, resulting in more accurate navigation around obstacles.
2. ZED 2i stereo camera lane detection: Vega is equipped with a ZED 2i stereo camera for lane detection using techniques such as Canny edge detection to identify lane boundaries, a lane validity flag and the ability to fall back on the USB camera.
3. ROS-based sensor fusion: Vega introduces a structured ROS-based fusion architecture where a dedicated arbiter node combines LiDAR and camera inputs before generating steering and motor commands for smoother autonomous navigation.

4. Mechanical Design

4.1 Overview

The vehicle design, inspired by Kaizen V2, follows a 3-wheel configuration for better stability, with two drive wheels at the front and a caster wheel at the rear. A modular aluminum chassis allows flexible mounting and easy attachment of components while acrylic and aluminum shielding protect the internal systems. The structure is designed to reduce body roll, maintaining stability even under heavier loads. Built using around 11 meters of aluminum, the vehicle offers good rigidity and supports a payload of up to 88 lbs. A 35° angle of attack improves its ability to navigate different terrains. The aluminum extrusion design is used as it allows easy shell replacement, and multiple mounting points add to its overall adaptability.

4.2 Chassis and build

Vega, as shown in **Figure 2**, uses a strong aluminum chassis made from 30×30 mm extrusion profiles, supported by aluminum L-brackets. The vehicle dimensions are 39.3 inches in length and 22 inches in breadth (excluding tire width), with a height of 33.8 inches. The three-wheel setup helps maintain proper weight distribution, with a center-heavy design reducing the risk of rollovers. The electronics are mounted on a 1.5 mm stainless steel base plate and an acrylic sheet is added to provide electrical insulation and prevent short-circuit risks. The electronics section is enclosed using aluminum extrusions, acrylic, and aluminum sheets, with access provided only from the top. The camera tower has been repositioned to the center of the chassis, improving overall camera vision compared to last year when it was mounted at the rear while an improved entry mechanism enhances water resistance.



Figure 2. Chassis Build

4.3 Capabilities

1. **Stability:** Vega utilizes a 3-wheel configuration with a wheelbase of 34 inches and a length of 31 inches, providing excellent balance and minimizing body roll during operation. Its balanced weight distribution helps reduce the chances of rollover.
2. **Speed:** The vehicle can reach a maximum speed of 3.57 MPH with the current motor and drive system configuration.
3. **Payload capacity:** Vega has been tested to carry payloads of up to 30 lbs. The front aluminum extrusion framework also allows payloads and additional components to be mounted securely.
4. **Incline handling:** The vehicle is capable of climbing inclines of up to 35°. With a ground clearance of 4 inches, the vehicle can move effectively across uneven and rough terrain.
5. **Structural Protection:** The vehicle uses 6 mm acrylic side panels for protection. Electronics are mounted on an acrylic insulation sheet placed over a 1.5 mm stainless steel plate to minimize unexpected short circuits while also protecting the underbody from debris.

5. Electrical and Power Design

5.1 Overview

The electronic architecture of Vega is designed to provide stable communication, power distribution and control for all onboard subsystems. It combines the onboard computer, microcontroller, sensors, motor drivers and auxiliary electronics into a single integrated system for reliable vehicle operation. The system also ensures smooth data transfer between components while maintaining stable power and control while the vehicle is functioning.

5.2 Power Distribution

Vega is powered by an onboard computer which handles all major processing tasks and communicates with the microcontroller for managing the vehicle’s components. The electronics are organized as a single integrated system responsible for power distribution, motor control, sensing, and onboard processing.

There are two 11.1V 3-cell LiPo batteries in series to provide all microcontrollers and motors with the required voltages and a total of 22.2V, which can reach up to 26V when fully charged. The power is delivered via a power distribution board (PDB) that provides a few outputs for the various subsystems and motor drivers. This provides an additional 11.1V battery to power the relay and emergency lighting system ensuring that the emergency light continues to operate should the main systems fail.

