Mega-Mind

2021 Intelligent Ground Vehicle Competition

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"I certify that the design and engineering of Mega-Mind by Gannon University has been significant and equivalent to what might be awarded credit in a senior design course."

Donald MacKellar | mackella001@gannon.edu
Faculty Advisor

Date Submitted: 5/21/2021

1. Introduction

1.1 Who We Are

The Gannon University Golden Knights Intelligent Ground Vehicle Competition (IGVC) team was established in 2019 as a student-led research group that explores hands-on learning opportunities in areas such as mechanics, electricity, software, and cybersecurity. Our members come from a variety of backgrounds and possess significant knowledge of electronics, neural networks, obstacle avoidance, motor control, mechanical design, drones, modeling and 3D printing. Considering these skills, the IGVC is the perfect outlet for developing and testing our latest engineering intricacies.

1.2 Organization

The Gannon Golden Knights team consists of students from a wide variety of different majors. Table 1, below, names each member, their academic standing and major.

Table 1: Team Member Organization

Phase	Name	Standing	Major
Mechanical	Peter Caulfield	Junior	Mechanical Engineering
	Chris Devine	Graduate	Mechanical Engineering
	Kenzie Lasher	Junior	Mechanical Engineering
Electrical	Mike Eckels	Senior	Electrical Engineering
	Georgios Petridis	Junior	Electrical Engineering
	Tyler Seelnacht	Freshman	Electrical Engineering
Software	Tenger Batjargal	Graduate	Embedded Software Engineering
	Niklas Bitters	Graduate	Embedded Software Engineering
	Yiming Han	Graduate	Embedded Software Engineering
	Jack Little	Junior	Computer Science
Cyber	Austin Detzel	Sophomore	Cyber Engineering
	Dan Hughes	Sophomore	Electrical Engineering
	Benjamin Lubina	Freshman	Cybersecurity

1.3 Design Process

Our team followed a specific design process that spurred the progress on Mega-Mind. The five-step process can be seen in Figure 1, on the right. Every problem/task was defined, discussed, delegated, tested and then reviewed. This cycle would continue until each task was deemed complete. For the sake of consistency, every task was subject to this process—no matter the size. This was our way of maintaining an industry-based approach, which we felt was best, due to the scale, complexity, and prestige of the IGVC.

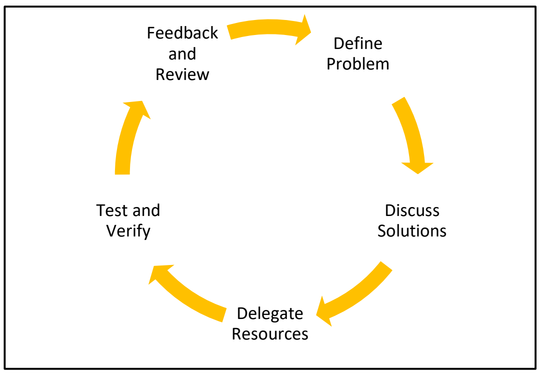

Figure 1. Design Process Flow

2. Innovations

2.1 Lessons Learned & Inadequacies

The 2019 IGVC featured the first team to ever participate from Gannon University. Although we concluded the competition with several encouraging takeaways, we knew we could improve drastically for the 2021 competition. The following points describe significant lessons that we learned from the 2019 competition:

- Object Avoidance – It was evident that we needed a more comprehensive and systematic approach for avoiding obstacles.

- Mechanical Vibration – We did not anticipate to encounter such significant camera movement and vibration. Finding damping methods for camera vibration would be crucial.

- Packaging and Frame – We needed form-fitting packaging that could neatly house our physical components, but also provide shelter and durability. Weatherproofing and modularity strategies received considerable attention.

2.2 New Design Innovations & Solutions

2.2.1 Neural Network-Based Object Classification & Avoidance

A two-part creation of merging a neural network-based object classification system and a collision avoidance system was endeavored. A neural network was established and trained to recognize traffic barrels, and image data for the neural network was captured from a single camera. Using a clever technique, even with a single camera, distance can be calculated. A detection and distance collage of results can be seen below, in Figure 2. Also, additional information can be found in section 5.2.1.

