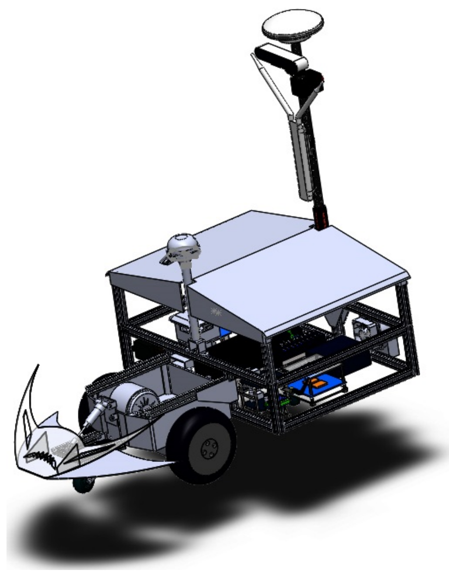
Military Technical College

IGVC 2025 Design Report: Zoser v2.0
Pharaohs Team

Team Leader: Bassam Salama, umistic-3@mtc.edu.eg

Team Members

Mohamed Zakaria Hassan
Mohamed Yasser El-Ragabi
Omar Khaled Omran
Mostafa Bahaa
Abdelrahman Mohamed
Ziad Fawzy
Seif Ahmed Amer
Ahmed Khaled Ahmed
Ahmed Yasser Ahmed
Omar Ahmed Ghonem Farw
Mostafa Menshawy
Mohamed Emad Attia



Advisors
Prof. Hosam Ragheb, h.ragheb@mtc.edu.eg,
Assoc. Prof. Mohamed A. Kamel, mohamed.kamel@mtc.edu.eg
Assoc. Prof. Tamer S. Attia, t.attia@mtc.edu.eg
Asst. Prof. Ahmed Bendary, a.bendary@mtc.edu.eg
Eng. Mohamed Mousad, M.mousad@mtc.edu.eg

I certify that the design and development of this project is significant and equivalent to what might be awarded credit in a senior design course.

Signature: 15/5/25 Ragheb MK A. Bendary

May 15, 2025

Abstract

This report outlines the design, functionality, and overall performance of the Zoser v2.0 robot during the IGVC competition, showcasing its capabilities as a competitive autonomous vehicle. The robot utilizes a LiDAR sensor for obstacle detection by emitting laser beams to scan the surrounding environment. In addition, we developed an AI model for efficient lane detection and following. To enhance the robot's navigation, the robot uses a Swift-Nav GPS for waypoint navigation. To improve the accuracy of localization for the robot, we designed a goal selection algorithm to achieve navigation through given waypoints. The system developed for our robot has enabled us to create a pioneering and efficient autonomous navigation system.

1 Design Process, Team Identification and Organization

1.1 Introduction

Innovations that could help the world are what **Pharaohs team** is passionate about. From Egypt, we represent the **Military Technical College (MTC)**. For this year, our goal is to compete in **(IGVC) 2025** successfully and push the boundaries of autonomous vehicle technology, combining engineering excellence, cutting-edge robotics, and innovative design to create an innovative vehicle that can navigate complex environments with high precision.

The achievements are a testament to our hard work, collaboration, and relentless pursuit of excellence. We achieved the fourth place in URC 2016, the second place in Virtual URC 2020, and the second place in ICMTC 2023.

Pharaohs team consists of talented and experienced students specializing in robotics, AI, mechanical engineering, and software development. We play a crucial role in creating our **Zoser v2.0**, by working together to overcome challenges and develop a smart and reliable vehicle from conceptual design to real-world implementation.

Thus, the Pharaohs team proudly introduces: **Zoser v2.0** that demonstrates our innovation and expertise in the design, control, and manufacturing of Zoser v2.0, as we participate in the **2025 IGVC Auto-Nav competition**.

1.2 Team Organization

Pharaohs team is made up of 13 undergraduate students from different departments and academic years, as shown in Figure 1 under the supervision of MTC faculty members. In addition, Table 1 lists the team members and their respective roles.

It is worth mentioning that an additional ten members from the first and second academic years have joined the team to gain experience from more senior students. Each sub-team is led by an experienced student from the third or fourth year to ensure strong leadership, knowledge transfer and teamwork.

Pharaohs team operates under a well-organized and dynamic structure that fosters collaboration, innovation, and leadership. With each member playing a key role, the team is structured to excel both through individual contributions and collective success. The leadership is strong and provides clear direction from senior members, ensuring the team remains focused on achieving its goals.

The unmanned ground vehicle **(UGV) Lab** (400 m^2) has access to digital libraries such as the **Egyptian Knowledge Bank** and all necessary software licenses required for the project. Being part of MTC, it guarantees excellent communication between teams and facilitates weekly meetings for each sub-group, as well as a general team-wide meeting.

1.3 Assumptions and Design Process

Each sub-team has specified problems to solve from theory, design, calculations, and practical perspectives such as ROS, Arduino, LabVIEW, Solid Works, Inventor, and Web API Design Suit. The overall system is simulated and tested before it is implemented using ANSYS, GAZEBO, MATLAB, ..., etc. The production phase is carried out in the Arab Organization for Industrialization (AOI) and workshops/labs at MTC. Then, all subsystems are integrated, and the overall testing is done through an emulated course with actual obstacles. To summarize, we carried out our survey and research. theory and design, calculations, simulations, fabrication, integration, testing and validation, feedback, and final Product.

1.3.1 Fund

MTC funds our project, and the entire components cost approximately 2500 USD including the manufacturing.

