Embry-Riddle Aeronautical University

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I hereby certify that the design and development of this vehicle described in this report was significant. Five of the student team members were awarded senior design course credit and the other students worked significant volunteer hours.

Dr. Charles Reinholtz, Faculty Advisor

CONDUCT OF THE DESING PROCESS, TEAM IDENTIFICATION, & TEAM ORGANIZATION

Introduction

For the 29th Annual Intelligent Ground Vehicle Competition, the Embry-Riddle Aeronautical University – Daytona Beach Auto-Nav team has worked to refine and improve their design entry from last year. The vehicle, named GAVIN (for Ground Autonomous Vehicle for Intelligent Navigation), is an autonomous vehicle designed to self-navigate the IGVC competition course with minimal setup and no user input during operation. Upgrades include improvements to the electrical, mechanical, and software systems. The teams main focus this year was improving the software for better and more 'intelligent' performance. Software improvements were complemented by important mechanical and electrical system upgrades that improved performance, reliability, safety, and ease of use. Additionally, several new innovations were incorporated, including a color-changing, wrap-around LED strip that indicates the planned path of the vehicle for the benefit of judges and spectators and also serves as a diagnostic tool for testing.

Organization

The ERAU Auto-Nav team is comprised of Mechanical and Aerospace Engineering undergraduate students. Table 1 provides the area of concentration of each member. To better streamline task completion, three work divisions were created: Mechanical, Hardware, and Software. The Mechanical division was charged with ensuring component layout as well as creating CAD designs for the vehicle. The Hardware division was responsible for selecting sensors, processors, electronics, and drive system components. The Software division worked to improve the ROS system and add more 'intelligence' decision making.

Table 1: Team responsibilities

Name	Major / Year	Mechanical	Hardware	Software	Hours of Contribution
Ana Alvarez	ME / Jr.		X	X	
Joseph Corry	ME / Sr.	X	X		450+
Kjarstie Corry	ME / Sr.		X	X	450+
Matthew Lake	ME / Sr.	X		X	450+
Timothy McNalis	ME / Sr.	X		X	450+
Kyle Falcey	ME / Sr.	X	X	X	194
Samantha Torres	ME / Jr.			X	
Dominic Marsh	AE / Jr.	X			

Design Process & Assumptions

The team followed a seven-step design process:

1. Customer Needs
2. Requirements Definition
3. Conceptual Design
4. Detailed Design
5. Fabrication, Test, and Evaluate
6. System Demonstration
7. Documentation.

First the customer was identified, in this case it was it is the IGVC competition and Judges[1]. The customer needs where set by the 2022 rules for the Auto-Nav IGVC competition.

The team created requirements for the year using the 2022 rules.

Next, each team member began researching different areas of interest with the main focus on emerging technologies, improved safety, and more complex software structures. Each member then presented their ideas to the team and discussed how they would improve GAVIN. These concepts were then evaluated and graded. From these grades, the best ideas where then chosen for detailed analysis and design review.

The detailed design review did an in-depth analysis to see if each concept would be able to fulfil the set requirements and adhere to the 2022 rules. CAD models were created for parts that required further visualization and design discussion. The team also researched if/what commercially available parts could be used. For custom parts, the time and cost of fabrication was considered when deciding whether the make the part.

Next, testing plans where created for each part/design change. Testing was conducted to determine if parts met the requirements and would be viable for competition. The vehicle was repeatedly tested to ensure good working condition.

Finally, the vehicle will be presented and demonstrated at the IGVC competition to show the vehicles abilities. This report serves as documentation that explains and details the different design concepts that where implemented this year.

EFFECTIVE INNOVATIONS

Updated Computer

The computer was upgraded this year from a Jetson TX2 to an Intel NUC7i7BNH. The Intel NUC provides the team with 512 GB of internal storge compared to the 32 GB in the Jeston TX2. This allows the team to store and analyze greater amounts of test data. Also, the NUC provides the team with two additional USB ports for a total of three. This allows for easier usability. Figure 1 shows the NUC attached to the inside of the Pelican protective case.

Sunview Monitor

A weather-proof SUNVIEW monitor was added to the vehicle to eliminate the need for an external monitor during start-up sequences and when making changes to the code. The SUNVIEW monitor was selected as it is IP67 rated and can easily be read in bright daylight. The monitor is impact resistant and has a touch screen for ease of user interaction. Figure 2 shows the Sunview monitor on GAVIN.

