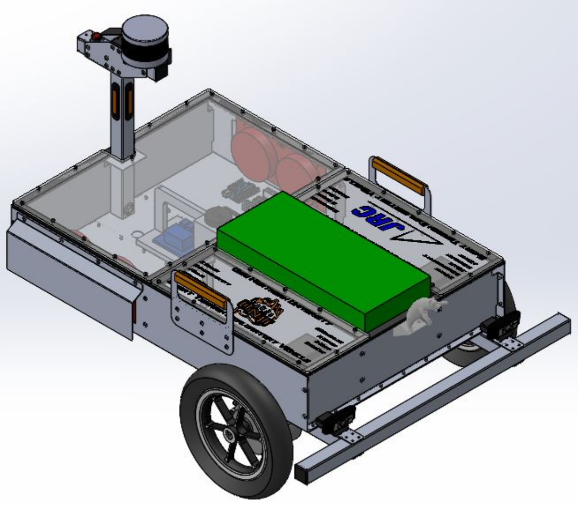
Ohio Northern University
Smart Terrain Exploratory Vehicle



Date Submitted: May 15, 2023

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Statement of Integrity:

I certify that the design and engineering of the vehicle by the current student team has been significant and equivalent to what might be awarded credit in a senior design course.

Dr. Louis DiBerardino
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INTRODUCTION

This year is the first time that Ohio Northern University (ONU) is competing in the Intelligent Ground Vehicle Competition (IGVC). Nine students have worked on this project as an interdisciplinary senior capstone project. Together, the team has designed and built the Smart Terrain Exploratory Vehicle (STEVE).

ORGANIZATION

The 2023 ONU team is comprised of five mechanical engineering students and four computer engineering students, for a total of nine students plus three faculty advisors. Listed below are each student's roles and contributions towards the project.

Table 1: Team Organization

Name	Position	Major	Grad. Year	Time (hrs)
Zach Binnix	ME Team Lead	Mechanical Engineering	2023	220
Alan Dranstott	ME Member	Mechanical Engineering	2023	187
Joshua Ellis	ME Member	Mechanical Engineering	2023	120
Nicholas Rothmann	ME Member	Mechanical Engineering	2023	100
Jason Zayac	ME Member	Mechanical Engineering	2023	130
Dominic Hupp	ECCS Team Lead	Computer Engineering	2023	207
Antonio Gonzalez	ECCS Member	Computer Engineering	2023	180
Robert Hayek	ECCS Member	Computer Engineering	2023	85
Austin McCoy	ECCS Member	Computer Engineering	2023	190

DESIGN ASSUMPTIONS AND DESIGN PROCESS

The team made a few design assumptions at the beginning of the project. Firstly, the team focused solely on the Auto-Nav challenge. Secondly, even though the IGVC rules do allow for internal combustion engines, the additional restrictions led the team to rule that out as an option and limit the design to electrical power only.

Every week, the team would meet with the faculty advisors to discuss what progress has been made and what was being worked on. Beginning in the fall, the first design decisions were focused around what sensors and electronics were needed, as well as what the drivetrain layout would look like. The chassis was then designed from there throughout the fall and winter. Once the chassis was built and electronics were ordered, software development began and continued throughout the spring semester. Sensors were coded and tested separately at first to ensure proper operation. The sensors were then added into the final prototype, ready for sensor fusion and testing. Along the way, multiple Progress Review Boards (PRBs) were used for faculty outside of the project to examine the team's progress on the capstone project.

INNOVATIONS

Since this is ONU's first time in the IGVC, the team started completely from scratch with no prior vehicle or prototype. As such, everything was designed for the first time from the ground up. Even though there are no innovations from a previous design iteration, there are several unique features.

Due to the motor and wheel selection, mounting encoders to the drive shafts would have been very difficult. For this reason, Inertial Measurement Units (IMUs) were used instead to determine the vehicle's heading. Additionally, in order to protect the electronics, they were placed inside a compartment integrated directly into the chassis design instead of building the chassis with a separate compartment attached to it. This simplified construction and design of the vehicle.