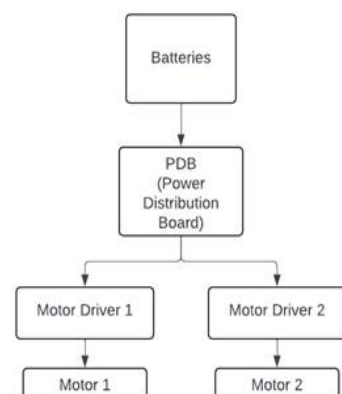


Figure 3. Power supply path for System, from the batteries to the motors

5.3 Motors and Motor Drivers

Vega is equipped with 2 Planetary Geared DC motors operating at voltage of 24V. These motors have a gear ratio of 1:23, providing an output of 120 RPM. The motors are rated for a

torque of 7.85 Nm. The vehicle uses tires of 10 inches and can reach a top speed of 3.57 MPH (5.75 kmph). The speed and performance of the vehicle can be modified by adjusting the size of the wheels used.

5.4 Electronics Suite

Vega's electronics architecture is an integrated system that controls motors, senses and processes onboard. The onboard computer is responsible for the most important functions, such as lane detection, LiDAR processing, autonomous navigation and communication with the microcontroller via a ROS bridge, allowing seamless coordination between perception and control. The primary microcontroller will be the Arduino Mega which will generate PWM signals for motor control as well as connect to other peripheral systems and sensors. The 24V DC motors are powered by the drive system which is provided by two Rhino MD20A motor drivers. The sensor suite includes an MPU9050 IMU for motion and orientation, a ZED 2i for stereo camera for depth perception and a RPLiDAR for obstacle detection. The sensors data is constantly processed on the onboard computer via ROS nodes that produce control signals and are sent to the motor controller to manage the vehicle's movement. **Figure 4** shows the overall electronic system architecture of Vega.

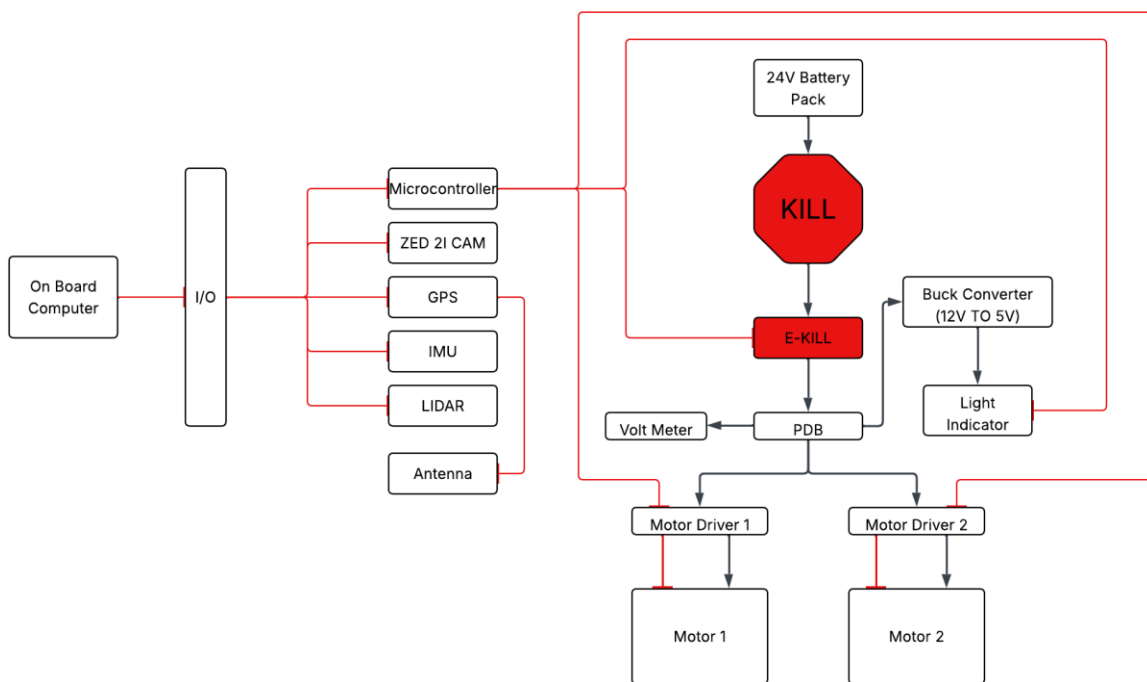


Figure 4. Electronic Suite of Vega

5.5 Safety Mechanisms

Vega incorporates multiple safety features to ensure reliable, controlled, and safe operation under all conditions. Before the system can be activated, it goes through a two-point safety check involving an emergency e-kill system and a toggle switch. This setup helps prevent accidental startup and ensures that the vehicle only operates when both conditions are enabled by the user. The primary safety feature is the emergency e-kill, which is directly