Figure 1: Intel NUC computer

Figure 2: Sunview monitor

Innovative High-Dynamic Range (HDR) Camera

A problem with typical computer vision systems used in outdoor environments is their inability to deal with a mix of bright sunlight and shadows. To help overcome problems with this inconsistent ambient lightning, the team adopted a High-Dynamic Range (HDR) camera. High-Dynamic Range directly refers to the wide range of light variation within an image. HDR cameras are produced specifically to deal with this varying light by taking an image at different exposure levels, via the cameras different shutter speeds, and merging them back together into a single image. This eliminates the overexposure and underexposure often left by non-HDR cameras. An example of this can be seen in the image below. To meet the need for a camera, the team selected the IMX390 [2][4]. Figure 5 shows the capability and advantage of HDR camera technology.

Figure 4: HDR camera

Figure 3: HDR camera mounted on GAVIN

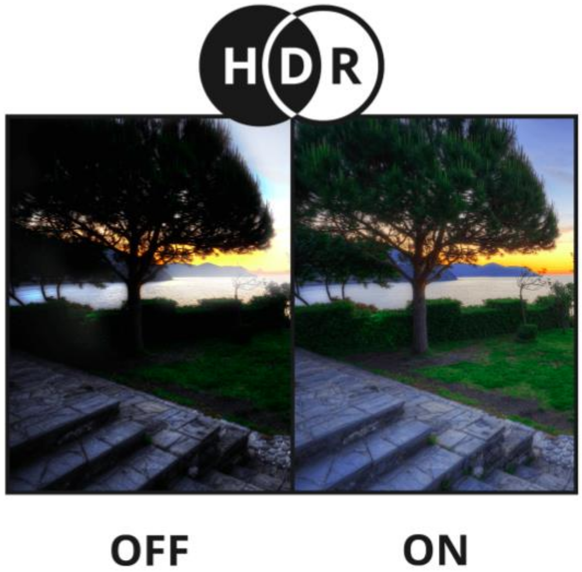


*Figure 5: An image taken from the website lorex.com showing the same outdoor area with the only difference being whether HDR is enabled or not. Notably the dark shadows are practically removed, and oversaturated area in the top right is also eliminated***.**

LED Obstacle Indication Strip

An LED strip for obstacle indication was added to GAVIN's chassis. The strip contains 60 LEDs and is mounted on the front of the chassis. Each LED represents one zone in the obstacle avoidance LIDAR code. The team is currently working on trying to receive the data from the LIDAR code that is needed to control the lights. The lights will display 3 different colors depending on how far away an obstacle is to the LIDAR sensor: green if any object is farther than 3 meters away, orange if any object is between 2 and 3 meters away, and red if any object is less than 2 meters away. This will give the team and IGVC judges a visual indication of where GAVIN's LiDAR is detecting objects. This innovation also helps the team visually diagnose the LiDAR system.

Figure 6: LED obstiacle detection strip on GAVIN

DESCRIPTION OF MECHANICAL DESIGN

Overview

GAVIN measures 29” wide, 43” front to back, and 62” tall. It is a differentially driven robot using twelve-inch diameter rear pneumatic wheels, with an eight-inch diameter pneumatic tire caster wheel in the front. To protect the sensitive electronics, a waterproof IP65 rated Pelican “Air” Case was utilized. The “Air” version of the Pelican case is 40% lighter than a standard case. While weight is not a direct factor in competition judging, a lighter vehicle increases run time and improves overall dynamic performance. Additionally, the use of a Pelican case makes the electronics more modular and easier to transport. The electrical system connections pass through a panel which uses IP65 rated connectors to allow sensor communication with the internal computing components while allowing the system to remain water resistant. The overall system is designed to be modular, allowing for easy assembly, disassembly, and transport.

Chassis

GAVIN’s chassis is made of a carbon fiber platform with Nomex sandwiched between the outer layers. The combination of these materials gives the robot an incredibly rigid platform while remaining lightweight. The electronics case is mounted to the chassis using two threaded studs, making assembly quick and easy. This is the same frame used for the 2019 and 2021 coemption. While changes were considered this year, it was ultimately decided to keep the same proven chassis design.