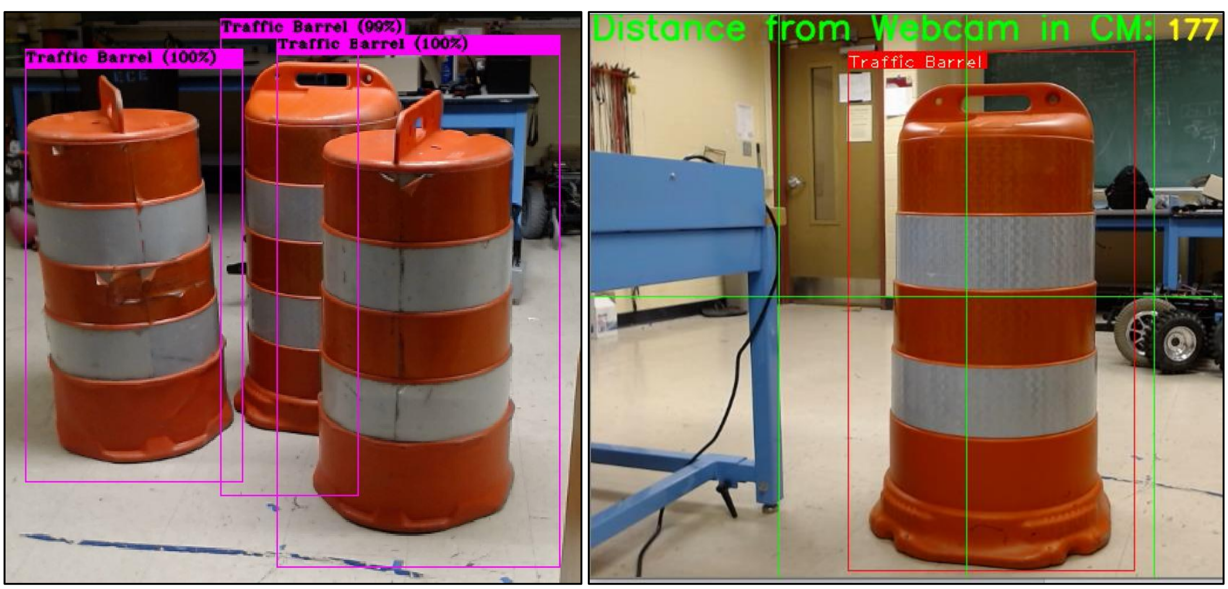

Figure 2. Traffic Cone Detection with Distance

2.2.2 LiDAR

Our team utilized LiDAR previously, but in very limited capacity. Since the previous competition, significant work has been executed to use the full potential of LiDAR. Although LiDAR is relatively common in the autonomous vehicle field, for our purposes, it opens many doors. This is our primary detection system. Additional information can be found in section 5.2.2.

2.2.3 Mechanical Damping

As mentioned in section 2.1, vibration was our enemy at the previous IGVC. Although a grass field may look relatively flat, even the smallest unevenness reverberates throughout the rest of the system. The main mechanical damping technique consisted of utilizing softer springs. The softer springs result in a smoother ride for the rest of the system— including the camera and sensor mounts. Additional information can be found in section 3.3.

2.2.4 Packaging and Frame

Our vehicle packaging is now more weatherproof, modular, and visually appealing. Our mechanical members did a fantastic job of constructing a comprehensive concurrent package/frame. The packaging and frame feature precision laser-cut incisions, 3D modeled compartments, and scrupulous welding— all performed by team members in-house. Additional information can be found in section 3.2.

2.2.5 Multiple Vehicles

Readying up a vehicle for the IGVC is no small task, as all participating teams know. With that being said, it is not easy to share a vehicle platform between multiple people. For example, some team members may wish to use the vehicle to install rims, while others may want to test motor functionality. To avoid these roadblocks, our team agreed on a simple solution— create more vehicles. Our "fleet" now consists of what is below in Figure 3, but only one vehicle will be partaking in competition.