activated by the controller via the wireless communication link in the ROS system. When activated, the command is sent to the Arduino, which immediately stops all motor signals and brings the vehicle to an instant halt. This makes it possible to intervene fast during unsafe or unexpected behaviour of the system, even at a distance. A solid-state relay (SSR) is also used as a hardware safety layer in addition to this software-based shutdown. It physically disconnects the power supply to the system whenever required, ensuring a complete and fail-safe shutdown of all electronic subsystems.

6. Software Logics

6.1 Overview

Vega’s software architecture is based on ROS Noetic which provides a modular approach to communication between various subsystems via the publish-subscribe model. The lane detection, obstacle avoidance, GPS navigation, motor control, IMU processing and handling of operator input are all performed by separate ROS nodes. The Arduino Mega is used with ROS to send motor commands to ROS and to receive PWM signals from ROS. The system can be operated either manually or automatically based on the presence of an Xbox controller at startup.

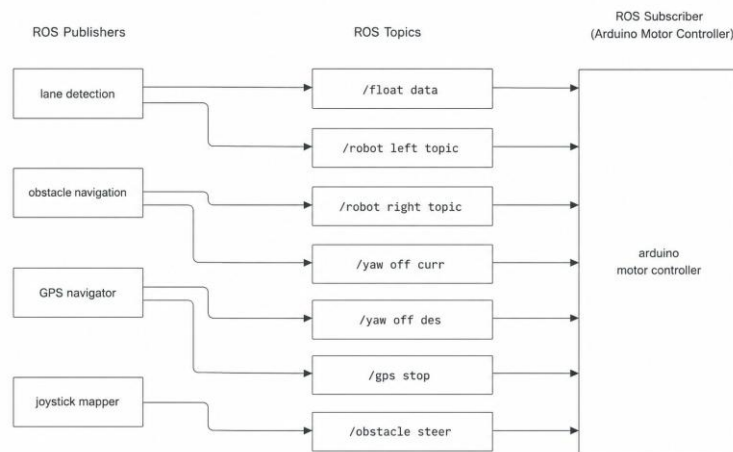


Figure 5. ROS data published and subscribed to Vega

6.2 Lane Detection Code

Lane detection subsystem combines a ZED2i stereo camera and two side mounted cameras on the USB bus that are used for lane tracking and steering correction. The ZED2i image stream is converted to an OpenCV compatible frame (cv_bridge library) and is then processed in the HLS color space. Threshold masks are used to detect the white lane markings and barrel-colored regions followed by Gaussian blur and a trapezoidal region of interest mask to remove noise and isolate the visible ground area. The lane boundaries are then detected by column-wise pixel summation and `scipy.signal.find_peaks` function. The steering offset angle is determined from the lane midpoint detection and sent as a Float32 message. The predefined regions of interest are worked out in USB cameras and the Int8 bitmask values are published for further lane correction in autonomous navigation.

6.3 Object Navigation Code

The obstacle avoidance part of the system is based on an RPLidar A series sensor connected via a serial Python driver. The LiDAR node reads the scan data continuously, converts the distances from mm to m and publishes the data as a LaserScan message on the /scan topic. The obstacle navigation node uses scan data in a forward facing 120° field of view and performs obstacle return check between 0.15m and 3m. The gap finding algorithm is used to find obstacle free areas from the scanned data and the biggest gap is chosen as the best path to navigate. The center angle of this gap is converted to steering commands and sent as Twist and Float32 ROS messages. The /lane_left and /lane_right topics are also used to help with lane boundary constraints for safety in vehicle movement.

6.4 GPS Navigation

The GPS navigation subsystem provides waypoint-based navigation using data from the GNSS receiver and the ZED2i onboard IMU. The GPS node subscribes to NMEA sentence data from the serial port, parses out the latitude and longitude data, converts it to decimal degrees, and publishes the values on the /gps_data topic as NavSatFix messages. The navigation node stores a list of pre-defined GPS waypoints and continually updates the rover heading based on quaternion data from the IMU. The desired heading towards the target waypoint is determined with the current GPS position and heading. Current and desired headings are transmitted as Float32 messages which are used by the Arduino motor controller to determine heading error and then PWM signals are sent to create steering corrections for autonomous navigation between waypoints.