Sensor Pole

A sensor mast carries the camera, LiDAR, safety lights, emergency stop button, and an Ubiquiti Omni-Directional Antenna. It is fabricated from a 1” square carbon fiber tubing mounted upright from the base of the frame. Carbon fiber was chosen for its rigidity, strength, and lightweight. The wires for the components are fastened to the sensor pole in a manner that allows for rapid swapping of sensors or lights. The components are fitted using 3D printed friction mounts designed to allow for secure attachment to the sensor pole. These mounts were also designed to prevent undue stress which could compromise the structural integrity of the carbon fiber, while also providing the highest amount of stability for the sensors.

Drivetrain

The drivetrain includes the motors, their mounts and adapter plates, and the sub-frame. The sub-frame is a 2-foot section of 15 series T-slot 8020 extruded aluminum that provides a strong, rigid mounting structure. An adapter plate was machined to match the size of the motor mounts and 8020 rails. The motor mounts hold the motors by clamping onto the cylindrical gearbox. The motors generate 20 in-lbs. of torque and uses a 15:1 gearhead to reach and maintain the maximum speed limit of 5MPH while going over the ramps described in the IGVC rule document while also carrying the required 20-pound payload.

Vehicle Cost

The cost of the vehicle can be described using two different cost models, as shown in Table 2. The first model represents the raw (non-discounted) cost of the platform if all components were purchased at full retail price in the current competition cycle. The second model represents the cost to the team for the year. Due to sponsorships and the reusability of components from previous years. This allowed for a versatile system on which sensors and mechanical parts can be swapped at a low cost. Overall, this allowed for a low-cost system that is both versatile and efficient.

Table 2: Auto-Nav vehicle cost breakdown

Item	Unit Cost	Qty	Raw Cost	Team Cost
LED Strip	$ 15.00	1	$ 15.00	$15.00
Wheels	$ 30.00	2	$ 30.00	$ -
8020 3030 (24')	$ 48.00	1	$ 48.00	$ -
Pelican Case	$ 200.00	1	$ 200.00	$ -
RC Transmitter	$ 200.00	1	$ 200.00	$ -
Wiring and Misc.	$ 200.00	1	$ 200.00	$ -
Power board	$ 200.00	1	$ 200.00	$ -
Ubiquity Network System	$ 380.00	1	$ 380.00	$ -
NUC7i7BNH	$ 400.00	1	$ 400.00	$ 400.00
Carbon Fiber Frame	$ 550.00	1	$ 550.00	$ -
Lipo Batteries (6s)	$ 216.00	3	$ 648.00	$ -
HDR Camera	$ 799.00	1	$ 799.00	$ 799.00
SunView Monitor	$ 800.00	1	$ 800.00	$ 800.00
LiDAR	$4,000.00	1	$ 4,000.00	$ -
Quicksilver Motors	$2,000.00	2	$ 4,400.00	$ -
IMU	$5,000.00	1	$ 5,000.00	$ -
Total			**$ 17,855.00**	**$ 1,999.00**

DESCRIPTION OF ELECTRONIC & POWER DESIGN

Overview

Updates to the power and electronics system include a NUC computer, SunView Monitor, HDR camera and LED light strip. Figure 7 shows how all the components connect and communicate with each other.