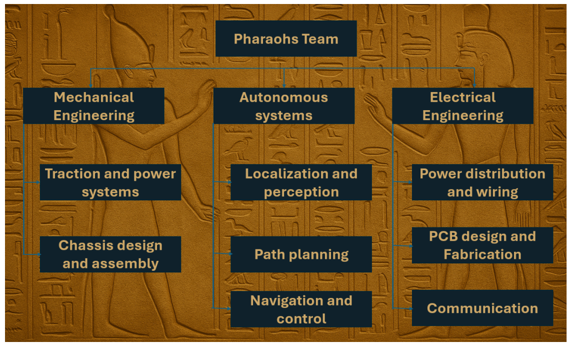


Figure 1: Team structure of Pharaohs

Table 1: Team members and their role

Name	Class	Major	Role	Hours
Bassam Salama	2026	Communication Eng.	Team Leader	220
Omar Ahmed Farw	2027	Civil Eng.	Chassis Design	220
Mostafa Menshawy	2027	Computer Eng.	Simulation	100
Mohammed Zakaria	2025	Civil Eng.	Assembly and Fabrication	200
Abdelrahman Mohamed	2025	Computer Eng	Path Planning	250
Omar Khaled Omran	2026	Computer Eng.	Image Proceeing	400
Mohamed Emad Attia	2026	Computer Eng.	Communications	150
Ahmed Yasser Ahmed	2026	Communication Eng.	Communications	180
Mohammed Yasser El-Ragabi	2026	Computer Eng.	Media	160
Ziad Fawzy ElSayed	2027	Electrical Eng.	Image Processing	120
Ahmed Khaled Ahmed	2026	Electrical Eng.	Wiring	130
Mostafa Bahaa	2026	Electrical Eng.	Communications	190
Omar Wael	2027	Civil Eng.	Chassis Design	150
Yehia Shata	2027	Electrical Eng.	Communications	170
Hamdy Gaber	2027	Electrical Eng.	Communications	180
Mostafa Abdelhamed	2028	Mechanical Eng.	Power	120

1.3.2 Weight and Transportability

Our robot is lightweight 22 KG relative to the rules of the IGVC competition. This reduced weight offers several practical advantages. First, it simplifies transportation to and from the competition site, allowing the team to move Zoser v2.0 without requiring specialized equipment. Second, manageable weight improves the ease of handling during setup, testing, and storage. Finally, the lightweight design contributes to safer manual lifting and reduces the risk of damage during packaging and shipment. In general, the robot's weight has been optimized to strike a balance between structural integrity, system performance, and portability.

1.3.3 Safety

"Our safety comes first." This is the first rule we learn after being accepted into the competition. We check the equipment and electric components. However, the design of our robot is designed to protect both the system and the individuals in proximity to the robot. To mitigate the risk of damage, we incorporate several safety features. We chose **high-quality fuse boxes**, **relays**, and **safety kill** switches which are strategically integrated into the system to ensure that no short circuits or potential component failures could occur. These systems disconnect the power from the battery, minimizing the risk of further damage. The first enemy for any electric project is the weather, such as rain, dust, temperature, ... etc., ·, etc. As a result, we prioritize **weather-proofing** to enhance Zoser v2.0 performance under different environmental conditions by using insulating material between assembled parts, helping us to enhance robot protection. It is worth mentioning that we use efficient fans on the sides of the compartment to decrease the incoming heat from the electric component and keep it as low as possible. In addition, our motors are mounted in protective casings, ensuring resistance to splashing and water exposure. We chose a suitable type of wheel to enhance the traction and reduce the slippage. These comprehensive safety procedures are committed to ensure the reliability and safety of our systems.

1.3.4 Reliability and Durability

After many iterations during the design phase, the system has exhibited consistent performance. In addition, Zoser v2.0 has shown the ability to withstand testing conditions without any signs of wear, tear, or deterioration under different testing conditions. To reinforce critical points and improve overall durability, steel supports are used as additional support. In addition, all components are securely mounted with screws, ensuring robustness and stability even in challenging environments. In addition, modularity is an important key aspect in our design. All electrical and mechanical components are easily replaceable in case of failure.

2 System Architecture

2.1 Mechanical Components

- Chassis: Custom aluminum frame designed for weight and strength balance.
- Suspension System: Independent spring-damper setup for stability on uneven terrain.
- Sensor Mounts: Rigid aluminum brackets for the camera, LiDAR, and GPS antenna to ensure a fixed field of view.
- Motors: 350-watt Segway motors.
- Housing: 3D printed parts to fix the robot component.

2.2 Power Components

- Battery: 24V DC lithium-ion battery with 22000 mAh capacity.
- Power Distribution Board (PDB): Custom PCB with fuses and switches for isolating components.
- Buck: Step down converter from 24V to 19V, 12V and 5V.
- Relays: used as a mechanical switch to connect motors with drivers.

2.3 Electronic Components

- Microcontroller: Arduino Nano for low-level control.
- Mini PC: NUC for running AI models and the ROS stack.
- Motor Drivers: Cytron 30A DC to control DC motors via PWM/serial.
- GPS Module: For RTK-based localization.
- Inertial Measurement Unit (IMU): VectorNav for orientation and acceleration sensing.
- Lidar: RPLIDAR A2M12 2D for obstacle avoidance.
- Camera: Logitech camera for lane detection.

2.4 Safety Devices

- Mechanical E-stop: Hardware emergency stop button on chassis.
- Wireless E-stop: Remote control to cut power to motor drivers.
- Overcurrent protection: Fuses and circuit breakers for all high-current-consumption lines.