MECHANICAL DESIGN

Overview

The mechanical design for STEVE is built around a sheet aluminum chassis that everything else is connected to. The drivetrain includes two independent drive motors at the front of the vehicle with a single caster in the rear. The payload is placed at the front of the vehicle, and the electronics are inside the rear. The safety lights, e-stop button, and LiDAR are all mounted on the mast on the back of the vehicle. A picture of the final prototype is shown in Figure 1.

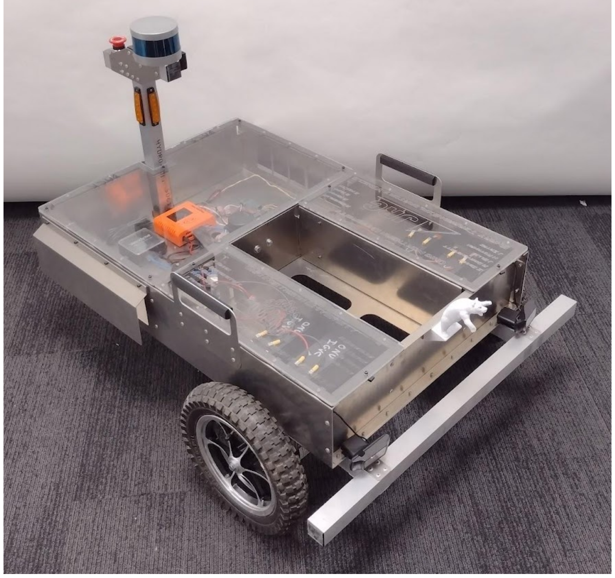

Figure 1: Final Prototype of the ONU STEVE

Frame and Structure

The chassis of STEVE is constructed of 14 gauge sheet aluminum riveted together, as shown in Figure 2. The sheet aluminum keeps the vehicle very lightweight while maintaining rigidity. The box structure also creates internal compartments for the payload and electrical components. Rivets were chosen to fasten the components together due to being very quick and easy to install without warping the assembly as would be a risk using welding. Rivets are also easy to drill out if modifications need to be made later. The layout of internal components puts the heavy payload and batteries towards the front of the vehicle, directly over the drive wheels, providing great traction in all conditions on all surfaces.

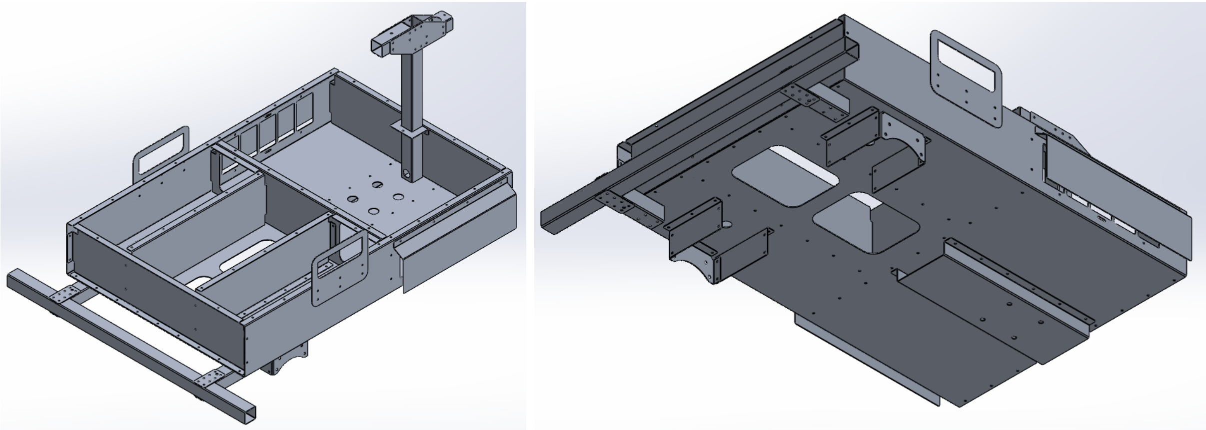

Figure 2: Top (left) and bottom (right) of the sheet aluminum chassis

Drivetrain

The drivetrain has two drive motors at the front and a single caster in the rear, as shown in Figure 3. The drive motors are 250W 120 rpm brushed DC motors with an internal gearbox. The drive wheels are from an electric wheelchair with 12.5 inch pneumatic tires. The rear is supported with a passive pneumatic caster. Both motors and the caster are mounted to the underside of the box chassis. The 120 rpm motors with 12.5 inch wheels gives STEVE a maximum speed of about 4.5 mph.