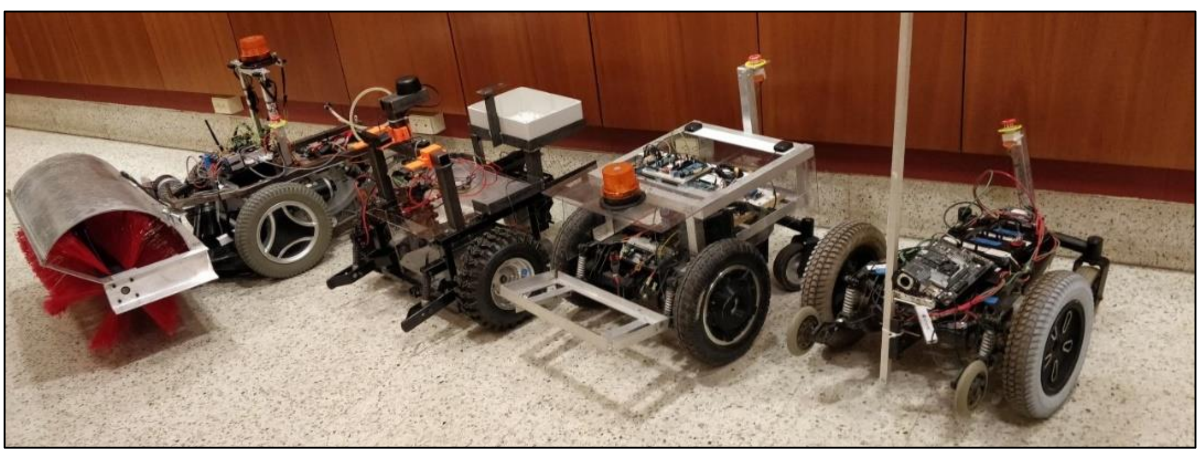

Figure 3. Our Vehicle Fleet for Testing

3. Mechanical Design

3.1 Overview

The main focus for Mega-Mind's mechanical design was to develop a chassis that was clean, modular, compact, weatherproofed, and component accessible. The foundation of the chassis was modeled from 2019 IGVC designs, which began with a Jazzy wheelchair base. Additionally, evidence gathered from the previous competition was used to generate a more efficient and functional structure to house the on-board components. The enhancements made also allowed for a smoother overall function. These improvements focused mainly on suspension, slippage, and appearance. The suspension was improved by replacing the stiff wheelchair suspension springs with much softer ones. The slippage was reduced through the use of thicker tires with improved traction. Lastly, the appearance was improved with better placement of electronics/sensors and the use of junction boxes.

3.2 Frame Structure/Housing/Design

The vehicle design consisted of three main parts: the base frame, electronic component boxes, and sensor mounts. The frame began with a Jazzy wheelchair base which already contained wheels, motors and support material composed primarily of square box tubing. Pieces of angle iron and box tubing were welded onto the preexisting square frame to allow for the placement of the electronic boxes and sensor mounts. The entire frame was designed to keep the vehicle's center of gravity as close to the ground as possible to alleviate any possibility of the vehicle overbalancing. The two electronic boxes are weatherproof component junction boxes that hold all electronics inside, and are sealed for weatherproofing purposes. These boxes are placed on angle iron shelves attached to the back of the vehicle. The sensor mounts are located at the front of the vehicle and are where the LiDAR and cameras are attached. These were kept relatively low to the ground to keep the vehicle compact. A 3D model of our design can be seen below in Figure 4.

