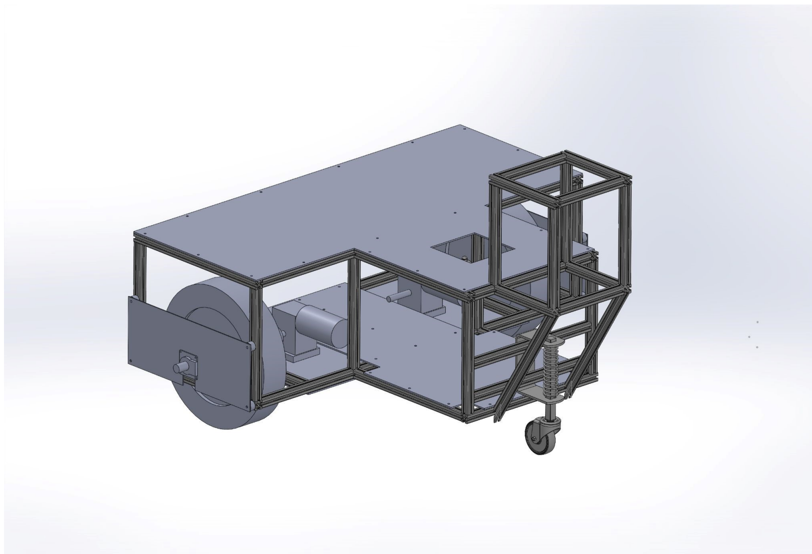
Lawrence Technological University

Blue 2.0



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Statement of Integrity:
We have neither given nor received unauthorized aid in completing this work, nor have we presented someone else's work as our own.

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Intelligent Ground Vehicle Competition

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1. INTRODUCTION

The team is ready to compete in the upcoming IGVC competition at Oakland University, scheduled from May 31st to June 3rd. The primary goal is to showcase a fully autonomous vehicle capable of precise navigation and successful course completion. The competition will be held at Oakland University on the course shown in Figure 1. Technical expertise will be demonstrated by employing technologies such as LiDAR, GPS, and computer vision-based lane-following algorithms.

Throughout the design process, the V-Model (Figure 2) and rigorous engineering practices were followed. This structured approach ensured thorough verification and validation at each stage of development, resulting in a robust and reliable autonomous vehicle. Beyond the competition, the vision includes substantial technical and professional growth, fostering multidisciplinary expertise and an innovative culture. The team comprises Eric Beeler as the Mechanical Lead, Lauren Crist as the Team/Programming Lead, and Jayson Tilley as the Electrical Lead. The organization chart can be seen in Figure 3Dedication to mastering the technical aspects of the autonomous vehicle and contributing to the future of autonomous mobility at Lawrence Technological University is paramount.

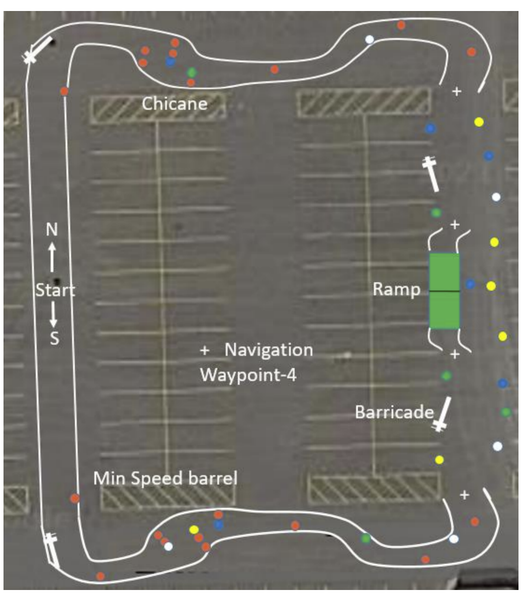

Figure 1. 2024 Oakland University IGVC Auto-Nav Course.

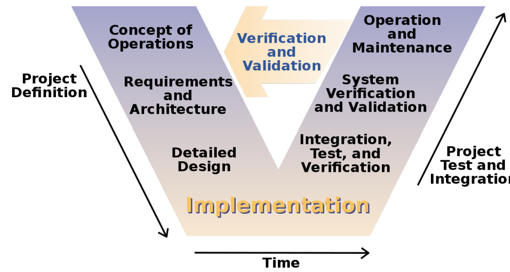

Figure 2. Design process utilized by the 2024 LTU IGVC team.

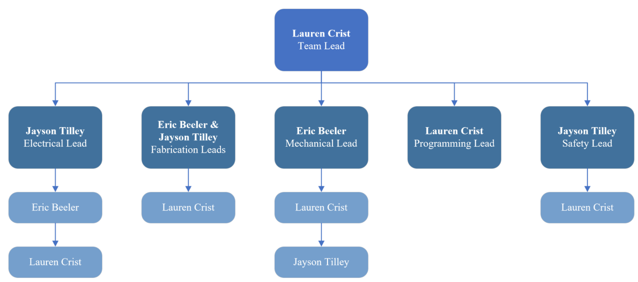

Figure 3. LTU IGVC team organizational structure.