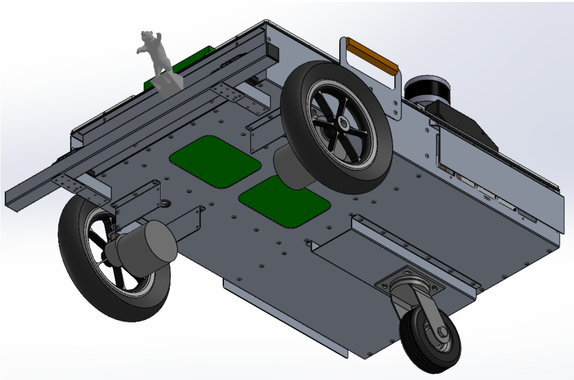

Figure 3: Drivetrain on the bottom of the chassis

Suspension

To improve simplicity, the current design has no suspension. The drive wheels are mounted directly to their motors, and both motors and the caster are mounted directly to the chassis. After testing, it was clear that suspension may be helpful, and future iterations may incorporate suspension to the design.

Weather Proofing

In order to keep the electronics protected from the weather, they are placed inside the rear compartment in the chassis. Acrylic panels with foam tape weatherstripping are bolted down on top of the sheet metal in order to maintain a waterproof seal, as shown in Figure 4. Ventilation slots were cut in the side of the chassis, and side shrouds were added to deflect rain water away from the electronics bay.

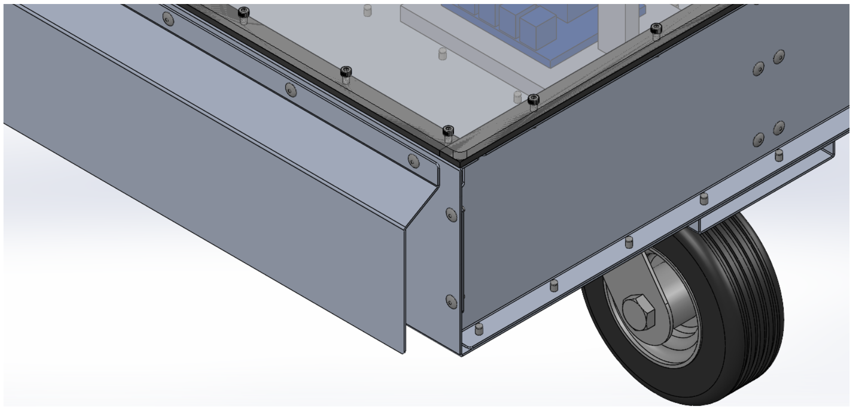

Figure 4: Weatherstripping and side shrouds

ELECTRONIC AND POWER DESIGN

Overview

STEVE uses two sets of 12V batteries. For the motors, two 12V batteries are wired in series to obtain 24V power. For the electronics, two 12V batteries are wired in parallel, as a power supply. A level shifter is used to obtain proper voltages to power the computing platform as well as other sensors. Motors are controlled using a SaberTooth motor controller, requiring an input signal range of 0V-5V represented as -100% to 100% motor speed.

Power Distribution System

The power supply used for the design are four 12V 9Ah batteries, allowing STEVE to run for a total of 1.5 hours. By having the brains of the robot and the motors powered separately, STEVE is able to start its autonomous mode and read data without the motors moving. In case of an emergency stop, the motors can be disconnected from the motor controller using a wireless relay, leaving the computing platform running. This allows the team to look at the computing platform and analyze for any errors or outputs before failure mode. Figure 5 below shows the wiring sketch of STEVE.