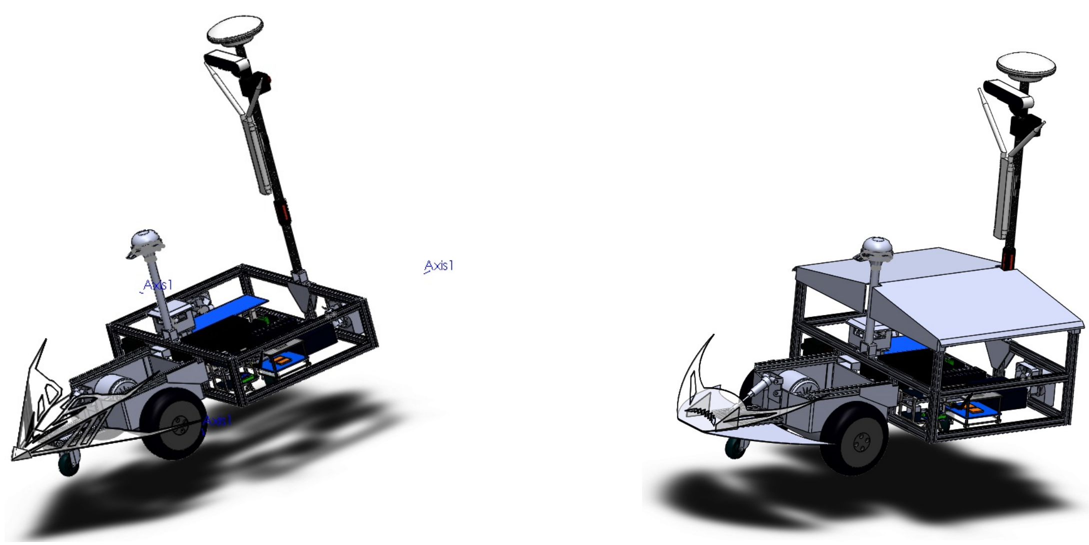
2.5 *Software Modules*

- Sensor Drivers: ROS nodes for GPS, IMU, LiDAR, camera vision, and encoders.
- Perception: Semantic segmentation using E-Net for lane detection and obstacle detection using LiDAR data processing.
- : Navigation using GPS and IMU provides accurate, real-time location tracking.
- Control Module: PID velocity controller for motion execution.

2.6 *System Interaction and Integration*

Zoser v2.0 autonomous vehicle is a modular system built on the Robot Operating System (ROS), integrating hardware and software components to achieve perception, localization, planning, and control. At its core is the Intel NUC, which manages high-level processing tasks such as sensor data handling, decision-making, and path planning. It interfaces with an Arduino that handles low-level motor control. The vehicle is equipped with various sensors, including a 2D LiDAR, a Logitech camera, RTK GPS, and an IMU, all of which provide real-time environmental data. This data supports deep learning-based semantic segmentation for terrain and lane detection, as well as LiDAR-based obstacle localization. Localization is achieved through an Extended Kalman Filter that fuses GPS, IMU, and encoder data to maintain accurate positioning even when GPS is intermittent. The control system converts planned trajectories into velocity commands, which are executed by an Arduino Nano controlling the motors through cytron drivers. Power is distributed via a centralized board that supplies 24V, 19V, 12V, and 5V through regulated buckling converters.

3 *Effective Innovations*



(a) Zoser (b) Zoser v2.0

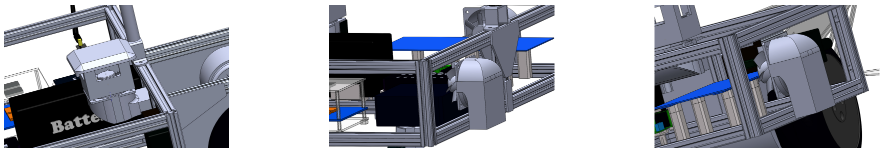
Figure 2: Zoser vs Zoser v2.0.

3.1 *Mitigating Unstable USB Connections*

A recurring issue was random USB disconnections. This was resolved by assigning persistent device names, which allowed the system to search for the device by name rather than relying on a specific USB port. This ensured stable reconnection even if the device was connected to a different port.

3.2 *Overcoming Overheating Problem*

The system experienced thermal issues during prolonged operation and testing. To address this, we designed a cooling system to overcome the overheating problem. Three cooling fans were added, two to exhaust hot air as shown in Figures 3a and 3b, and one to draw in fresh air from outside, these results, as shown in Figure 3c, in significant temperature regulation.



(a) (b) (c)

Figure 3: Three cooling fans.

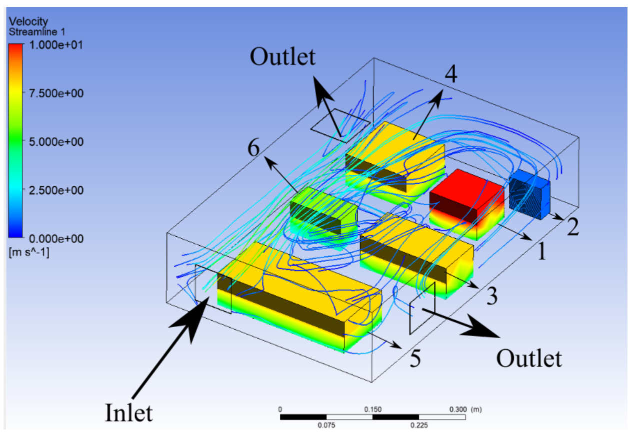


Figure 4: Heat distribution of cooling system.1- Motor drivers, 2- Arduino, 3- Battery, 4- NUC, 5- PCB, 6- USB HUB.

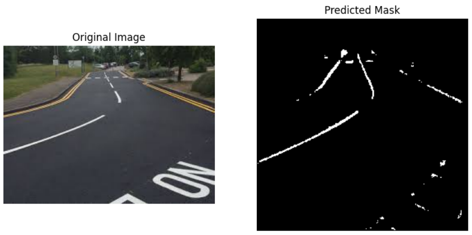
3.3 *Lane Detection and Following*

This year, we use an AI model based on the E-Net, which is a simplified version of the U-Net. This model is chosen because of its lightweight and high capability in performing Semantic Segmentation, where it identifies and classifies each pixel in the image. The main task of the model was to detect the presence of lanes on the road. The model was trained to assign a label to each pixel in the image as white if it belongs to a lane and black otherwise.