2. SYSTEM ARCHITECTURE

The robot's mechanical design underwent significant enhancements for the 2024 iteration, featuring a simplified chassis with eliminated tiers, a relocated stack, and internally supported wheels with dual bearings, constructed from $\frac{3}{4}$" T-Slot and metal angle brackets. The drivetrain, a product of the 2024 team, integrates motor block assemblies, bearing blocks per wheel, and motor couplers, limited to a maximum speed of five miles per hour as per IGVC 2024 rules. Baseplates, crafted from $\frac{1}{8}$" aluminum, cater to payload storage and electronic mounting needs, while an acrylic top plate adds weatherproofing and peripheral mounting space. The E-Stop Tower, fulfilling IGVC regulations, extends from the rear chassis, constructed with T-Slot aluminum and acrylic weatherproofing. On the electrical front, safety enhancements include full grounding, fuse integration, diode protection for the Arduino, and wireless/wired emergency stop systems, alongside power system redesign featuring a two-battery arrangement for extended operating time. Programming relies on Linux, Python, and ROS, facilitated by a Lenovo Thinkpad P1 Gen 5, coordinating functionalities like lane following, object detection, and waypoint navigation through ROS nodes and Arduino intermediation, ensuring seamless interaction and decision-making within the robotic system.

2.1. *Mechanical*

The design and construction of a robotic platform for the Intelligent Ground Vehicle Competition (IGVC) necessitates meticulous attention to detail across various subsystems to ensure optimal performance and compliance with competition regulations. This overview delves into four key subsections: Chassis, Drivetrain, Base and Acrylic Plating, and the E-Stop Tower. The chassis section discusses modifications made from the previous year's design, including the elimination of the middle tier and relocation of components to enhance stability and functionality. Drivetrain details the incorporation of robust support mechanisms for the wheels and adherence to speed regulations set by IGVC rules. Base and Acrylic Plating elucidate the structural elements supporting payload storage and electronic mounting, along with weatherproofing measures for peripheral devices. Lastly, the E-Stop Tower subsection highlights a crucial addition to the design to comply with IGVC safety standards, underscoring the interdisciplinary considerations integral to successful robotic platform development.

2.1.1. *Chassis*

The chassis shown in Figure 4 is a simplified version of the 2023 design. Key changes include the elimination of the middle tier, relocation of the stack to the rear, and internal wheels now supported by two bearings each. The chassis is constructed from $\frac{3}{4}$" T-Slot, secured with corresponding nuts and bolts, and reinforced with full metal angle brackets.

2.1.2. *Drivetrain*

The drivetrain design shown in Figure 5 was developed by the 2024 team to ensure the wheels are well supported. It includes the refurbished motor block assembly from 2023, two bearing blocks per wheel (1), and a coupler (2) on each side with the respective motor shafts. The motors (3) are regulated to run at a maximum speed of five miles per hour, in accordance with IGVC 2024 rules.

2.1.3. *Base and Acrylic Plating*

Figure 4. Chassis design for Blue 2.0.

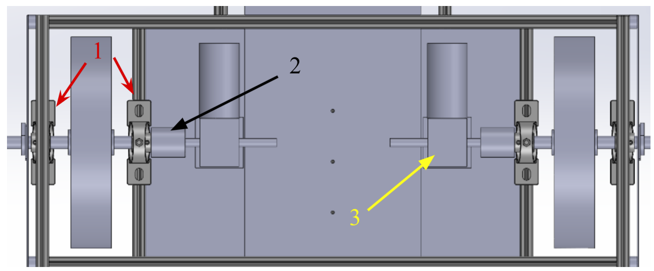

Figure 5. Drivetrain top view with references to significant components.

The baseplates were designed to accommodate payload storage and electronic mounting. Both were custom routed based on the CAD models and made from $\frac{1}{8}$" aluminum. The bottom plate on the left provides structural support to the long box at the front of the robot and allows for level mounting of the motor blocks. The top plate on the right houses two twelve-volt DC batteries and serves as the main payload storage. The payload is an 8"x8"x16" cinder block weighing about 20 lbs. The acrylic top plate shown in Figure 2-1.1 primarily adds weatherproofing and provides space to mount peripherals such as the camera and LiDAR systems. It is made from $\frac{1}{8}$" acrylic sheeting.

2.1.4. *E-Stop Tower*

The E-Stop Tower was a late addition to the design but proved to be crucial. IGVC 2024 mandates that the E-Stop button must be located at the rear of the robot and be a minimum of 2' above the ground. Consequently, the team opted to construct a tower at the rear to maintain the low-profile "T" shape of the chassis. It is built using T-Slot aluminum and will be enclosed with $\frac{1}{8}$" acrylic plates, ensuring weather resistance on all sides.