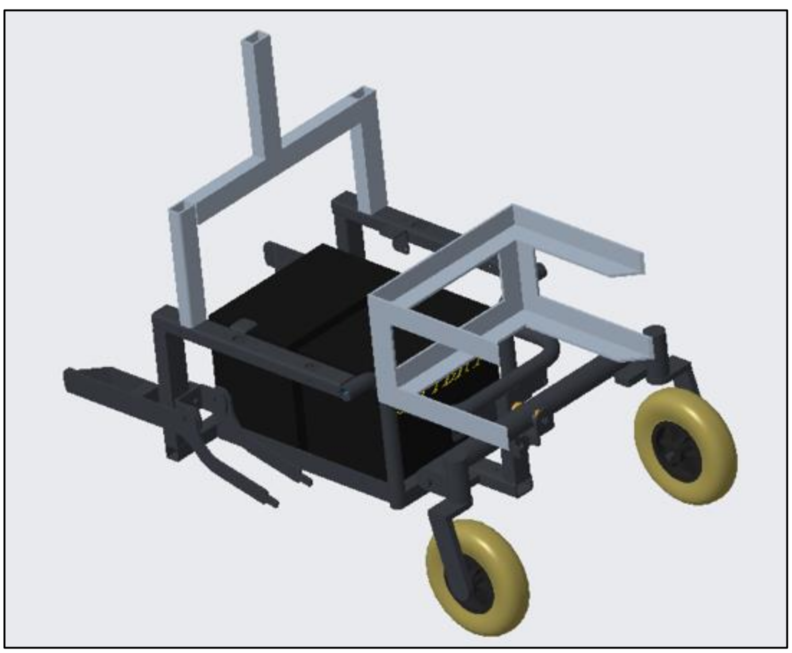

Figure 4. Mega-Mind 3D Frame Model

3.2.1 Electronic Component Boxes

The electronic component boxes consist of two plastic junction boxes into which all power and processing components are placed. These boxes are used to keep all the electronics and wires organized. The first box is for power. It contains the motor control, 24VDC to 5VDC converter and 24VDC to 19VDC converter. The second box is for processing— containing the Jetson TX2 and GPS system. For power purposes, the modules inside each box need to be accessible from the outside. To accommodate this, holes were laser-cut into each junction box. Velcro was used to secure the two component boxes onto two separate shelves, which were made using angle iron.

3.2.2 LiDAR/Camera Mount

The in-house requirement for the LiDAR/camera mount was simple— it must hold three different-positioned cameras. Those positions being: one camera facing forward, one to the left, and one to the right. The mount must also hold the LiDAR horizontally above the rest of the vehicle— ideally, above the center of the axis of rotation of the two main wheels. The mount can be seen below in Figure 5.

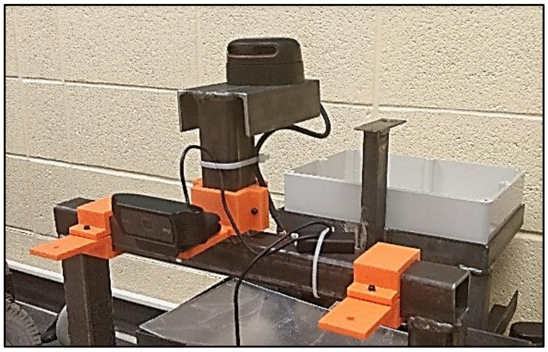

Figure 5. LiDAR/Camera Mount

The main structure is welded box tubing. Camera mounts fabricated with additive manufacturing are clamped to the primary horizontal bar, with a column rising above this height to support the LiDAR base plate. The LiDAR is screwed directly onto this plate, while the cameras are held on the plastic mounts. This structure is bolted onto the pre-existing wheelchair frame to allow for easy removal during design iterations. The use of bolts, rather than welding, also increases the modularity; thus, as various configurations are developed, the attachment of various sensors and mounts may be readily accomplished. Similarly, the use of clamped camera mounts lends modularity to the design, as these may be changed out for others optimized for any new sensor type.

3.3 Suspension

The original suspension for the wheelchair base was tuned to the normal operating conditions of an electronic wheelchair. This meant the springs used were extremely stiff (with spring rates ranging from 300-800 lbf/in) to accommodate the considerable weight of a sitting passenger. Mega-Mind's new frame weight is at least one order of magnitude lower than the original wheelchair base, rendering the original springs unsuitable. New springs were obtained with spring rates between 50 and 100 lbf/in. With the new springs placed in the existing suspension framework, the overall stiffness of the system was decreased significantly. Ideally, this will have reduced the natural frequency of the system to a level below the disturbing frequency from uneven terrain. This places the input into the isolation range, stabilizing sensitive electronics and sensors. Data quality used for vehicle control is thus increased.

3.3.1 Wheels & Hubs

At IGVC 2019, our vehicle lacked traction on wet, muddy grass. The 2019 design, like the current design, was built on a wheelchair base. However, it utilized the original wheels. The stock wheels, while well-suited for a heavy payload on solid ground (pavement/flooring), were poorly equipped to handle more rugged conditions. A major redesign was thus needed. The redesign required obtaining tires with much deeper tread to provide greater traction. Rims were bought to fit the chosen tires, and custom aluminum hubs were designed and manufactured to hold the rims to the existing motor axles. A drawing of the hub design is shown below in Figure 6.