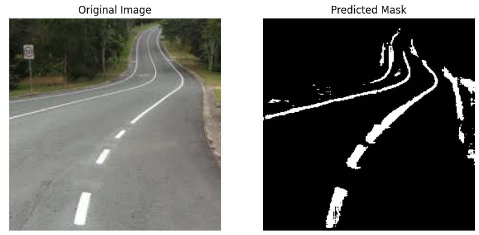
This approach is effective in recognizing lanes in images captured from the roads, which contributes to enhancing the performance of autonomous driving systems and provides accurate information about lanes location. For the data set, we use the TU Simple dataset, which is a well-known data set that contains images captured from a car on the road. We perform pre-processing on this dataset to make it suitable for use in our lane detection task. Once the model generates the output, we apply a Canny edge filter to refine the results. Based on the output and position of the lanes, we then make a decision about the location of the detected lane.

3.4 *Obstacle Avoidance*

To enhance the robot's navigation, we upgraded the LiDAR for greater precision and range, enabling faster and more accurate obstacle detection. This reduces collision risk and boosts overall safety. The improved LiDAR now works synergistically with the IMU, enhancing motion control through better environmental awareness, resulting in smoother and more stable movements. Previously, IMU scaling issues across different regions caused inconsistent readings. We addressed this by filtering LiDAR data and implementing auto-calibration, ensuring reliable performance regardless of location. These upgrades significantly improve obstacle avoidance, stability, and navigation reliability.



(a) Sample 1



(b) Sample 2

Figure 5: E-Net model output

3.5 Maneuverability

Maneuverability is one of the main challenges in the design of unmanned ground vehicles. We came up with a novel but simple idea to decrease the turning radius, which is to place the motors in the middle of the robot to rotate about its center. With this configuration, we achieved the minimum turning radius of about 130 cm, as shown in Figure 6. In addition, to reduce the total inertia of the robot during turning, we placed the payload above the motors.

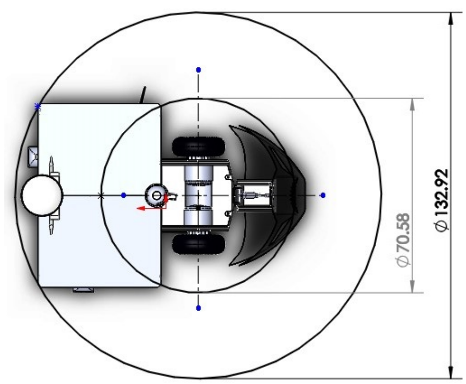


Figure 6: Novel maneuverability via minimizing the turning radius of the robot.

3.6 Preserving Continuous Traction

Placing the motors in the middle of the robot could cause traction loss if not managed intelligently. This problem is clearly observable when ascending uphills, as shown in Figure 7a. Our solution is to keep the wheels in continuous contact with the ground using a hinged mechanism that is designed for this purpose, as shown in Figure7b.

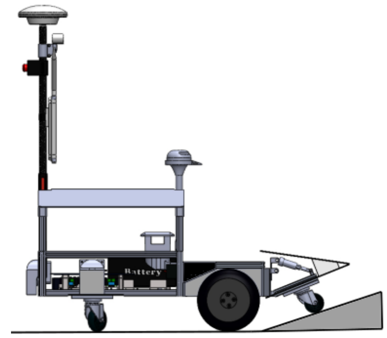
4 Mechanical Design

We are inspired the main chassis for Zoser v2.0 from a Segway scooter, along with additional components and parts. A tower is added to hold the GPS antenna, camera, E-stop switch, router, and the safety light. Figure 2b shows the overall design of the robot.

4.1 Chassis

The main chassis is made of aluminum profiles, carbon fiber rods, steel supports, and 3D printed parts. The design takes into consideration the regulations of the Auto-nav challenge regarding the weight and the dimensions. The main

(a) Losing traction.



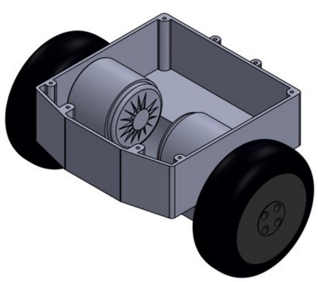
(b) Preserving continuous contact.

Figure 7: Motion of our robot when ascending uphill.

purpose of using 3D printed parts is to obtain the lowest cost, weight, and modularity of the robot. The 3D printed parts are used to fix some components such as the camera, the mechanical E-stop, and the battery.

The chassis consists of two main parts: the Segway body and the additional compartment. Starting from the additional compartment that compactly houses the main electrical components and the robot's power system. To ensure easy maintenance and serviceability, the roof can be easily opened to handle any possible problems. However, the Segway body houses the DC electrical motors with encoders and the main fuse box, as shown in Figure 10a. The compartment is attached to the body of the Segway and is supported by a castor wheel installed in the center, as shown in Figure 10b. The aluminum profiles are used in the compartment on the edges and the sides that are made of acrylic. To increase stability and maximize maneuverability, we made the ground clearance of the chassis (the least distance between the lower end of the chassis and the road) relatively small. To increase the ruggedness and strength of the chassis, the steel supports shown in Figure 8c are placed at critical points. To avoid the issues encountered in the previous iteration, we made several key modifications to the robot:

1. Added three cooling fans (right, back, and upper) to prevent overheating of the components during extended use.
2. The caster wheel was upgraded from aluminum to steel to improve durability and prevent bending when climbing ramps.
3. The LiDAR holder was redesigned to accommodate the new LiDAR sensor, ensuring secure mounting and accurate data collection.



(a) Main body.

(b) Castor wheel.

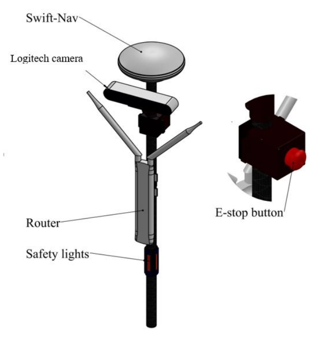
(c) Steel supports.