7. Attack Surfaces and Countermeasures

7.1 NIST RMF (Risk Management Framework) Overview

The NIST Risk Management Framework (RMF) is a critical cybersecurity process designed to assist organizations in establishing and governing secure information systems. It offers a structured and standardized methodology to identify, assess, and manage risks associated with IT infrastructure. The primary goal of the RMF is to facilitate the development of secure and resilient systems by implementing essential security controls and promoting continuous monitoring. This proactive approach, as shown in **Figure 6**, aims to counter the evolving cyber threat landscape and ensure the robustness of information systems. It involves:

1. **Categorize:** In this initial step, organizations identify and classify their information systems based on the potential impact levels of a security breach.
2. **Select:** Organizations choose and implement appropriate security controls based on the categorized systems. These controls are tailored to address specific risks and vulnerabilities identified in the earlier step.
3. **Implement:** The selected security controls are put into practice across the organization's information systems.
4. **Assess:** Regular assessments are conducted to evaluate the effectiveness of implemented security controls.

5. **Authorize:** Following successful control implementation and assessment, the organization authorizes the operation of its information systems. This step involves a thorough review to confirm that the security measures are in place and operational.
6. **Monitor:** Continuous monitoring is a crucial aspect of the RMF, involving ongoing surveillance of information systems to detect and respond to emerging threats.



Figure 6. Risk Management Framework used in Vega

7.2 Threat Cases and Impact Analysis

A scenario with the threat to the vehicle being how it could be compromised software-wise by rival teams at the pit can involve multiple vulnerabilities, with varying degrees of threat.

Table 3. Vulnerability Control Codes and Threat Modelling

Vulnerability	NIST Cyber Control Code	RMF Step	Confidentiality	Integrity	Availability	Overall Impact Rating
Unauthorized Code Repository Access	AC-16, AC19, IR-4	Implement / Assess	High	Low	Low	Low
Unauthorized Hardware Insertion	PE-3, PE-6, PE-9, PE-5	Implement / Monitor	Medium	Medium	Medium	Medium
Unauthorized Remote System Access	AC-17, AC7, AC-18	Assess / Authorize	Medium	High	High	High
Sensor Spoofing/Tampering	IA-5, IA-8, IA-9	Assess / Monitor	Low	Low	Medium	Low

Wireless kill Switch Interception	SC-12, SC-13, SC-40, IA-7	Select / Monitor	Medium	High	High	High
Soft Kill System Exploitation	SI-2, SI-3, AC-7(2), SC-39	Implement / Monitor	Low	High	High	Medium
ROS Topic Injection or Hijack	SC-7, SC-28, SC-44, IA-5	Implement / Monitor	High	High	Medium	High

7.3 Implementable Security Control Measures

To harden our system, we implemented multiple security measures including:

1. Establishing an RBAC (AC-2): By implementing a Role Based Access Control System on the Linux system with each file having different permissions for different users, we protect the integrity and confidentiality of the system.
2. Physical hardening (PE-3(5)): To prevent any unauthorized access via any attacker, we have disabled all unused ports of our device with the help of tamper proof seals, allowing only the ports to be utilized by our systems, like visual input device, microcontrollers, and input output system.
3. Alert Systems (SI-7): Notifications and alert mechanisms were included to inform the operators about unauthorized access attempts or unusual system activity.
4. Password Rotation (PS-1): Implementing a program that would be required to be executed on a regular basis, preferably weekly, which would generate a new password for the root user that would be then encrypted before being stored in the shadow file.
5. Emergency wipe (AC-7(2)): Having a hard kill that could encrypt all the system files and delete its encryption key to permanently hide the information of the system from any attacker as a last stage measure would protect the integrity and confidentiality of the system at the cost of the system's availability.
6. E-Kill Button: Risk management and threat mitigation through interconnected e-kill systems.
7. User Access Management (AC-2): Separate user accounts with limited permissions were maintained on the Ubuntu-based onboard computer to prevent unauthorized system changes.
8. Software Update Management (SI-2): The Ubuntu operating system and ROS packages were regularly updated to improve system stability and reduce software vulnerabilities.