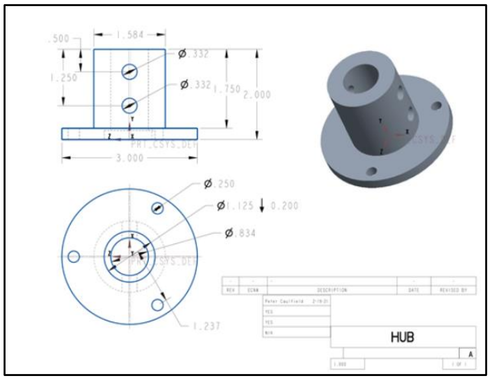

Figure 6. Hub Design

As seen in Figure 7, hub performance was analyzed in ANSYS Workbench. The mechanical loading was developed from the maximum power drawn by the motors, which was converted to torque output at the operating speed of the vehicle. The remaining boundary conditions applied to the mesh were a cylindrical constraint to the central hole of the hub and a frictionless support to the back face. The resulting stress map is below. It indicates a minimum factor of safety above 20, more than sufficient for this application.

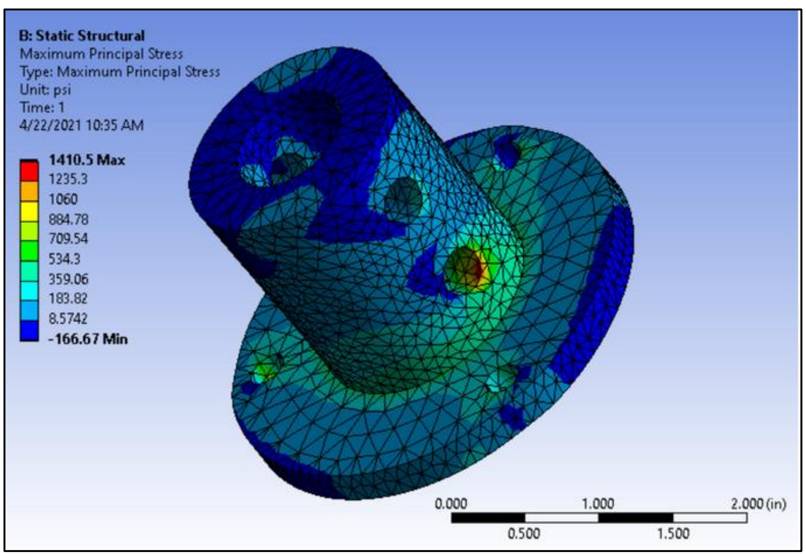

Figure 7. Stress Map Produced from Static Analysis in ANSYS Workbench

3.4 Weatherproofing

Weatherproofing also became a focus this year due to previous years' difficulty with rain. With this competition being outdoors, it is important to be prepared for rain or any other mild weather conditions. The electronics and batteries are obviously the main items of weatherproofing concern. All other parts of the vehicle can experience weather conditions without being affected. For the electronics, two plastic junction boxes were used as housing. The only potential exposed area of the boxes was that from the wired connections. This problem was solved by sealing each connection hole to keep water from seeping inside. As for the batteries, their location happens to be between the wheels at the base bottom. This makes it possible for water to be kicked up. To shield the batteries from this water, a box of clear acrylic material was created around the batteries. Sealant was then applied in the gaps between the acrylic sheets— for additional protection.

4. Electrical Design

4.1 Overview

The electrical schematic of Mega-Mind can be seen below, in Figure 8. As showcased in the figure, our vehicle power source is 24VDC, consisting of two 12VDC batteries. Within the system, there are three different voltages utilized— 5VDC, 19VDC and 24VDC.