Figure 8: Chassis of Zoser v2.0.

4.2 Carbon Fiber Tower and Suspension Design

The robot tower is constructed from carbon fiber due to its lightweight nature, stiffness, and high strength-to-weight ratio. This tower supports critical components such as the mechanical E-stop switch, antenna, GPS, and camera, which expands the field of view to enhance navigation capabilities. In addition, the safety lights on the tower illuminate when the power is connected and blink when autonomous driving is activated, providing clear operational indicators. Figure 9a shows the CAD model of the carbon fiber tower with the attached components.

To improve robot mobility, especially on uneven terrain, we adopted a suspension system inspired by the 'wishbone' design. A hinged mechanism combined with a spring damper suspension is installed in the front of the robot, allowing it to ascend inclines up to 20°. This system absorbs impacts from road imperfections and enables the suspension on each front wheel to independently react to obstacles, maintaining stability by keeping all wheels in continuous contact with the ground. A spring with 1 kN/m stiffness was chosen to provide adequate support for the robot's weight while ensuring smooth operation. Figure 9b illustrates the spring action during ramp ascent.



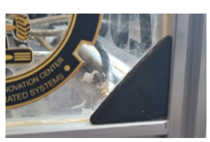
(a) Carbon fiber tower.

(b) Suspension design.

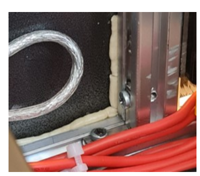
Figure 9: Carbon fiber tower and suspension design.

4.3 Weather Proofing

To weatherproof the robot, we use insulating materials between assembled parts to seal against water and dust, enhancing durability under various conditions, as shown in Figures 10a, 10b and 10c. Splash-resistant motors with protective casings were chosen to prevent damage from exposure to water. In addition, we redesigned the top cover by adding an acrylic sheet shaped like a gable roof to shield internal components from rain and dust and further improve protection and reliability.



(a)



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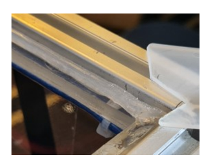
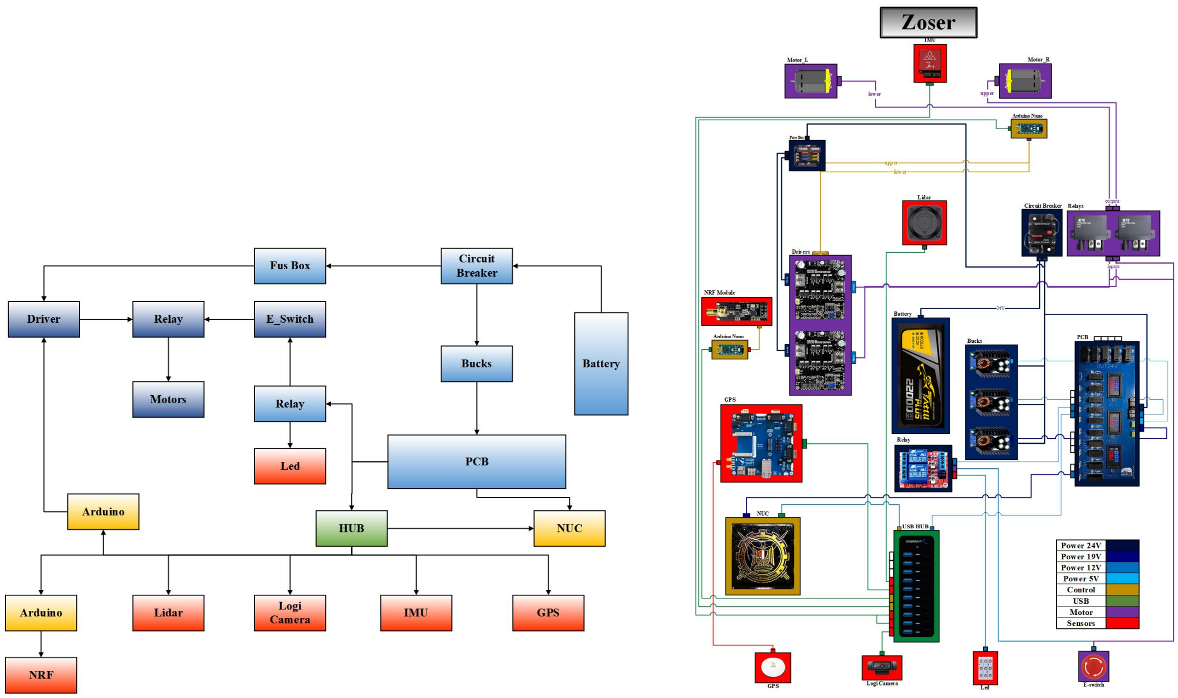


(c)

Figure 10: Weather proofing.

5 Electronic and Power Management Design

The reliability and durability of the system are our main focus for electronic and power design. To mitigate overload, a fuse box is added to protect motor drivers in addition to safety relays, and circuit breakers are chosen to achieve additional safety. We designed a modular PCB to distribute the required voltage for all boards and components. Our PCB integrates fuses for improved safety and protection. The power management system is made up of a 24V DC battery, a modular PCB that feeds all components with the required power, a fuse box, safety relays and circuit breakers, and two kill switches (mechanical and electrical). To improve the robustness of the control system, we use an Intel NUC mini-computer as our high-level controller that runs ROS and communicates via serial bus with the microcontroller. Then we use Arduino as a low–level controller that communicates with motor drivers. A PID controller is designed to improve the response of the motors during mission execution and decrease latency when receiving or sending the data. Our complete electrical system architecture is shown in Figure 11.



(a) Block diagram. (b) Schematic diagram.

Figure 11: Electrical system.