2.2. *Electrical*

The pursuit of safety and efficiency underscores the core objectives driving the evolution of this year's

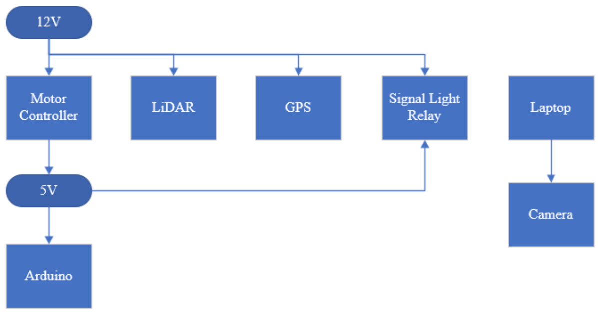

Figure 6. Electrical system breakdown chart.

robotic platform, as outlined in two key subsections: Safety and Power. The Safety subsection illuminates the meticulous measures taken by the electrical team to fortify vehicle safety and reliability. Grounding the chassis and integrating terminal blocks and DIN rails align with industry standards, elevating maintenance practices and overall safety. Notable safety enhancements include fuse installation to safeguard against overcurrent situations and the integration of a mini diode with the Arduino to mitigate back voltage concerns. Furthermore, the incorporation of wireless and wired emergency stop systems, alongside a compliance-driven safety light, ensures prompt response to critical situations. Meanwhile, the Power subsection delves into the redesign of the power system, transitioning from a three-battery setup to a more streamlined two-battery configuration. This strategic shift not only enhances energy efficiency but also extends operational endurance, facilitated by the utilization of 12V batteries in parallel. Leveraging the onboard 5V converter optimizes power distribution, streamlining the setup and maximizing overall system efficiency. The electrical system can be seen in Figure 6 These concerted efforts underscore a commitment to innovation, safety, and performance optimization within the project's framework.

2.2.1. *Safety*

For the electrical team, the primary focus has been on enhancing vehicle safety and reliability. This has been achieved through various measures. Firstly, the chassis has been fully grounded to mitigate electrical hazards and improve user safety. Following industry standards, terminal blocks and DIN rails were incorporated, conforming to professional practices and enhancing maintenance and overall safety. A critical safety feature includes the installation of a fuse directly after the battery and before the motor controller, designed to protect against overcurrent situations.

To refine the design, last year's model was revisited and simplified, with a focus on enhancing both safety and functionality. A mini diode was integrated with the Arduino to prevent harmful back voltage from affecting the motor controller, addressing issues observed with previous motor controllers. The implementation of both wireless and wired emergency stop systems ensures immediate shutdown capability in emergencies. Additionally, a safety light has been mounted to meet competition standards. Efforts are also underway to standardize wire colors, facilitating easier troubleshooting and diagnostics.

Electrical Requirements						
Component	**Voltage Supply**	**Voltage Necessary**	**Voltage Rating**	**Current Supply**	**Max Current Draw**	**Current Rating**
Batteries	12V			22 Ah		
LTU Laptop						
GPS		12V			41mA	
Stack Light		12V			4mA	
Arduino Uno	5V	7V	12V		17mA	
Remote Control Reciever		5V				
Camera (ZED 2i)		5V			38mA	
Motor Controller		7-45V				60A
Battery Switch			12V			100 A
Wireless E-Stop			12V			10A
Hardware E-Stop			12V			2.5A
Motors		12V			40A	
				TOTAL	42A	

Figure 7. Evaluation chart used for battery sizing.

2.2.2. *Power*

In this year's project, the power system has been redesigned, transitioning from a three-battery setup to a more efficient two-battery arrangement. This new system employs two 12V batteries in parallel, doubling the capacity to 44 amp-hours while retaining the 12V output. This extension allows the robot to operate for over an hour. Additionally, we've utilized the onboard 5V converter from the motor controller to power all of the 5V components, optimizing efficiency and simplifying the setup. The battery and power requirements can be seen in Figure 7.

2.3. *Programming*

In the development process, the team harnesses a variety of tools and structures. The programming environment predominantly revolves around Linux, specifically Ubuntu Focal Fossa, complemented by Python and ROS (Robot Operating System). The central processing unit of the robot is the Lenovo Thinkpad P1 Gen 5, a school-issued laptop, which handles all control functionalities. ROS facilitates communication between different components through the utilization of nodes. These nodes enable concurrent transmission and reception of messages pertaining to lane following, object avoidance/detection, and waypoint navigation. By employing flags, the team effectively utilizes these messages sent through the nodes, enabling sensor fusion for enhanced decision-making. The Arduino serves as an intermediary between the laptop and the motors, facilitating communication by sending serial messages through

Figure 8. Motor controller utilized for the 2024 IGVC robot.

Figure 9. Camera utilized for the 2024 IGVC robot.

the ROS nodes and subsequently generating output signals to drive the motors. This comprehensive integration of tools and structures forms the backbone of the programming framework, ensuring seamless interaction and coordination within the robotic system.