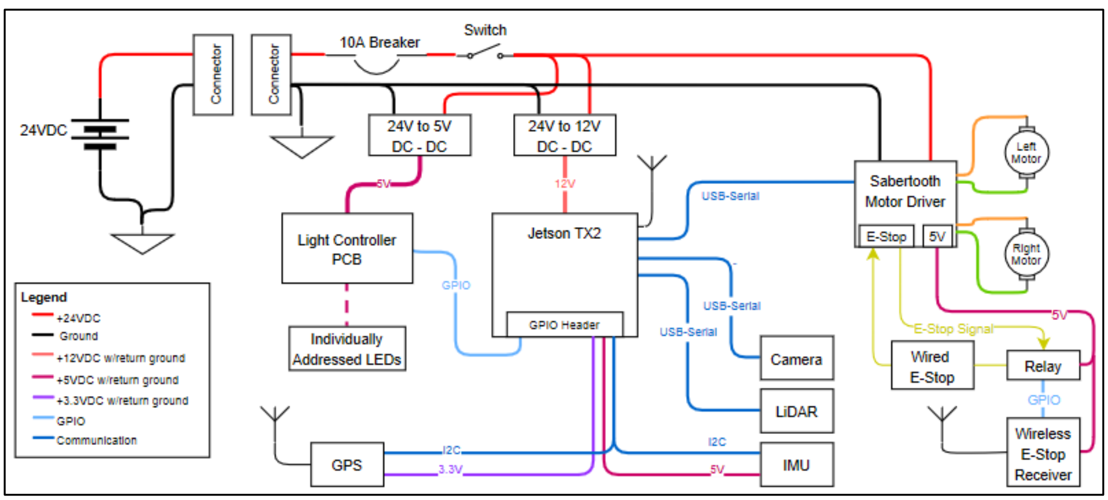

Figure 8. Mega-Mind Electrical Schematic

4.2 Power Distribution System

The motors are controlled through the motor driver, powered with an output of 24VDC from the batteries. The Sabertooth Motor Driver can convert the 24VDC to 5VDC at 1 ampere of current and supply power to the Status Light Controller and E-Stops. A buck-converter is stepping down 24VDC from the batteries to 19VDC for the Jetson TX2 module. The TX2, in turn, can power the camera, LiDAR, and GPS modules with 5VDC via the provided USB-Serial Ports. Similarly, the Jetson TX2 can meet the 5VDC requirement for the IMU.

4.3 Electronics Suite

In 2019, our team utilized a laptop with a built-in graphics processing unit (GPU), due to ease of use and familiarity with the development environment. This time around, we wanted to explore more comprehensive options. We considered our three main options for the main processor as: another GPU-based laptop, motherboards from processors, or embedded computers such as (Raspberry Pi, BeagleBone, or NVIDIA Jetsons). However, since we wanted to incorporate a neural network approach for obstacle detection— a powerful GPU was necessary. For that reason, we selected the Jetson TX2. Not only does the TX2 provide a GPU, but it provides an optimal and well-traversed environment for neural network experimentation. Additionally, the Jetson TX2 is compact as seen in Figure 9.

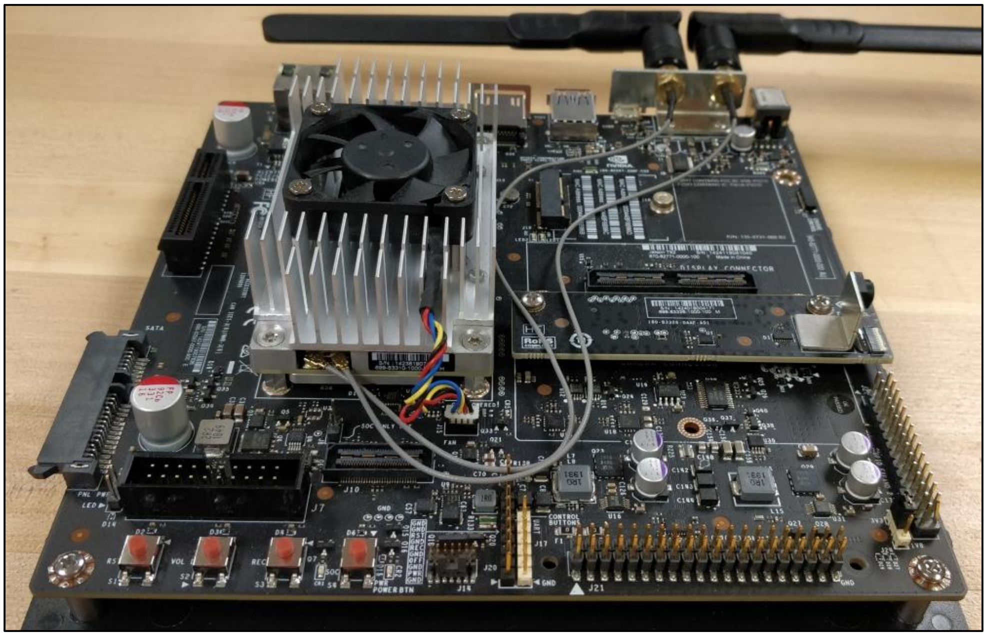

Figure 9. NVIDIA Jetson TX2 for Processing

4.4 Safety Devices

4.4.1 Status Lights

In order to share the current status of the robot, Mega-Mind is equipped with Safety Status Lights. These lights consist of individually addressed LEDs that are connected with an Arduino. Inside the Arduino, a program has been written to synchronize vehicle functionality with a coordinating color. The status strip is placed on the top of the vehicle. The color states are as follows:

- Solid Green - The vehicle is in safe state, the emergency brake needs activated.
- Solid Blue - The vehicle is being manually operated by a user.
- Flashing Orange/Blue - The vehicle is running autonomously.
- Flashing Red/White - The vehicle is in an error state.