To optimize power distribution, our robot depends on a 24V DC lithium-ion battery with a capacity of 22000 mAh. The robot operation requires multiple voltages, including 5V, 12V, 19V, and 24V. Recognizing the need for a streamlined and efficient power distribution system, we designed and fabricated a custom-made PCB. It offers several key benefits, including compactness, reliability, ease of customization, and the required connection of components. Taking this step, we achieve a solution that ensures efficient power distribution while minimizing space requirements, in addition to minimizing the weight of the robot. This innovative approach not only enhances robot performance but also shows our commitment to using different cutting-edge technologies. Figure 12 shows the PCB.

Figure 12: Printed Circuit Board.

Our robot takes its main power from the LiPo Cell battery that provides 24V DC with a nominal discharge rate of 30A and a capacity of 22000 mAh. The wiring system is based on a PCB distribution board. It feeds 24V DC to the motors and router, 19V DC to the Intel NUC, 12V DC to the GPS, USB hub, relays, and safety lights. The system can operate for two hours and is charged in six hours. In addition, we use LCDs on the designed PCB to observe the distributed voltage and make sure that all output ports give the correct voltage. To minimize complex wiring, power distribution PCBs are designed and fabricated to feed the components with suitable voltages. Based on our experience, complex wiring leads to overheating, reduces system serviceability, and reduces fast troubleshooting ability. Therefore, in this robot, we use our designed PCB in addition to using fans to extrude the hot air from the inside of the compartment.

5.1 Schematic Diagram

As part of the Zoser v2.0 development process, Visu created a comprehensive circuit map to document and organize all electrical connections, as shown in Figure 11b. This circuit map served as a crucial tool for ensuring that all components are properly integrated and function as expected. By clearly mapping the connections between the sensors, the motors, and the central processing unit, the team was able to identify potential issues early and ensure efficient troubleshooting during both the assembly and testing phases.

5.2 Electronics Suite

The electronics suite in Zoser v2.0 is structured into three modules: control, sensors, and power, as illustrated in Figure 13. Two levels of control are implemented: a high-level controller (Intel NUC) and a low-level controller (Arduino Nano). The NUC serves as the main computer, enabling sensor fusion (LiDAR, GPS, IMU, and camera), fast data exchange via USB 3, and SSH-based communication with the control station. Collect data and send control signals to the Arduino Nano, which generates PWM signals for motor drivers. Perception begins with data collection from the LiDAR and camera, used to detect lanes and obstacles. Localization relies on GPS, IMU, and encoders to estimate pose. For added reliability, ultrasonic sensors assist in object detection if LiDAR fails. The encoders in each motor measure angular position and velocity, providing feedback to the NUC along with IMU and GPS data. The NUC then computes control inputs and sends them to the Arduino. A PID controller is used to minimize velocity error and improve system response.

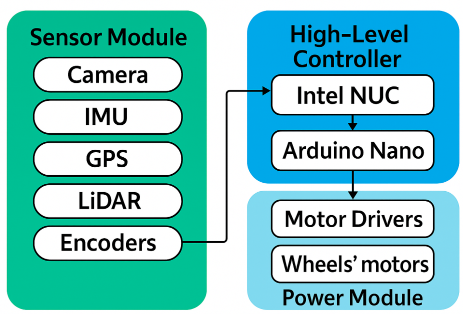


Figure 13: The electronic suite

5.3 Safety

To ensure the safety of the system and prevent any damage or potential risks, we have implemented robust safety features, as illustrated in Section 1.3.3. For potential short circuits and component failures, fuse boxes and safety kill switches are incorporated into the design. Batteries are equipped with a battery cell meter, which is set to provide an alert at low battery voltage. Efficient fans are placed on the sides of the compartment to remove the hot air and protect the circuits and electronic components from overheating. We use silicon on the chassis of Zoser v2.0 to prevent water from entering the electronics. In case of any unpredictable problem, we made mechanical and wireless E-Stop buttons to make the robot stop instantly.

5.3.1 Mechanical E-Stop

The mechanical E-stop switch is placed at a height of 80 cm above the ground on the tower for easy access and immediate activation. It is a distinctive red button that serves as a quick and reliable means of disconnecting power from batteries in emergency situations to prevent electric components from causing possible damage.

5.3.2 Wireless E-Stop

The wireless E-stop system utilizes an NRF communications module with 2.4GHz bandwidth as a transmitter, paired with a receiver to stop the system's operation. This allows us to stop the robot in emergency situations within a range of 80 meters (260 feet). Upon receiving the activation signal, the NRF receiver triggers a relay, effectively shutting down the system. A 3D printed case is mounted to the robot body, where the NRF module is mounted on it.

5.3.3 Safety Lights

The safety lights are placed on the tower to be visible, as shown in the figure. They indicate the condition of the robot. The lights illuminate when power is connected and start to blink when autonomous mode is running. They are protected against different weather conditions, allowing operation at any time. The lights are powered by 12V DC from the PCB feed.

6 Software

We use ROS as the main base for the software design to make it modular and fault-tolerant. The software uses a set of packages with nodes. This gives us a fault-tolerant capability, as in case any part of the system fails, we can run the robot without the failed part. Figure 14 shows the architecture of the designed software. In addition, ROS is the main connection between all parts of the robot.

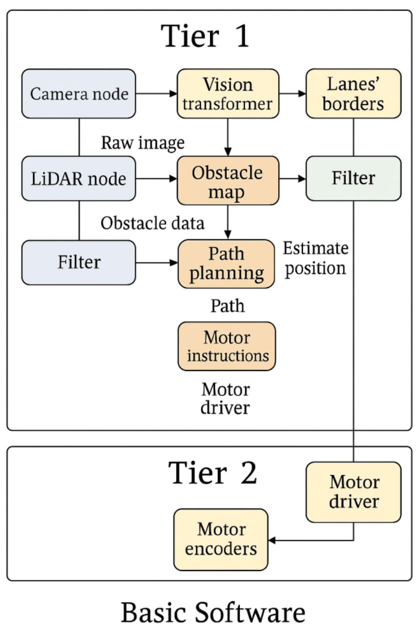


Figure 14: Software system

6.1 Lane Following System

To enable robust and real-time lane detection, the vehicle employs an AI-powered Microsoft vision system based on the E-Net architecture, a lightweight semantic segmentation model designed for embedded and real-time applications.