8. Failures faced, and resolutions made

Table 4. Failure points faced across Software, Electrical and Mechanical fronts

Failure Points	Cause	Resolution
Delay in dual camera processing	Simultaneous camera streams introduced input latency during runtime	The camera setup and processing pipeline were simplified
Inconsistent lane detection	Improper saturation levels and lighting conditions affected detection	Camera calibration and saturation tuning improved lane detection
Software integration issues	ROS nodes worked individually but conflicted after integration	Code restructuring and debugging improved node synchronization
Vehicle drifting toward one lane	Steering corrections remained biased despite correct lane detection in RViz	Lane weighting and steering correction logic were adjusted
Connection loss during operation	Loose wiring and vibrations from rough terrain interrupted connections	Electrical connections were secured more effectively to minimize disconnections on rough terrain.

9. Simulation

9.1 Mechanical performance

The mechanical design of Vega was tested to evaluate stability, strength, and payload handling under different conditions. The 3-wheel configuration, reduced chassis width, centered pole placement, and precision-fit components improved balance, maneuverability, and reduced body roll during operation. The aluminum extrusion chassis also provided improved rigidity while maintaining the required payload capacity.

9.2 Electrical system review

The electrical system of Vega was tested to evaluate the reliability of the power distribution, motor control, and onboard processing systems. The Rhino MD20A motor drivers were tested under continuous load, while the onboard computer, Arduino Mega, and sensor modules were verified for stable communication through the ROS framework. The PDB and DC-DC buck converters were also tested to ensure proper voltage regulation and reliable subsystem operation during extended runtime conditions.

9.3 Software review

The software system was tested in Gazebo simulation environments involving lane following, obstacle avoidance, while the GPS waypoint logic was verified through software simulation. The ZED 2i stereo camera detected lane boundaries, while the LiDAR system identified

obstacles and safe navigation paths. The ROS-based fusion system combined these inputs to generate smooth steering and motor control during autonomous operation.

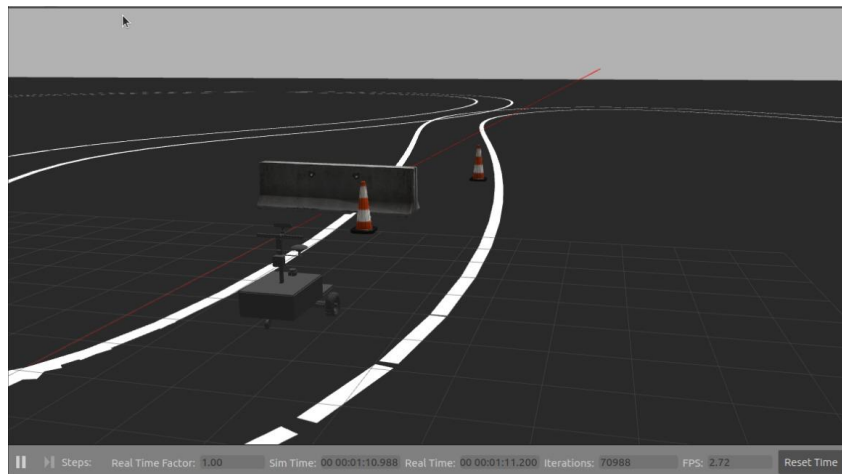


Figure 7. Gazebo simulation for Vega's Lane navigation

10. Performance Assessment

The performance of Vega was tested under both full-load and ideal operating conditions. During full-load operation, the onboard computer handles tasks such as lane detection, LiDAR processing, and autonomous navigation together while the motors operate with the vehicle payload and onboard electronics. Runtime was measured based on the combined power consumption of the onboard computer and drive system. The controller range can vary depending on the vehicle's enclosure and panel configuration while the RF-based physical kill switch maintains a stable operating range under different conditions.

Table 5. Evaluation elements at varying conditions

Evaluating Element	Full Load Analysis	Ideal Analysis
Motors (motor1 + motor 2)	4A + 4A (3.5MPH full load)	2.75A + 2.75A (2MPH)
Runtime	40 mins	75 mins
Speed	3.5 MPH	1.5 MPH
Payload Capacity	88 lbs.	20 lbs.
Range (E-Kill)	100 feet	100 feet
Range (Controller)	100 feet (No side panels)	100 feet