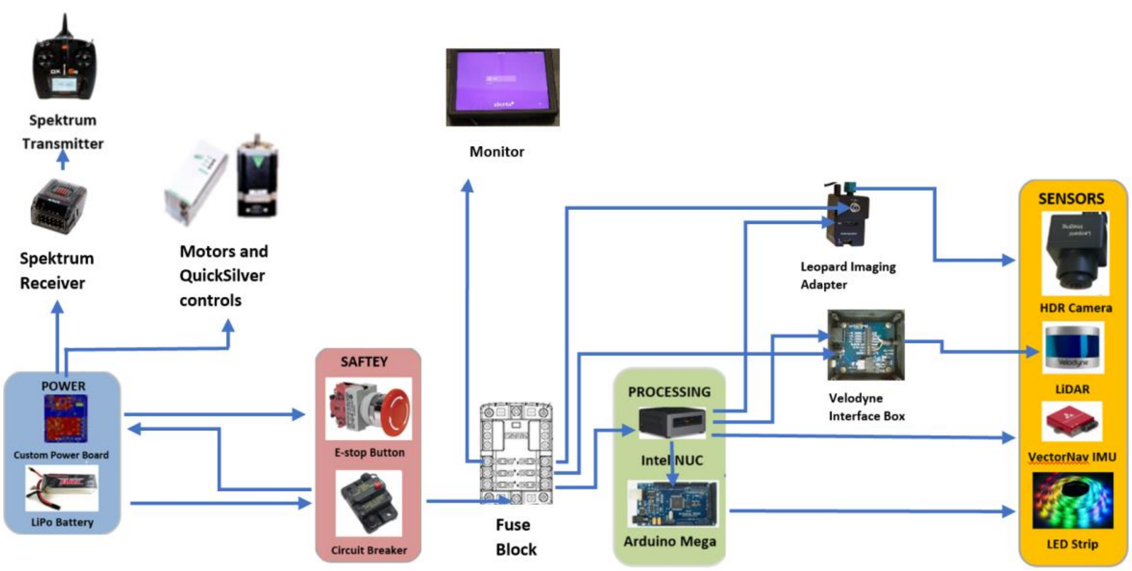


Figure 7: Auto-Nav vehicle electrical and communication chart

Power Distribution

The power distribution uses a TP6600-6SE55 battery. The battery model is a six-cell lithium-polymer battery that provides this specific system a runtime of around $\frac{3}{4}$ -1 hour during course navigation. Standby time where all the sensors are connected but motors are not drawing power is $2\frac{1}{2}$ - 3 hours. Both times are approximations recorded based on outdoors and indoors testing days before battery had to be replaced.

Computer

The Intel NUC7i7BNH is used to process and communicate all data. It has a 3.50 GHz processor, 32 GB RAM, with an internal storage of 512 GB. The NUC runs on Linux Ubuntu 20.04, and ROS Noetic to run the software. The system's software is written using Python as the programming language.

LiDAR

The Velodyne Puck Hi-Res is a 16-beam LiDAR capable of full 360 horizontal FOV with a resolution of 0.1-0.4 degrees, and a 20-degree Vertical FOV which gives 1.33 degrees between channels. The LiDAR generates 300,000 points per second, and can measure a range up to 100 m with an accuracy of ±3 cm. It is rated for IP67 environmental protection. An aviation passthrough connector was used to feed the LiDAR through the pelican case and into the Velodyne interface box.

IMU/GPS

The Vectornav VN-300 Rugged is a high-performance Dual Antenna GNSS-aided INS. The system uses two Tallysman GPS Antennas to give accurate heading measurements of +/- 0.2 degrees, along with the IMU to ensure accuracy and precision with and without the vehicle moving. The IMU collects data at 800 Hz while the GNSS has an update rate of 5hz. Sensor fusion occurs within the VN-300 itself to provide the most accurate data to the system.

Sunview Monitor

The SunView RWD104E is touch screen, waterproof monitor with a resolution of 1024 x 768. It has a 8-36V DC input with a typical power consumption of 8W. It has an Aluminum/PVC-ABS chassis that is IP65 rated. It is 9.7 in x 7.2 in x 1.1 in and weighs 2.2 lbs. The SunView monitor is rated to operate in temperatures ranging from -20 degrees Celsius to 60 degrees Celsius.

LED Obstacle Indication Strip

The LED strip is an WS2812B Individual Addressable RGB LED Strip Light, compatible with Arduino and Raspberry Pi. It has 60 LEDs and requires 5V. The lights can display any RGB color value and are all individually addressable.

Safety Devices

GAVIN incorporates a direct voltage cutoff system built into the power board as part of the safety system requirements. This system cuts off power to the motors but keeps the sensors running to avoid an extended restart time. E-stop buttons are located on the sensor pole and the RC controller. When the E-stop is pressed, power to the motors is killed. The addition of the circuit breaker provides a way to shut off all power from the source in the event of a safety-critical emergency, such as an electrical fire.

In addition to the hardware E-stop, the power board has a software E-stop for the motors as a secondary safety option. Whereas the hardware E-stop kills the power to the motors, the software E-stop sends a zero-speed command to the motors, which allows for a shortened restart time after removal of the stopped state. The RC controller emergency stop has a range of 0.25 miles. Should GAVIN go beyond that range and lose connection with the controller, it is automatically stopped.

SOFTWARE STRATEGY & MAPPING TECHNIQUES

Overview

The intelligent navigation software that operates GAVIN will be loaded to the onboard Intel NUC 7i7 prior to deployment. The software provides feedback to verify that all systems are operational and optimized for navigation. Once all systems are running, the user will simply flip turn 'auto' mode on with the RC controller, and the vehicle will begin autonomous operation.