A wide-angle webcam is mounted on the top of the vehicle tower to provide a broad and elevated field of view. The captured video frames are preprocessed and passed into the E-Net model, which segments each frame into lane and non-lane regions at the pixel level. Unlike traditional methods that depend on edge detection or color thresholds, E-Net provides a semantic understanding of the scene, allowing the system to recognize lanes even under challenging conditions such as shadows, faded markings, or uneven lighting.

The model is trained using a diverse set of annotated road images to ensure generalization in various lighting conditions, lane shapes, and road textures. Once deployed, E-Net operates on the NUC.

Post-processing steps are applied to the segmented output to identify the centerline of the lane and compute the vehicle's lateral offset and heading relative to the path. These values are published through ROS and used by the control system to adjust the steering of the vehicle and maintain lane alignment.

6.2 Obstacles Detection

We utilize a LiDAR sensor for obstacle detection by emitting laser beams to scan the surrounding environment. This scanning process produces a dense set of distance measurements, allowing the system to identify and locate nearby obstacles with high accuracy.

Beyond mere obstacle detection, the LiDAR data are further processed to identify the largest navigable free space in the environment. By analyzing the spatial distribution of the detected points and calculating the angular gaps between obstacles, the system determines the widest area that is free from obstructions.

Once the largest verified free space is selected with the aid of the camera system, the system generates a movement command directing the robot or vehicle toward it.

6.3 Navigation, Localization and Motion Monitor

To increase the precision of localization for the robot, the system utilizes a Swift-Nav GPS for waypoint navigation. The purpose of this step is to get the best precision of the location of the robot. An IMU is used to detect the robot's orientation, facilitating angle adjustments to navigate accurately towards the specified direction of a given waypoint.

For obstacles and lane detection, we combined the usage of camera and LiDAR to increase the precision of the results. The data collected are used to determine the position of the robot.

To measure the velocity and distance, encoders are used. These encoders are integral to the PID control system. The PID controller is embedded in the Arduino. This ensures accurate velocity regulation and precise distance tracking. Data collected from the camera and LiDAR are processed to determine the robot's path, ensuring real-time decision-making based on environmental changes.

6.4 Goal Selection

For the auto-nav challenge, we designed a goal selection algorithm to achieve navigation through given waypoints. To determine the appropriate actions, we made the algorithm rely on sensor outputs. The actions are based on the robot's position relative to the given four specified points.

First, the robot starts in lane-following mode until it reaches the first point. After reaching this point, it automatically switches to GPS waypoint navigation, continuing this mode until the last point, where it reverts to lane-following mode. If the robot is more than three meters away from the first point, it operates in lane-following mode with obstacle avoidance.

Conversely, if it is within three meters of the first point, the robot switches to GPS waypoint navigation. These operational modes, lane following, GPS navigation, and lane following with obstacle avoidance, define the running states of the robot, ensuring efficient and adaptive navigation.

6.5 Sensor Fusion

To estimate the pose of the robot, we use a combination of wheel odometry, IMU data, and GPS data. Wheel odometry is derived from encoders on DC motors, with local odometry calculations based on the kinematics of a two-wheel differential drive system governed by PID control.

Concurrently, IMU data are collected, providing additional insights into movement in 3D space. GPS data is integrated into our localization strategy to enhance accuracy. Motion estimation is further refined using visual input from consecutive camera frames, allowing us to determine changes in position and orientation over time.

7 *Cyber Security Analysis Using RMF*

To maintain the security of Zoser v2.0, we follow the NIST framework.

1. **Identification of Assets**
   Identifying critical assets is the first step in the framework. These consist of the ground station and the NUC (onboard computer) for our system. These IP-based gadgets form the backbone of Zoser v2.0 processing, control, and communication. To keep the robot working and the data intact during competition, these parts must be secured.

2. Categorize and Impact Analysis: We categorized our assets according to the impact and likelihood of being attacked or exposed to failure. Then we prepared our risk matrix.

3. **Select and Implement Suitable Controls:** We have put in place several layers to reduce risks such as communication traffic sniffing and interference from other teams.

   a) **MAC Address Filtering:** The system network can only be accessed by devices that have been pre-approved.
   b) **Username and Password Authentication:** Credential-based login limits system access to authorized personnel.
   c) **Disabling USB Automount:** USB automounting has been turned off to minimize the attack surface and stop the execution of untrusted media. This measure ensures that any physical device connected to the robot must be manually authorized, preventing potential hazards such as malware injection or system disruption.
   d) **Configuring a Firewall (UFW):** A host-based firewall (UFW) was set up to allow only necessary communication ports, such as those used for secure remote access or ROS networking, while blocking all other incoming connections by default. This setup minimizes external exposure and ensures that only trusted endpoints communicate with the system.

      This layered security approach significantly reduces the likelihood of unauthorized access or data interception, especially in the high-interference environment of a robotics competition.

4. **Test and assess:** Testing is executed to check security or operational vulnerability. Security, penetration testing, and software audits are key assessments to identify weaknesses and mitigation status.

5. **Accept or reject risk:** As long as our robot can traverse the course, functioning well and safely, we can reject extra measures. This should be approved by our faculty advisors or our team leader.

6. **Monitor and log:** Continuously monitor the implementation of control and the risks to the system. In addition, reporting and documentation are key to our success. This is done to mitigate repeat failures/breakdowns as well as to provide continuous assessment.