3. INNOVATIONS

The team has introduced significant innovations across various disciplines. Mechanically, a suspension caster has been implemented, marking a departure from previous practices where suspension was not utilized. This incorporation of suspension enhances stability and feedback from the Stereolabs ZED camera (Figure 9), while also paving the way for future teams to consider full suspension implementation on all wheels. Electrically, substantial circuit reduction has been achieved compared to previous years. Leveraging the capabilities of the Cytron MDDS60 Motor Controller (Figure 8), the team now benefits from a low voltage supply for the Arduino and select peripherals. By utilizing the motor controller's switch port, the team has eliminated the need for a previous relay circuit associated with the motors for both wireless and hardwired emergency stop functionalities, streamlining the circuitry from previous iterations. On the programming front, the team has focused on developing a configurable simulation environment and dynamic reconfigure feature. This enables swift adjustments during competitions, with configurable parameters such as robot-to-object distance and object recognition thresholds. These adaptive features empower the team to optimize performance in real-time scenarios, showcasing a meticulously crafted robot design driven by innovative solutions.

4. DESIGN: MECHANICAL

The Chassis, Drivetrain and Suspension, and Weatherproofing sections encapsulate pivotal aspects of the robotic platform's design and functionality. The Chassis subsection meticulously outlines compliance with IGVC regulations, detailing dimensions and features tailored to meet competition standards while accommodating payload and drivetrain components. Drivetrain and Suspension delve into the meticulous assembly of components to ensure stability and functionality, addressing setbacks encountered in previous iterations and innovatively integrating suspension for improved performance. Finally, the Weatherproofing strategy, employing acrylic to shield electronic components, underscores a proactive approach to safeguarding critical systems from environmental hazards. Together, these subsections reflect a commitment to meticulous design and robust functionality in the robotic platform.

4.1. *Chassis*

The chassis design meticulously adheres to the stringent requirements outlined by IGVC regulations. With a width of 37.07 inches and a length of 36.33 inches (Figure 10), the design incorporates specific features to ensure compliance. A rear stack facilitates easy access to the Emergency Stop at over 2 feet off the ground, aligning with competition rules. It also allows visibility for the safety light stack. The chassis length is thoughtfully engineered to accommodate both the payload and drivetrain components, including the brick's dimensions, two batteries, the motor controller, and the rear emergency stop stack. Anticipating a nominal body height of approximately 4 inches above the ground, the robot's overall height remains comfortably under the 6-foot limit stipulated by the rules. Furthermore, the width of the chassis is meticulously engineered to accommodate the entire drivetrain assembly, the brick, and batteries, ensuring compliance with competition standards. Through simulation (Figure 11), an optimal wheelbase of less than 29.64 inches is determined for navigating inclines, with the current distance between the wheels falling within the range of 22.57 inches to 25.07 inches, a configuration that seamlessly aligns with recommended guidelines.

4.2. *Drivetrain and Suspension*

To secure the driven wheels firmly in place, the team employed shaft collars on either side, augmented by locking nuts on the bearings. A critical consideration involves the variation in shaft sizes between the wheel and the motor, which necessitates the use of an adapter lock jaw coupling. This component will effectively transition the motor shaft from $\frac{1}{2}$ inch to the wheel shaft's $\frac{3}{4}$ inch diameter. The assembly is shown in Figure 12. It is worth noting that meticulous fabrication of the

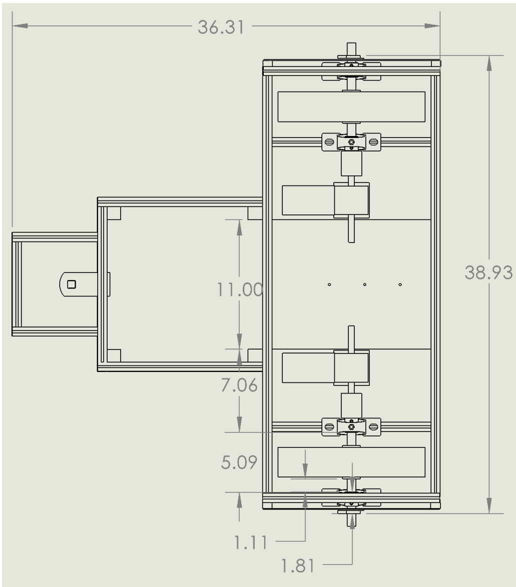

Figure 10. Length and width dimensions of the 2024 IGVC robot.