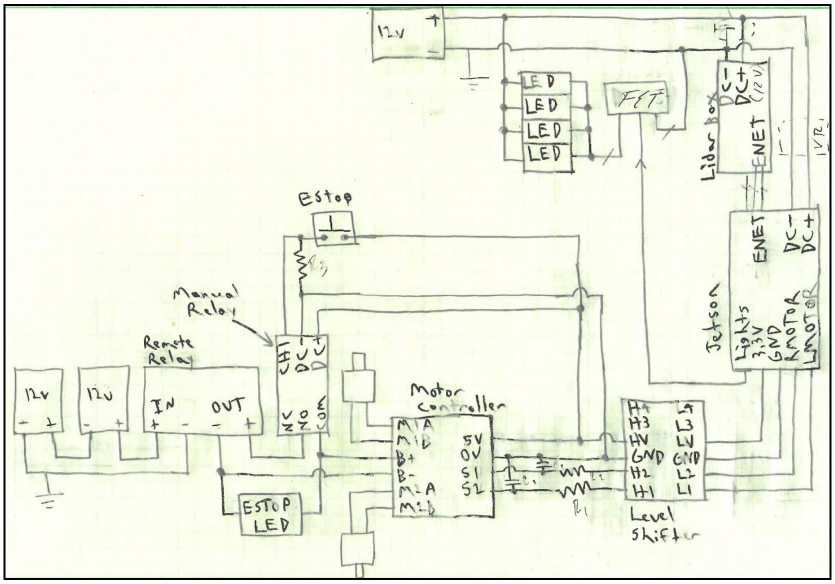

Figure 5: Wiring Sketch

Electronics Suite Description

STEVE is controlled by a Jetson Xavier NX, a developer kit made by NVIDIA. This computing platform was perfect for the project as it has low power consumption and high processing power, capable of intaking and analyzing all data from the sensors.

Three different kinds of sensors were used for this design. IMUs are used to measure heading as well as distance. This is mainly used for when STEVE is going through the straight-away. STEVE also uses a serial GPS for “No Man’s Land” where the lines are discontinued for a short distance. This GPS allows STEVE to navigate between waypoints. Finally, STEVE uses two Logitech C920 Webcams for vision, looking for potholes, boundary lines, as well as obstacles.

A LiDAR was initially used for this design, however, the team was unsuccessful to get the sensor working efficiently as the part arrived late. This was going to be the primary sensor in obstacle avoidance, but after further consideration, the team decided to move forward with using the 2D cameras for obstacle avoidance.

Safety

As required by the IGVC competition, STEVE is equipped with a physical E-stop as well as a mechanically-based wireless E-stop. As mentioned previously, the wireless E-stop disconnects the motors from their power supply, bringing STEVE to a halt. The physical E-stop has the same effect.

Also on STEVE are safety lights mounted high for better visibility. As required, these lights are solid when the robot is turned on and flashing when the vehicle is in autonomous mode. These lights allow others to know when STEVE is on/off as well as operating.

SOFTWARE DESIGN

Overview

In order to complete this project, we decided to use the Robot Operating System (ROS). ROS is an open-source operating system that provides tools and libraries for robot applications. Python was used for this project as every team member had previous experience with this language. There are also many online resources that use Python for when troubleshooting needed to be done. Other functions were custom made such as source code for the IMUs.

Obstacle Detection and Avoidance

Detecting obstacles was a challenge for this project as we couldn't get the LiDAR working in time. Therefore, we used our 2D webcams to identify obstacles. This is done by looking at a frame and finding objects in front of us with a minimum area to guarantee that the object is close range. After finding an obstacle, STEVE adjusts its heading to avoid the obstacle while also checking that we are within the boundary lines. Figure 6 shows a sample frame with the 2D webcam identifying the obstacle in its path.

Figure 6: Obstacle avoidance

Software Strategy and Path Planning

To ensure that the robot would be able to complete the course in the shortest possible amount of time, the course was divided up into states, each representing a portion of the course and the sensors required. For example, the straightaway portions prefer input from the IMUs and line detection over the LiDAR and GPS. Consequently, the object avoidance through the webcam detection was prioritized in the sinusoidal portions. To ensure the robot will always make forward progress, the heading calculated from the IMUs are constantly zeroed out with the preprogrammed goal to continue at this heading for as long as possible. This is then combined with the line following aspect to ensure that the robot can navigate through curves while still maintaining the ability to circumvent obstacles.