Obstacle Detection & Avoidance

The obstacle detection and avoidance algorithm has been modeled using a vector field histogram with the LiDAR Puck Hi-Res. However, it has been simplified to only use the beams that project parallel to the ground at a height of 2.7ft. Only 140 degrees of the LiDAR points are processed, and the 140 degrees that we are looking at is broken up into 60 zones, resulting in each zone being 2.4 degrees. An obstacle will only be recognized if it is within 2m of the LiDAR puck. Instead of looking for obstacles, GAVIN looks for free paths around obstacles. Since GAVIN is 1m wide we look for paths at a distance of 2m that show a clear path wide enough for GAVIN to drive through. Since each zone is 2.4 degrees and we are looking at a distance of 2m, there needs to be 13 consecutive zones for GAVIN to be able to drive between obstacles. If there are 13 consecutive zones that do not have an obstacle in them, GAVIN will log the 7th zone in the set as a potential path. By cross-referencing this series of potential paths with either the heading to a GPS waypoint or the angle between the white lines on the course, GAVIN will choose the optimal free zone to navigate to.

Lane Following

The lane following algorithm is divided into three main parts. The first part of the software is entirely dedicated to eliminating noise and picking out the color value of the lanes within a received image. This is done by changing the hue saturation values (HSV) for the image until nothing, but the white lines of the lanes are showing through a mask designed to black out all other colors detected by the camera.

The second part of the software establishes left and right points to be placed at the endpoints of the found left and right lines via a grid of the camera's pixels. The grid's top left is (0,0), top right is (0,720), bottom left is (1080,0) and bottom right being (1080,720). At what would be the bottom center of the image, the point (540,360) was established. From here the grid was divided into left and right sides of the grid with detected points popping up as left and right respectively. When a point is detected on the left and right sides a midpoint is established on the grid. The width and height to the midpoint is then found using the bottom center point as a starting point. Atan2 is then used to discover the angle at which the midpoint has strayed from the center bottom center.

Figure 8: The image on the left is a raw image of the bot without the software applied. The one on the right shows what occurs after the HSV filters are applied to focus on the white line. The orange point is the left point dropped on the endpoint of the left line, the blue is the right point dropped on the endpoint of the right line and the white point is the midpoint between the left and right points. The blue line is created to show how far the midpoint is off from the bottom center point and the white centerline. The blacked-out areas were removed to eliminate unwanted noise that might be produced by seeing too far out or seeing the vehicle itself.

For the last part of the algorithm power to the motor drivers was then created by establishing an if statement around the found angle of the midpoint. If the midpoint was within two degrees of the bottom center from negative two to positive two, then GAVIN would proceed forward in a straight line with the same power to each motor being provided. Otherwise, if the angle is less than negative two, additional power would be added to the left motor to turn right or, if the angle is greater than two, turn left. This allows GAVIN to make smooth turns within the lane as he progresses along the taped path.

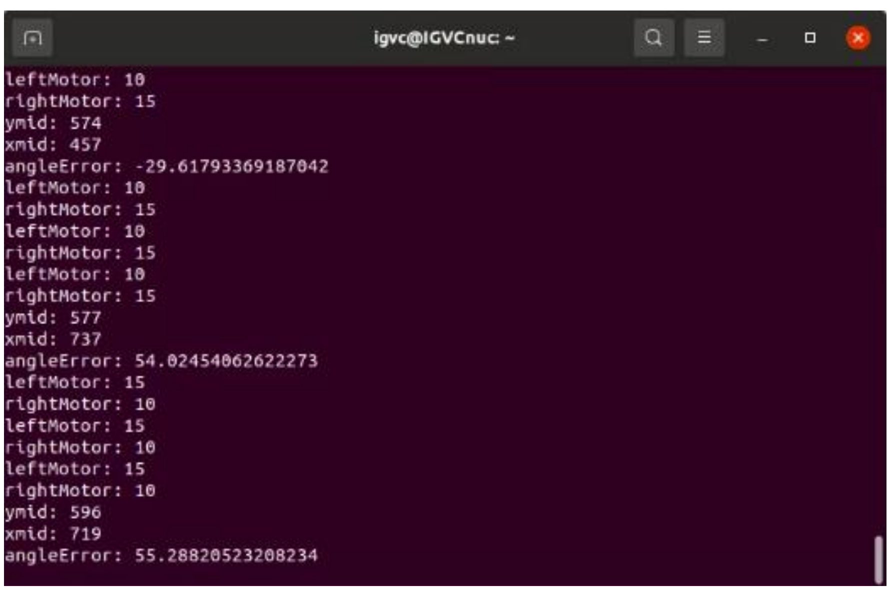


Figure 9: The image above is from the data received while testing the lane following code as it enters a right turn. Here we can see that a midpoint was established on the grid. An angle from the midpoint is then derived from the center bottom point of

(540,360), providing us an angle value which directs where the motor speed should be given. When negative, the angle gave more power to the right motor and when positive it gave more power to the left.