Additionally, the vehicle features a second LED strip underneath the vehicle. These LEDs function as under-glow and are purely for style. They can be set to any color, separate from the status strip.

4.4.2 E-Stops

Mega-Mind features two separate emergency stopping options— one mechanical and one wireless. The mechanical e-stop is on the vehicle itself. The wireless e-stop utilizes a X8R 8-Channel 2.4 GHz full duplex telemetry receiver. This receiver was chosen because it can be paired with a Taranis Q-X7 remote transmitter, which can coordinate saved channel calibrations and fine-tuned drive trimming.

5. Software Design

5.1 Overview

As previously mentioned, the software design received a major overhaul for the 2021 competition. The usage of IMUs and GPS are the two software-oriented components that have remained generally the same. The other software components have either been greatly improved or newly introduced. LiDAR and line detection have been improved, while the neural network system was introduced.

5.2 Obstacle Detection & Avoidance

5.2.1 Neural Network-Based Object Classification & Avoidance

The neural network system allows boundary boxes to be placed around the traffic barrels in real-time, and it was found possible to extract the pixel dimensions of the boundary boxes being placed. Using the pixel values with additional measurements, a distance algorithm was found to determine a real-time distance between the traffic barrels and camera. The single camera system is very unique, because it does not inherently contain a means of distance measurement, like external sensors or multi-fed camera systems. Although, it still need more data and training for perfection. The system is based on a combination of YOLOv3, OpenCV and Python.

5.2.2 LiDAR

As mentioned previously, our LiDAR in 2019 was quite lackluster. This time around, the LiDAR has been implemented more prudently. We have chosen to use the RPLIDAR A2, which provides 360 degrees of scanning in a 12m radius. The sampling rate can be adjusted by controlling rotation speed. Typically, we run 10-12Hz with 600-750RPM. This allows us to obtain roughly 200-250 samples per rotation. Figure 10, below, depicts Mega-Mind traversing through a cone/chair chicane using only LiDAR.

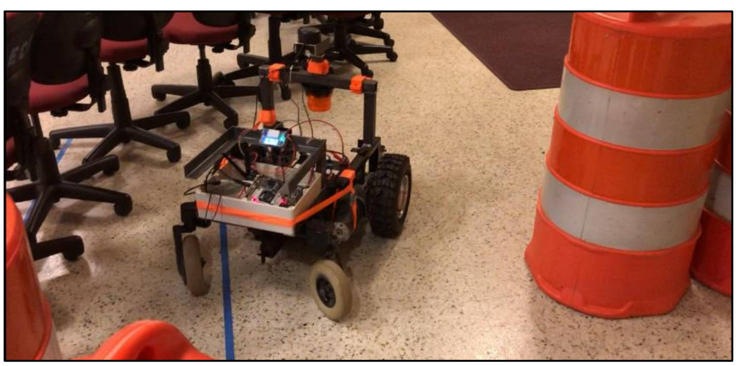

Figure 10. LiDAR usage in chicane

5.2.3 Line Detection

The line detection for Mega-Mind is based on camera feed input. The CPU runs a Python program that filters out all colors, except those specified to bypass the filter. In this case, we would not want the white color of painted ground lines to be passed. Then, a threshold value is placed on the camera scope, which determines where the lines are in relation to the vehicle. If the lines are above 50% threshold value, the lines are on the right. If the threshold is below 50%, the lines must be on the left. The case for in front of the vehicle should never happen, since the vehicle will start placed between two lines. As the vehicle moves, self-adjusting to avoid the lines will take place.