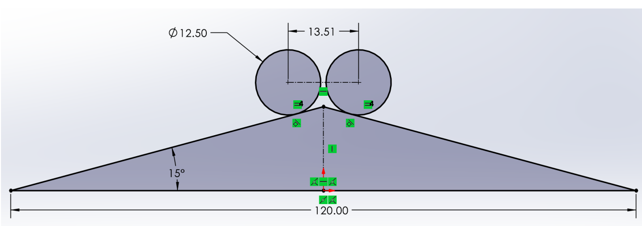

Figure 11. Simulation to determine wheel base for traversing the incline.

drivetrain is paramount, as last year's robot encountered significant setbacks in this area, making it a pivotal aspect of this teams' design focus. The robot has a differentially-driven design, granting it the advantage of pure rotation about its z-axis. With an infinitesimally small turning radius (Figure 13), the 3-foot performance metric for turning is well within reach. Although the course guarantees a minimum 5-foot turning radius, the team has deliberately set the bar high, aligning the teams standards with precision and excellence in maneuverability. Due to the team's lack of experience in implementing suspension systems, coupled with the one-year development timeline and the absence of suspension in previous iterations, the decision was made to integrate a caster wheel with built-in suspension as seen in Figure 14. Delving deeper into the mechanics, we determined that the caster would bear a considerable load, approximately 60 lbs. This was determined by weighing the rear of the previous years' robot near the caster wheel, which justified the selection of a caster capable of withstanding a maximum compression of 100 lbs. This

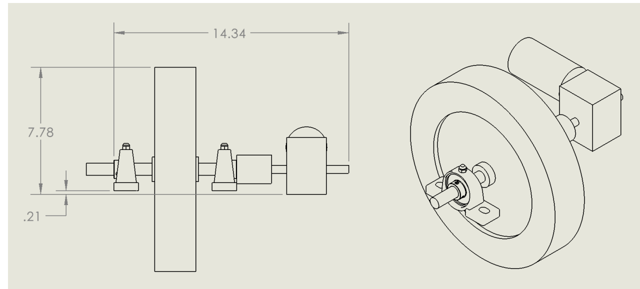

Figure 12. Detailed view of the teams drivetrain.

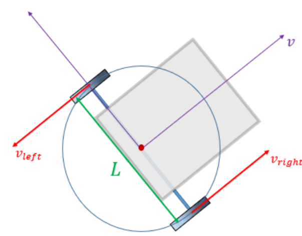

Figure 13. Turning radius provided by a diferential robot design.

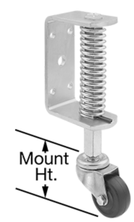

Figure 14. Suspension caster chosen for suspension implementation.

approach facilitated the implementation of suspension with minimal complexity and optimal efficiency. The introduction of suspension has notably enhanced camera stability, marking a significant improvement for the team.

4.3. *Weatherproofing*

Strategically, the team employed acrylic to shield the main electronic components from potential damage. The acrylic is securely fastened using M4 screws and epoxy, guaranteeing a snug and protective seal.

5. DESIGN: ELECTRICAL

Within the robotic platform's architecture, three critical subsections, namely Powertrain, Sensors and Computing, and Wiring, collectively underpin its operational prowess and reliability. The Powertrain segment delineates a meticulously crafted setup, featuring a strategically mounted 12V 44Ah system on the chassis's lower level. Key elements like the main power switch with integrated safety measures, parallel battery configuration, motor controller, and dual emergency stops converge to optimize stability, safety, and power efficiency. In Sensors and Computing, the top acrylic plate serves as the nerve center for essential components, including cameras, LiDAR, Arduino, laptop, relay, and GPS. This arrangement fosters seamless integration and functionality, facilitating real-time environmental scanning, navigation, and precise positioning. Meanwhile, the Wiring aspect underscores the meticulous selection of wire gauges to ensure safe and efficient power transmission throughout the system, ensuring the robustness and reliability of the robotic platform. Together, these subsections epitomize a holistic approach to design and implementation, culminating in a formidable solution poised to meet the project objectives with precision and efficiency.

5.1. *Powertrain*

The 12V 44Ah powertrain is strategically mounted onto the lower level of the chassis, optimizing stability with a low center of gravity and minimizing noise interference in sensor data for precise readings. Key components include a main power switch with a built-in 100A fuse for safety, a parallel battery setup to enhance current capacity, the motor controller, motors, and dual emergency stops (E-stops). The selected batteries provide up to 44Ah of usage, while the robot typically draws an average of 45A during operation. With anticipated usage totaling less than an hour of consecutive use during testing and performances, the 44Ah capacity proves ideal. The MDDS60 motor controller accommodates steady currents of 60A, with peaks of 120A, suitable for the NPC2212 motors (Figure 15) drawing nearly 40A. It also supplies 5V for the Arduino, with a diode incorporated to prevent voltage feedback into the 5V output. The controller was chosen based on in house availability, which eased the workload on the small team. The motors were also selected with the same practicality in mind. The motors are each protected with 60A fuses. In previous iterations, E-stops were wired to car starter relays for low-current wireless E-stop use. The motor controller's switch port, experiencing only mA of current, facilitates wireless E-stop integration. Both E-stops are wired in series into the switch port, ensuring motor shutdown when activated. The wireless E-stop functions at distances exceeding 100 feet as per regulations, while the manual E-stop remains easily locatable and accessible.