Goal Selection and Path Generation

As mentioned in the previous section, the primary objective of the robot is to head towards the zero heading. For example, in the straightaway, the zero heading is the same direction that we started at; however, it represents the direction through obstacles in other portions of the course. When an obstacle is detected and is in the desired path of the robot, the robot will turn until clear of the obstruction before moving forwards and attempting to regain the desired heading. Once this happens, the robot continues to move forwards until another obstacle is encountered.

Additional Creative Concepts

As the robot doesn't feature encoders to track robot position, two IMUs are utilized to track robot heading. These filters are passed through separate FIR filters and then averaged together, resulting in a typical drift of 0.4 degrees every minute with a total drift of 4 degrees in a 45 minute window. In addition, total distance is not possible to accurately calculate, leading to a design decision where the robot is set to run forever, prioritizing the return to the desired heading.

FAILURE MODES, POINTS, AND RESOLUTIONS

Vehicle Failure Modes and Resolutions

Table 2: STEVE failure modes and resolutions

Failure Mode	Resolution
Tipped Over	Using the IMU, sense high acceleration in any direction with a y axis heading of 90 degrees or more. Activate E-Stop.
Sensor Failure	Pause and wait for sensor to reconnect
Power Short	Wait for Jetson to reboot and continue run

Vehicle Failure Points and Resolutions

Table 3: STEVE failure points and resolutions

Failure Point	Resolution
Possible short circuit	Ensure all wires are properly fastened, leaving no exposed wires. This is done using wire clamps.
Surge of power	In case of power surge, the Jetson will turn off automatically as it has built-in protection. This will also deactivate all sensors.
Frame bends from contacting object.	Bumper was installed in case of a front impact. This will reduce damage done to frame and electronic components.
IMUs drift due to high vibration.	Two IMUs are used in order to obtain an average. A filter is also used to ensure low drift. It is calculated that the IMUs should only be able to drift 0.4°/5 min.
Corruption of microSD card for Jetson.	Another microSD will be on hand in case of emergency with code loaded onto it.

All Failure Prevention Strategy

In order to understand failure modes, the team needed to consider what could possibly go wrong with the design. After brainstorming what state the robot could end up in while operating, the team reverse engineered to see where these problems could stem from. After identifying possible failure points/modes, the team worked to build systems/protocols that would prevent such failures and reduce damages.

Failure Testing

Table 4: Failure safety testing

Test Plan	Expected Result
Sensor is disconnected.	Robot stops operation and waits for reconnection.
Robot is tipped or layed on its side.	Robot stops operation and sends error to log file.
Power is shorted, turning off the Jetson.	Robot reboots and continues operation.

SIMULATIONS

Simulation Testing

In order to test our circuit design as well as our LiDAR, simulation was used. LTSpice was used to verify that all circuit components would operate as expected, specifically our level shifter which is used to give components proper voltage. During simulation, we found that current was an issue for the GPS, therefore, an arduino was introduced to supply enough current.

The LiDAR was also tested as we were able to map our surroundings in our workspace. This test was done as validation for the LiDAR as well as a look into what data we could expect to work with. Figure 7 below shows the image acquired from the LiDAR sensor.