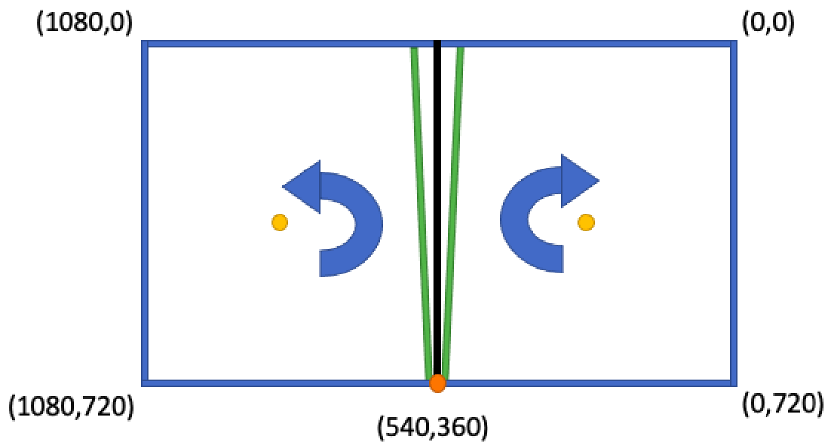
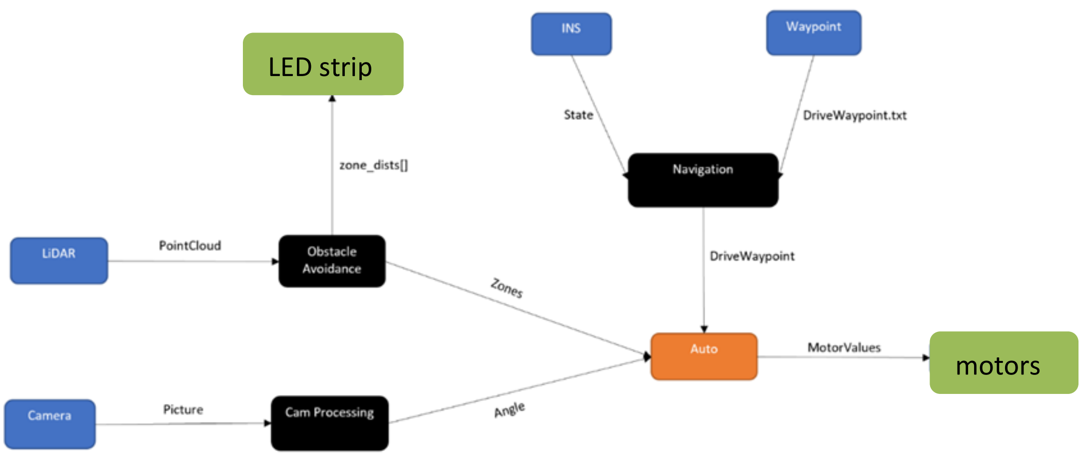


Figure 10: The image above is a visual representation of the grid previously mentioned. The orange point represents the bottom middle, the yellow points are for possible detected midpoints. The midpoint if detected on the left, with a corresponding angle, will give extra power to the right motor to turn left and one detected on the right will give extra power to the left motor to turn right. The black line in the center separates the two zones with the green lines symbolizing the two-degree zone in which if the midpoint is detected will equalize the motor speed and have the vehicle move straight.

Software Strategy & Path Planning



The flowchart above represents the software structure for the system. The blue blocks represent the sensors the system subscribes to and collects raw data from. The black blocks are the written programs for data processing. The arrows represent the messaging system for publishers and subscribers within ROS. The orange block is the decision-making node where GAVIN combines all the information it receives to send commands to the motors. The green blocks are the resulting outputs from the software programs.

The program called Navigation subscribes to the raw data (INS in latitude and longitude coordinates) provided by the VN-300, processes the data, and publishes a message to Auto called DriveWaypoint containing two variables. The first variable is the yaw angle difference between current heading and the desired waypoint. The second variable is the Euclidean distance between the current state point and the desired waypoint in x, y coordinates. DriveWaypoint.txt is a text file planned to contain the two given waypoint pairs for the course and the additional two waypoints in No-Man's Land [1].