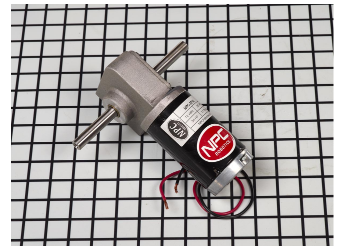

Figure 15. NPC2212 motors utilized on the 2024 IGVC robot.

5.2. *Sensors and Computing*

For the sensor and computing aspect of the design, the top acrylic plate serves as the mounting area, accommodating the 5V system and a couple of 12V sensors. Key components include a camera and LiDAR for real-time environmental scanning and navigation, an Arduino serving as the motor control unit, a laptop as the main processing unit, a relay for the light stack, and a GPS unit for precise positioning. The camera utilized is a first-generation ZED camera, handed down from the previous year for simplicity's sake. It draws power from the laptop and communicates via USB. The LiDAR utilized is a Hokoyu UTM-30LX (Figure 16) with a 270-degree viewing angle, powered by a 12V supply, and easily interfaced with ROS nodes. It was chosen based on in-house availability and communicates via USB with the laptop. The GPS used is the Atlaslink GNSS Smartlink (Figure 17), powered from the 12V supply and easily interfaced with ROS nodes through USB connection. The Arduino is powered from the motor controller's 5V supply, chosen due to team familiarity, and interfaces with ROS using the rosserial node and serial communication. It controls the motors. The team employs a Lenovo Thinkpad P1 G5 (Figure 18) for its computing power. A relay connected to the Arduino controls the light stack. The camera is mounted on the left front of the robot for efficient lane following, utilizing the left lane line. The LiDAR is positioned in the middle front for full range visibility for object detection, while the GPS is centered for precise waypoint navigation. The internal space of the stack on the rear of the robot houses the Arduino and facilitates cable management, optimizing functionality and space utilization.

5.3. *Wiring*

For wiring, 6AWG wires were utilized for power transmission, 14AWG for the motors, and 22AWG for the 5V system. This selection ensures optimal safety and efficiency in power distribution.

6. DESIGN: PROGRAMMING

Figure 16. Hokoyu UTM-30LX LiDAR utilized.

Figure 17. Atlaslink GNSS Smart Antenna utilized.

Figure 18. Lenovo Thinkpad P1 G5 utilized for computing.

The seamless integration of Framework and Sensor Fusion, Lane Following, Object Detection and Avoidance, and Waypoint Navigation delineates a sophisticated control architecture vital for the robot's dynamic navigation in complex environments. Central to this architecture is the Framework and Sensor Fusion, orchestrating smooth transitions between lane following and waypoint navigation while dynamically responding to object detection cues. Lane Following, powered by camera input and sophisticated proportional control algorithms, ensures precise motor control for optimal trajectory tracking, bolstering the robot's navigation capabilities. Object Detection and Avoidance, leveraging LiDAR technology, empowers the robot to autonomously detect and navigate around obstacles, seamlessly integrating with the overarching navigation strategy. Meanwhile, Waypoint Navigation, driven by GPS coordinates and IMU orientation data, provides accurate position tracking and navigation between predefined waypoints, facilitated by a robust ROS program orchestrating node interactions and driving commands. Together, these subsections epitomize a comprehensive approach to control and navigation, underpinning the robot's capability to navigate challenging terrains with agility and precision.

6.1. *Framework and Sensor Fusion*

The robot's primary control mechanism revolves around lane following. However, upon detection of an object by the object detection and navigation node, a message is dispatched to the main node, instructing it to disregard move messages from the lane following node. Once the main node receives confirmation that object avoidance maneuvers are complete, it reverts to lane following mode. This cycle repeats until the main node receives notification from the waypoint navigation node, indicating entry into the waypoint navigation section of the course and nearing a GPS coordinate. Upon reaching the fourth waypoint, the main node resumes lane following, while remaining vigilant for object avoidance requirements. This systematic approach ensures efficient navigation through dynamic environments, seamlessly transitioning between lane following and waypoint navigation as required.

6.2. *Lane Following*

The lane following node is pivotal in motor control, relying on a camera for lane detection and employing proportional control techniques for precise tracking. Data from the camera is received via the `/usb_cam/image_raw` topic, with a focus on the lane line within its field of view. An innovative feature involves adjusting a reference line's distance from the lane line centroid, ensuring safe robot positioning away from lane boundaries. Through pre-performance testing, the optimal distance is determined. Masking techniques minimize noise and errors in centroid calculations, particularly around curves, with adjustable masking areas. The program then utilizes the `/cmd_vel` topic to compute required angular and linear velocities for the motors. These velocities are sent to the Arduino via the `/comms/arduino` topic for motor control, where arithmetic ensures the lane line centroid aligns with the reference line via proportional control which can be seen in Figure 19. This iterative process guarantees consistent and reliable motor control, essential for effective lane following.