8 *Analysis of Complete Vehicle*

8.1 *Lesson Learned During Construction and System Integration*

In the project of designing and manufacturing Zoser v2.0, we faced many problems such as the following:

1. **Improvement of software skills:** This was achieved through short courses and workshops offered at MTC. Our team attended two workshops in ROS and SOLIDWORKS. In addition, the team received training in mechanical and electrical fields from certified professors and applied this knowledge in the development of Zoser v2.0. We also focused on learning various programming languages to allow flexibility in designing the main control system of the robot.

2. **Difference between theoretical study and real-world manufacturing:** During the initial phase of manufacturing, we observed deviations between the CAD design and real-world implementation. This was due to the slight oversight of details that had significant effects during the assembly process. For example, the density of filament in 3D printing caused part fractures. Another example involved aluminum profile connectors; although stress analysis confirmed their strength, some failed during assembly because the actual material properties differed

from those assumed in the simulations. As a result, we now increase the safety factor during design to ensure that the components can withstand unexpected loads.

3. **Resources management:** To minimize the cost of the robot, we reuse previously purchased components and carbon fiber rods. This approach not only reduced costs but also contributed to lowering the weight and increasing the modularity of the robot.

8.2 Failure Modes and Resolutions

In this section, we present the possible failure modes that could prevent the success of the competition and how we can mitigate them, as shown in Table 2.

Failure	**Solution**
Mechanical failure	Modular, replaceable parts
Payload dislodgement	Redundant fixation
Electrical failure	Replaceable components
Electrical arcing	XT60 connectors used
Camera failure	Lane detection via color sensors
LiDAR failure	Obstacle detection via ultrasonic
Encoder error	IMU-encoder data fusion
E-stop loss	Ping monitor; halt on failure

Table 2: Failures and Mitigations

8.3 Simulation

We aim to improve the reliability and efficiency of the system by performing both software simulation and physical tests. In our approach, we use a simple robot model within the Gazebo simulation environment to experiment with our codes and systems, as shown in Figure 15. The robot was equipped with both a LiDAR sensor and a camera, allowing us to test the lane detection algorithm. This setup was crucial for evaluating the performance of our model in a controlled environment before deploying it to real-world scenarios.

Using Gazebo, we were able to simulate various driving conditions and observe how our model interacts with the data collected from the robot sensors. This process helped us identify any bugs or errors in the software or the main system before proceeding to physical testing. The reason for conducting physical tests is to identify and modify any remaining issues, as well as to gain field experience.

We rely more on physical testing than software testing, as it allows us to better assess the system's real-world performance. For mechanical testing, we conducted mechanical simulation using SolidWorks Motion Analysis for a comprehensive system analysis. Each component was simulated individually to test its strength, and an overall system analysis was performed to verify the system's capability to operate without failure. This dual approach—combining both software simulation and mechanical testing—ensures that both the software and mechanical aspects of the system are thoroughly validated and ready to compete in the main competition.

(a) Initial setup

(b) Simulation progress

Figure 15: example for simulation testing using Gazebo

8.4 Testing And Performance Specification

To test our robot, we made a similar version of the IGVC course to test the system and optimize robot performance, as shown in Figure 16. This test is performed on MTC streets and laboratories. For the charging and battery system, Zoser v2.0 can run up to 160 minutes, but the battery charging time is about six hours. The robot holds two batteries with the same specifications, so the total time could be up to 320 minutes. This gives our robot more time if needed, allowing us to conduct more tests with different levels of difficulty.

We conducted both outdoor and indoor tests to observe the robot's performance under different conditions. Initially, the software design was tested on the indoor track to optimize it. Afterward, outdoor testing was performed for further validation and improvement. Following these tests, Zoser v2.0 demonstrated its ability to complete the entire track, and the actual specifications of the robot are as follows.

- Maximum speed: up to 3.13 mph, which is equivalent to 1.4 m/s.
- Minimum speed: 1.49 mph, which is equivalent to 0.67 m/s.
- Operational time: about 120 minutes.
- Maximum ascending slope: 25°.
- Wireless E-stop range: 50 m with line of sight.

Figure 16: Testing field

9 Initial Performance Assessments

After a long trip of hard work and continued tests, our Zoser v2.0 has finished and is ready to compete. At the time of submission, Zoser v2.0 successfully detected the lanes in different lighting conditions. In addition, we successfully completed the primary stages of obstacle avoidance. We successfully tested complex and dynamic obstacles. Note that all tests performed are done with the payload. The waypoint navigation is integrated with software design. The manufacturing is completed successfully, and all selected components are bought and assembled to the robot. Each programming node operates independently, showcasing individual functionality and readiness. The electrical components have been thoroughly tested and demonstrate full functionality.

9.1 Robot Specifications

Table 3: Robot Specifications

Parameter	**Specification**
Dimensions (L × W × H)	1016 mm × 660 mm × 995 mm
Weight	24 kg
Battery	22V, 22000 mAh Li-ion battery
Drive System	2-wheel drive with DC motors
Operational Time	About 120 minutes
Max Speed	Up to 4.5 mph
Payload Capacity	20 kg
Sensors	LiDAR, GPS module, IMU
Obstacle Detection Distance	60 cm
RPLIDAR Detection Range	Up to 0.5 m
Communication	Wi-Fi (2.4 GHz)
Control System	Intel NUC
Operating System	Ubuntu
Weatherproofing	Silicone seals, foam insulation, acrylic canopy
Lane Detection Accuracy	E-Net model Dice Coefficient = 93%

10 Conclusion

The Pharaohs team is confident that Zoser v2.0 is well-prepared to compete among the entries. The system developed for our robot has enabled us to create a pioneering and efficient autonomous navigation system. Throughout this experience, we learned the significant role of teamwork in generating innovative ideas with minimal effort. Additionally, we focused on enhancing our skills to maximize the robot's efficiency. Each member's unique perspective contributed a strong quality to the robot, allowing us to finalize its development. Despite the remaining minor integrations, we are satisfied with our current progress and eagerly anticipate participating in the competition and engaging with other institutions at the event.