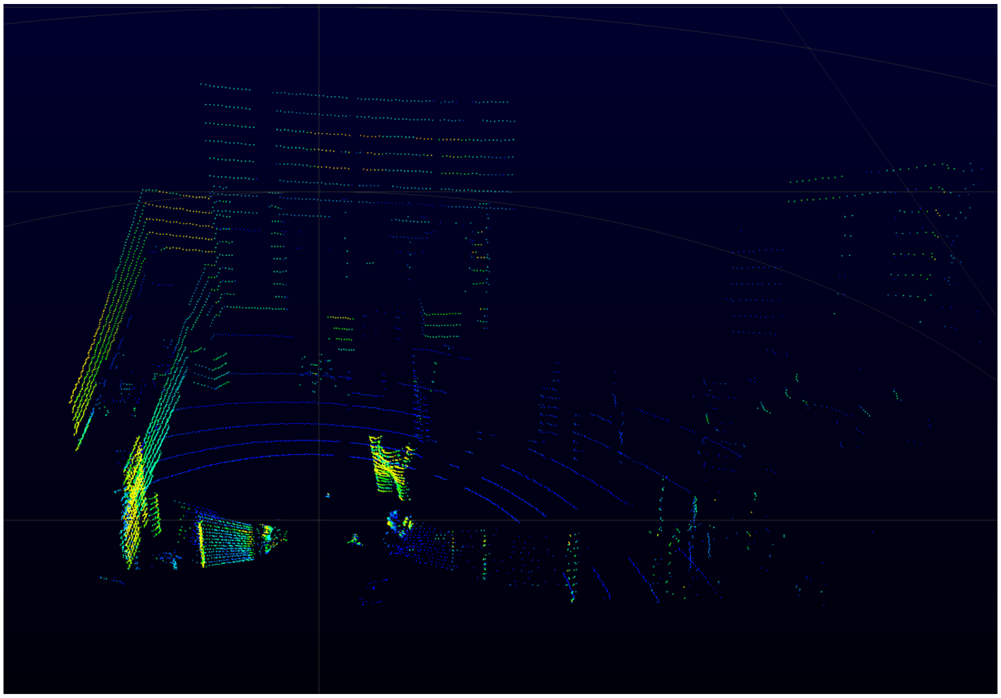

Figure 7: LiDAR Image

PERFORMANCE TESTING

During testing STEVE has demonstrated consistent operation with the hardware and electrical components it is equipped with. STEVE is able to maintain a speed between 1-5 miles per hour in a flat, straight line. It is equally capable of this with more than the required payload up and down a wooden test ramp of the competition specified 15% incline with ease. Let it be noted STEVE has climbed higher grades with less road friction under the same load circumstances as a factor of safety. STEVE is continuously being fine tuned as the competition date nears.

The team is additionally able to detect obstacles within 6 feet of the robot while utilizing the 110 degree FOV camera window. This allows for the robot to respond to any environmental obstacles. Furthermore, the system is able to accurately track the speed and angle of the robot, noting things such as a fall off the ramp for an automatic power off. Ideally in the future, these systems would be compared against LiDAR output data to validate the subsystems; however, this wasn’t necessary for the current implementation.

INITIAL PERFORMANCE ASSESSMENTS

To date, STEVE’s mechanical performance has met or exceeded all expectations. It is capable of maintaining speed without exceeding the maximum on a variety of terrains. Climbing the 15% incline poses no challenge. Maneuverability and turning is fluid and smooth. The only real challenges are with the autonomous navigation system, primarily in obstacle detection and avoidance. As previously mentioned, the team has had trouble interfacing the LiDAR with the computing system, and decided to focus on using the cameras instead.

CONCLUSION

Given that this is ONU’s first appearance at the IGVC, the team is mostly satisfied with STEVE’s performance to date, but there is still significant room for improvement. One of the struggles the team faced was utilizing the LiDAR sensor to its full potential. No members of the team had previous experience with this type of sensor, and getting the device to interface with the Jetson proved more difficult than expected.

Another challenge was the size and composition of the team members. While nine team members made certain parts of the project easier to delegate tasks, it also introduced many challenges such as organizing meetings. Furthermore, the distribution of five mechanical engineering students and four computer engineering students was not the ideal balance. It would have been very beneficial to add both electrical engineering and computer science students to the team, even if it meant losing a few mechanical engineering or computer engineering students.

Overall, every member of the team learned a lot of new information and gained new experiences through working on this project. The real world application of our academic knowledge and learning to work together with a large team taught everyone lessons that they will carry with them throughout their professional careers. Additionally, not only did everyone fulfill their capstone project requirements, but STEVE has also laid the groundwork for future teams to continue representing ONU at the IGVC well into the future.