6.3. *Object Detection and Avoidance*

Leveraging LiDAR technology, the team detects objects within a customizable distance threshold. Adjustments to this threshold are essential for competition, ensuring a safe distance for object recognition and subsequent avoidance maneuvers. Upon object detection via the `/scan` topic, the robot advances until reaching a

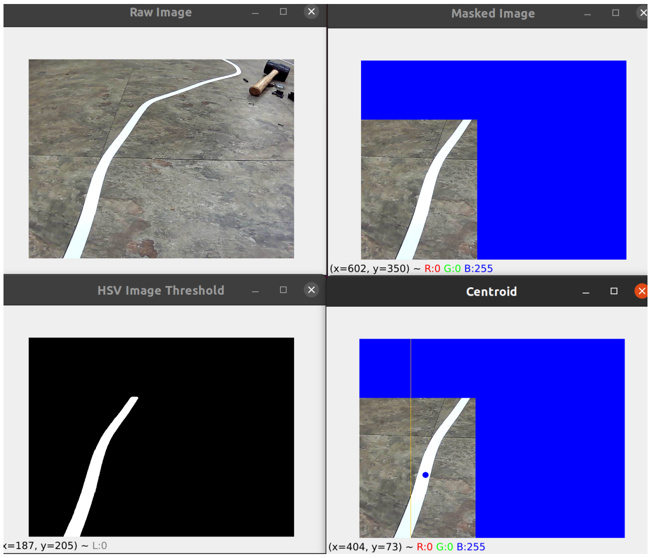

Figure 19. Lane following techniques utilized.

specified adjustable distance, at which point it records and stores its heading. Subsequently, the robot executes a 90-degree rotation to the right, aligning with the lane-following strategy, and continues straight until the object is visible in the designated rear window of the LiDAR scan. Once the object is passed, the robot performs a left 90-degree rotation and repeats the previous process. This iterative sequence continues until the horizontal lane node signals the robot nearing the course border. At this point, the robot resumes its original heading and lane-following trajectory, integrating object detection seamlessly into its navigation strategy.

6.4. *Waypoint Navigation*

The ROS program utilizes four GPS coordinates provided pre-competition to determine navigation for the waypoint section. The AtlasLink GNSS Smart Antenna delivers live GPS data with 16 centimeters accuracy, parsed by the ROS `nmea_navsat_driver`. Latitude and longitude coordinates are transmitted via the `/fix` topic. To supplement GPS, an IMU determines orientation, ensuring accurate navigation between waypoints. The 9-axis IMU, linked to an Arduino UNO, provides the robot's heading (yaw angle) via the `/yaw` topic. A computation node combines GPS and yaw data, calculating distance and bearing angle using the haversine formula and trigonometry. The navigator node, functioning as a listening state machine, orchestrates node interactions based on if-else conditions. It subscribes to computation and object avoidance nodes, prioritizing the flags to execute driving commands accordingly. In absence of obstacle or specific waypoint conditions,

$$\omega_L\left(\frac{rad}{s}\right) = \frac{linear.x}{r} - \frac{L(angular.z)}{r}$$

$$\omega_R\left(\frac{rad}{s}\right) = \frac{linear.x}{r} + \frac{L(angular.z)}{r}$$

$$\omega_L(RPM) = \frac{60(linear.x - L(angular.z))}{2\pi r}$$

$$\omega_R(RPM) = \frac{60(linear.x + L(angular.z))}{2\pi r}$$

Figure 20. Motor control equations, where ω_L is the angular velocity of the left motor, linear.x and angular.z is the linear and angular velocities calculated in ROS, r is the radius of the tire, L is the distance between the two driven wheels.

it defaults to twist commands from the lane following node.

6.5. *Motor Control*

Motor control within the robot's system is facilitated by the Arduino microcontroller, working in tandem with the MDDS60 Motor Controller. Operational directives are conveyed to the Arduino via twist messages from the main node through serial communication. Upon receipt, the Arduino processes these instructions, calculating various parameters. Leveraging the kinematics of the differential drive robot, the team devised equations tailored to the application's needs. The Arduino translates linear and angular velocity inputs from the main node into motor RPM values (Figure 20), enabling precise control. This data is then utilized to execute motor commands, ensuring accurate movement and navigation aligned with the robot's operational requirements. Through seamless collaboration between the Arduino and the MDDS60 Motor Controller, the robot achieves efficient and responsive motor control functionality crucial for its operation.