Obstacle Avoidance subscribes to the LiDAR's specific laser beams to then publish a message to Auto called Zones which contains an array of the distance values returned in each zone, and an array that contains the zones available to drive through. The LED strip subscribes to the array of distance values returned in each zone. It uses those values to indicate where there are obstacles in the proximity of GAVIN. The camera capture frames which are then analyzed in Cam Processing. This publishes a message to Auto containing the angle needed to stay within the lines. Auto then uses all of these to make a decision on whether to go straight or do a zero point turn left or right. These motor values are then sent to the motors which cause GAVIN to move.

Goal Selection & Path Generation

GAVIN uses a priority system to select a goal and generate the desired motor values as a result. If there are lines present that GAVIN has to stay between, the heading to the next GPS waypoint is ignored and GAVIN only focuses on staying between the lines while avoiding obstacles. If there are no lines present, GAVIN will navigate to the next GPS waypoint while also avoiding obstacles. There is no path generation on GAVIN currently.

Map Generation

GAVIN does not use or generate any maps of the environment. The vehicle relies on real time analysis of its environment and current location on the course using the systems sensors. Navigation decisions are made during each run incorporating data from the LiDAR and HDR Camera. GAVIN use GPS waypoints to navigate to a desired location and uses the sensors to avoid any obstacles and remain within the course boundaries. This approach to course navigation was selected because it allows GAVIN to consistently navigate a changing environment using its software decision making process. The IGVC course can be rearranged and changed by the judged so that competition runs do not remain the same. GAVINs real time sensor analysis setup allows for the best navigation of the IGVC course.

Safety, Reliability, durability, and Failure Modes

Failure Modes & Resolutions

This year the team had issues with message types while improving the obstacle avoidance code. The message type sent by the LiDAR and read by the code was erroring out showing the message was not readable. The team was able to resolve this issue by consulting with ERAU faculty. The obstacle avoidance code is now able to run without erroring out.

Vehicle Failure Points

The vehicle has been consistently used at least two days a week throughout the academic year, both in teleoperated and autonomous modes. Each use of the vehicle usually lasts between forty-five minutes to an hour. While the vehicle showed durability throughout testing, two issues occurred with it this year. During one testing period, components on the inside of the pelican case became detached. They had been attached to the inside top of the Pelican case with Velcro. However, it was found that the Velcro was not suitable for some of the maneuvers the vehicle performed. This problem was solved by fastening these components to the top of the Pelican case with nuts and bolts. This solution did introduce a slight possibility of degraded water resistance since the holes were drilled completely through the Pelican case. However, the team took precaution by selecting fittings that eliminated the ability for water to enter the case through the holes.

Some of the heat shrink on the wires connecting the battery and breaker fatigued and caused the system to short. Thankfully, all electrical components were unharmed and still fully operational. After this event the team fixed those connections with proper insulation and conducted an in-depth inspection to ensure no other electrical connections were improperly insulated. The components remain, easily assessable and removable allowing for quick replacement of components in case of failure.

SIMULATIONS

Vision

Simulation for vision was implemented through the use of prerecorded videos. The simulation was conducted as follows. First a video would be taken of GAVIN running through a taped track while being controlled manually. Then the vision code would be modified to take the video. Once here the team was able to edit the hue saturation values to a point where the desired lane lines would show through. After this was established, GAVIN was placed on a block and connected to a monitor to see how GAVIN was reacting to the code when giving power to the motors and running the same video. Motor speed values were increased higher than normal to visually see when the motor speeds were correcting as they tried to bring the established midpoint from the code back to the center line. If the wrong wheel was given power when entering a turn, the team would immediately see the issue and look to correct it. This allowed the team to verify that the correct points were being established on the lines and that the placement of the midpoint was producing the desired power to the motors. This allowed the team to correct most of the errors in the code before even going out to the track to test. It also allowed the team to continue testing when ideal lighting conditions were not available and maximize our time on the track during ideal conditions.