5.3 Software Strategy & Path Planning

5.3.1 Waypoint Navigation

Mega-Mind will primarily be concerned with the GPS waypoints that are calculated. In general, it will move towards that specified area. However, any nearby obstacles have a much greater priority. In other words, the GPS waypoints are remembered, however, obstacles will be handled immediately as Mega-Mind sees them. The LiDAR is the primary source of obstacle avoidance, because it is the most polished. The neural network based system is the secondary source of obstacle avoidance. The line detection will have a slightly lesser role than obstacle avoidance, however, as upright obstacles take precedence over avoiding lines. Lastly, the MPU-6050 IMU chip helps the vehicle recognize orientation and position. This is useful after avoiding nearby obstacles, because then Mega-Mind can get back on track towards the GPS waypoints.

5.4 Map generation

Mega-Mind does not generate any maps. Our team felt that this was not a necessary feature, seeing as actual autonomous street vehicles do not generally generate maps. Therefore, our team has taken careful measures to ensure Mega-Mind operates in a reactive and priority-based fashion. Mega-Mind is not concerned about what is meters away, simply what is most nearby. If no obstacles are nearby, then Mega-Mind will move forward freely.

5.5 Goal selection & Path Generation

As mentioned previously, Mega-Mind operates on a priority basis. The most immediate obstacles are the most concerning, and handled first. If applicable, the highest priority items will always be upright obstacles. This level also has the redundancy of the LiDAR and the neural network system both actively scanning for obstacles. In all cases, however, LiDAR takes precedence over the neural network system. The next lesser priority item would then be the ground lines. Lastly, the GPS waypoints are the final priority. The vehicle aims to reach the GPS waypoint, but will handle obstacles, and then lines, as they are encountered.

6. Failure Identification and Resolution

6.1 Vehicle Failure Modes & Resolutions

As Murphy's Law states— anything that can go wrong will go wrong. With years of hardware and software experience, our team knows that we must be prepared for the worst. With that being said, we have designed Mega-Mind for modularity and hot swap capabilities. If sensors, processors, wires, or fasteners fail— we have numerous replacements for them all. It also helps that we have redundant systems. Similarly, we have backups, documentation, and dedicated repositories for all software utilized. Additionally, the size of our team allows for several members to be trained on every main area. Therefore, our team always has a willing and able body to perform repairs on the fly.

6.2 Vehicle Failure Points

6.2.1 Unseen Software Cases

There are always software cases that may not be accounted for in a system. Plus, these missing cases are harder to capture as more features are added. Separately, our software works. However, Mega-Mind may experience unexpected and untested situations.

6.2.2 Circular Reasoning

Since Mega-Mind does not use map generation, it is possible that the vehicle becomes "stuck" in an infinite loop of sorts. If the vehicle continuously decides movement based on the most nearby obstacles, it may direct itself toward other obstacles in a case that then redirects towards the initial obstacles again. This same circular logic decision could occur infinitely.

6.2.3 Previous Success Failures

As a team, we primarily attacked our weakest points from the previous competition. Therefore, while our weakness received the majority of attention, our previous successes saw less scrutiny. As we added improved hardware and software to the vehicle, we may have taken our previous successes for granted.

7. Simulations

7.1 ANSYS Workbench

As explained in section 3.3.1, our team utilized ANSYS Workbench to analyze critical areas for the vehicle. ANSYS Workbench provides evaluations for structural, thermal and fluid purposes. Essentially, these simulations showcase virtual physics climates. Furthermore, the ANSYS simulations go hand in hand with the 3D models that were created. The simulations have proved to be exceptional in terms of time-cost and accuracy.

8. Conclusion

8.1 Future Works

Our team at Gannon University has grown significantly since the previous IGVC. The hope is that our team continues to grow and spread the word of this great multi-disciplinary event. Likewise, there is always room for improvement. In addition to the observations made at IGVC 2021, we already have concepts and upgrades being discussed for IGVC 2022. The notions and models used for the IGVC have already been transferred to other groups and projects around Gannon University.

8.2 Closing Remarks

Mega-Mind is an autonomous vehicle that was defined, discussed, tested, reviewed and verified by the Intelligent Ground Vehicle Team of Gannon University— the Gannon Golden Knights. The Gannon Golden Knights feel that Mega-Mind contains a unique blend of innovate concepts and traditional proven techniques. Regardless of competition outcome, the team has learned valuable lessons in the areas of planning, teamwork, and accountability. As the competition draws closer, we look forward to unveiling Mega-Mind to the world.