6.6. *Dynamic Reconfigure*

By leveraging the dynamic reconfigure (Figure 21) feature in ROS, the team is positioned to make real-time adjustments during competition and refine the robot's calibration. This functionality enables swift modifications to parameters such as sensor thresholds, control

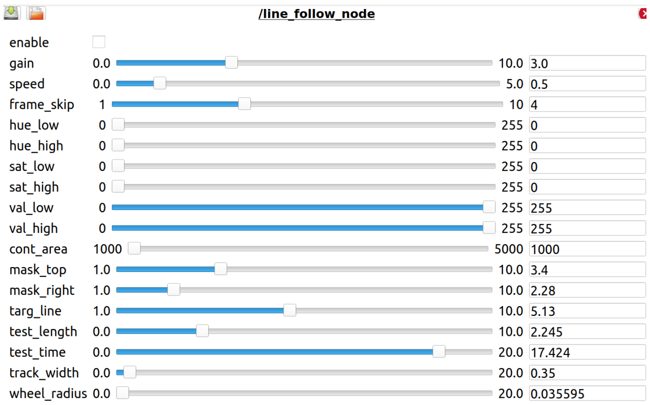

Figure 21. An example of the dynamic reconfigure that will be used in competition for ease of implementation.

gains, or navigation algorithms without necessitating a system restart. Such adaptability empowers the team to promptly address emerging challenges, fine-tune performance, and optimize the robot's behavior to suit varying environmental conditions encountered during competition scenarios. Consequently, this capability enhances the robot's agility, responsiveness, and overall competitiveness in navigating complex terrains or executing intricate tasks with precision and efficiency.

7. CYBER SECURITY ANALYSIS

Within the framework of the IGVC Auto-Nav Design Report, the team faces a notable challenge: the members are roboticists with limited exposure to the intricacies of cyber security. This deficit in expertise poses a significant hurdle as the team endeavors to comprehensively address the security aspects inherent in the design. Without a firm grasp of cyber security principles and methodologies, the team's ability to conduct thorough analyses and implement robust security measures is inherently compromised. Recognizing the critical importance of cyber security in the development of autonomous systems, the team must seek external guidance or expertise to bridge this gap. By leveraging the knowledge and insights of specialists in the field, the team can fortify its design against potential vulnerabilities and ensure the integrity and reliability of the autonomous navigation system.

8. DESIGN ANALYSIS

The Mechanical, Electrical, and Programming aspects form the cornerstone of the robotic platform's design, each undergoing rigorous analysis and refinement to ensure optimal performance and reliability. In the Mechanical domain, extensive stress testing uncovered critical vulnerabilities, driving the team to address issues such as nut and bolt looseness and inadequately secured bearings. Design analysis, facilitated by Solidworks, focused on dimensioning requirements and basic static analysis to validate load-bearing capacities. Meanwhile, the Electrical team adopted a trial-and-error approach to refine the system, streamlining components while integrating industry standards for enhanced efficiency and ease of maintenance. Lastly, the Programming team harnessed Gazellesim, a simplified simulation environment, to iteratively analyze and refine the design, laying a robust foundation for its eventual implementation and ensuring its efficacy in real-world scenarios. Together, these subsections underscore the commitment to meticulous design and iterative refinement, culminating in a reliable and high-performing robotic solution for the project objectives.

8.1. *Mechanical*

The rigorous stress testing of the robot uncovered critical vulnerabilities. Nut and bolt looseness emerged as a recurring issue, alongside inadequately secured bearings to the chassis. Comprehensive testing, including payload simulation and full-speed operation, was conducted to validate the robot's reliability for competition. Solidworks served as the primary tool for design analysis, focusing on dimensioning requirements. While Finite Element Analysis (FEA) was not conducted due to its non-essential nature and the team's limited familiarity with the process, basic static analysis was performed to verify the T-slot's load-bearing capacity at the driven motors.

8.2. *Electrical*

In the design analysis for the electrical system, a trial-and-error methodology was adopted to refine and optimize the design. This process included a thorough review of the previous year's system, aiming to identify and eliminate any unnecessary or over-engineered components, while integrating more industry standards. The objective was to simplify the design without compromising functionality. This simplification resulted in a significant reduction in the number of components compared to last year's design, while maintaining the same level of performance and functionality. This approach enhances efficiency and contributes to the overall reliability and ease of maintenance of the system.

8.3. *Programming*

The programming team has leveraged the Gazellesim simulation environment to thoroughly analyze the design. Developed by an LTU graduate student, Gazellesim offers a simplified alternative to Gazebo, a widely used robotics simulation tool. Due to its familiarity and ease of use, Gazellesim has proven indispensable to the team's implementation success. By conducting repetitive simulations and testing within this environment, the team gains valuable insights into the performance and functionality of the design. This iterative process not only refines the solution but also establishes a solid foundation for the eventual implementation of the final solution, ensuring its efficacy and reliability in real-world scenarios.

9. PERFORMANCE ASSESSMENT

As of the current stage, the team is on track to meet qualification requirements. Each programming node operates independently, showcasing individual functionality and readiness. The electrical components have been thoroughly tested and demonstrate full functionality. However, in the mechanical aspect, the final step of applying loctite to all screws is pending completion to ensure system integrity. Despite these advancements, the programming team faces challenges in testing the full implementation of nodes working in unison, primarily due to difficulties encountered with flags. Addressing these issues will be crucial to achieving seamless integration and overall system coherence, ultimately bolstering the team's readiness for competition.