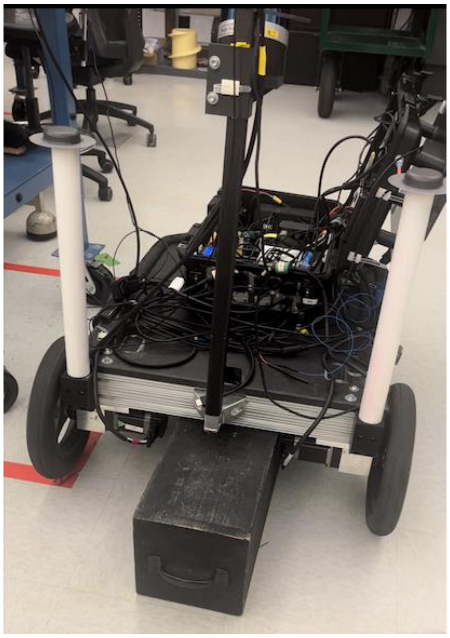


Figure 13: Picture of GAVIN on a block as we test Vision code with prerecorded video.

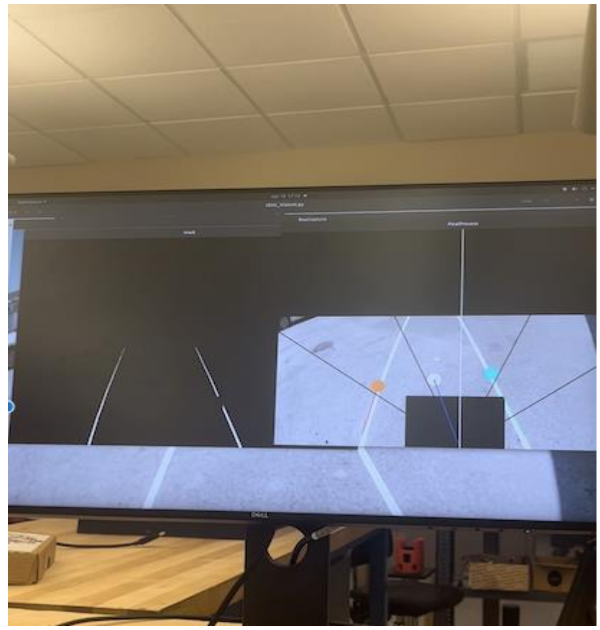


Figure 12: Picture of prerecorded video working with code to form the simulation. The portion on the upper left side is what the camera sees with the current saturation values with two white lines being pulled out of the video. On the top right portion of the screen you can see the left and right points, orange and blue respectively, of the lane being established with the midpoint being dropped between the two.

PERFORMANCE TESTING

GAVIN has been tested weekly and shown reliable operation of hardware and electrical subsystems in teleoperated and autonomous mode. Each test of the vehicle usually lasts between forty-five minutes to an hour. GAVIN can maintain set speeds between 1-5 MPH and will carry the required payload of 20 lbs up a ramp of 15% grade without difficulty. This teleoperated performance has been operational since last competition. GAVIN was repeatedly tested as improvements were completed to the LiDAR code and the vision code. With the new LiDAR code, GAVIN demonstrated an increased ability to detect and avoid obstacles. The updated vision code operating with the HDR camera demonstrated line recognition and following abilities as well as the capability to correct motor speeds depending on GAVIN's position between two lines. However, the vision code has not been integrated with the current code that will be used for competition. The team plans to have the updated LiDAR code, new vision code, and current GPS waypoint code operating in conjunction to qualify for a run before competition.

INITIAL PERFORMANCE ASSESSMENT

At the end of last semester, GAVIN was fully capable of teleoperated control, however GAVIN was only capable of rudimentary obstacle avoidance and did not possess any line following ability. GAVIN navigated by GPS waypoints and relied on basic LiDAR code to avoid detected obstacles. Updated LiDAR code and new vision code are still being testing. The updated LiDAR code uses a decision matrix that will allow GAVIN to pick the best path to navigate to the desired goal location. The team hopes to integrate and test the updated and new code before the start of the 29th IGVC competition.

CONCLUSION

The ERAU IGVC team has worked to make significant improvements and to incorporate meaningful innovations to the Auto-Nav vehicle GAVIN. Upgrades included an HDR camera and Intel NUC computer, for improved vision and processing power. Addition of the SunView monitor and LED Indication Strip, have improved ease of use, and diagnostic testing ability. New code for obstacle detection, GPS waypoint navigation, and line following allow for an interactive system between different sensors to develop the decision-making process. The team has worked with professors and peers to ensure GAVIN is a lightweight, modular, safe vehicle capable of intelligent autonomous course navigation.

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