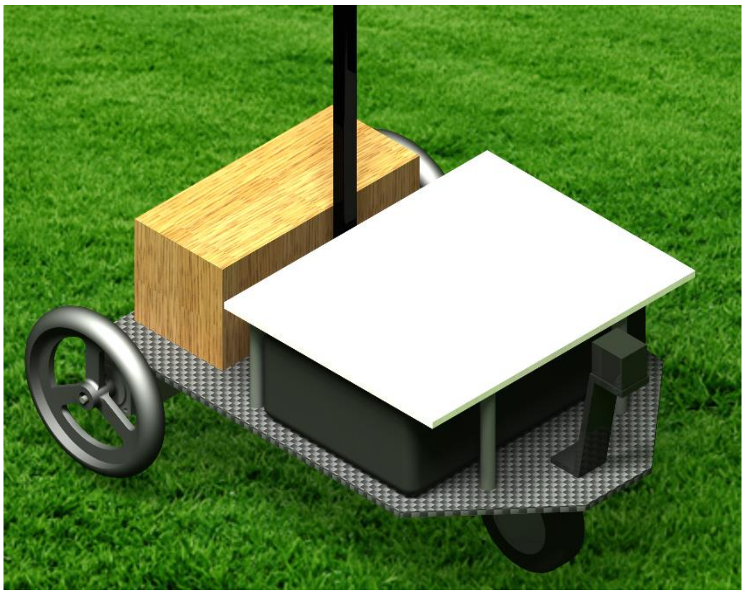
Embry-Riddle Aeronautical University

DAISI-C: Detailed Advanced Improvement System Initiative Carbon Edition



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Statement of Integrity

I hereby certify that the design and development of this vehicle described in this report is significant and equivalent to what might be awarded credit in a senior design course. This is prepared by the student team under my guidance.

Dr. Charles Reinholtz, Faculty Advisor

1. Introduction

DAISI-C, the Detailed Advanced Improvement System Initiative: Carbon edition, is an autonomous vehicle designed for navigation in unknown environments. The latest vehicle designed by student in the Robotics Association at Embry-Riddle (RAER), DAISI-C was built to improve upon a few of the shortcomings of last year's system. Although this is an improvement of the DAISI platform, the platform has been redesigned and optimized in order to better improve the mechanical and software systems. These improvements assist in producing a safer, more refined, and easier to use platform. This advanced IGVC vehicle includes desirable features not seen in many other competitors including portability, ruggedness, and remarkable agility during operation. This report outlines the development of these systems and the methods used for system integration.

1.1 Team Organization

The development of DAISI-C required a multidisciplinary engineering team capable of working on several different aspects of the vehicle, as seen in Table 1. The team consisted of 7 team members, each with their respective areas of focus as denoted by the symbol "X". These members cumulatively put more than 2,290 hours into the design, manufacturing, and implementation of DAISI-C and its software.

Table 1: Team Member Areas of Concentration

Team Members	Major	Mech.	Soft.	Elect.	Doc.	Hours
John Wardell	Unmanned Air. Sys/ Senior	X	X	X	X	440
Santiago Mujica	Human Factors/Junior	X		X	X	300
Lauren Kibler	Aero. Eng./Junior	X	X		X	300
Parker Tyson	Aero. Eng./Senior	X	X	X	X	250
Kody Miller	Mech. Eng./ Senior	X	X	X	X	250
Nick Middlebrooks	Mech. Eng./ Grad	X	X	X	X	450
Izzy Curry	Aero. Eng./ Junior		X	X		300

1.2 Design Process

The development of DAISI-C used a seven-step design process, as seen in Figure 1, that began with defining the problem as presented by the competition rules. Specifically, the problem was defined as follows: to develop a robot that can successfully navigate through an obstacle course and a series of waypoints, while reacting to visual cues from painted lanes and colored flags. The customers are the IGVC competition judges, advising faculty, and future team members. With those customers in mind, specifications were developed to meet the new competition standards.

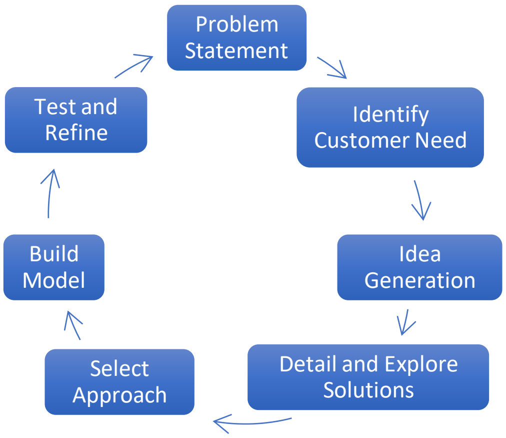

Figure 1: Design Process Approach

2. Innovations

2.1 Carbon Fiber Base

One of the driving passions behind DAISI-C and the previous DOLLE and DAISI platforms is to have a platform that is as lightweight as possible, without sacrificing performance and while maintaining structural integrity. Each year our team evaluates the platform to see what can be improved to make the system more lightweight, and this year the focus was on the structural base. Our team had reached the lightest weight achievable with aluminum tubing without sacrificing structural stability, so alternate materials were investigated.

To analyze what would be the best material, our team created the decision matrix seen in Table 2 to compare various materials. The matrix allowed the comparison of the materials considered for the base structure by ranking important design features by how important each feature is for the overall structure. The different materials compared were: sealed plywood, fiberglass, marine board, Nomex core carbon fiber, and aluminum. The features used in the comparison were: cost, ease of manufacturing, strength, rigidity, weight, and the visual appeal; on a scale of 1-10 where 10 was the best for each category. The material our team decided to go with was the Nomex Core Carbon Fiber, as although it is more costly, the strength as well as how light weight it is makes it the most optimal for our purpose. It also narrowly beat out Aluminum, showing just how good of a material the Aluminum has been for previous platforms, but also showing that there is more room to improve with the Nomex Core Carbon Fiber.

Table 2: Material Decision Matrix for Structural Base

Material	Material Cost	Ease of Manufacturing	Strength	Rigidity	Weight	Visual Appeal	Final Score
Sealed Plywood	8	10	6	4	7	10	45
Fiberglass	5	2	8	6	9	10	40
Marine Board	3	8	7	7	2	10	37
Nomex Core Carbon Fiber	2	5	10	10	10	10	47
Aluminum	4	9	9	9	5	9	45

2.2 Sun Prevention Device

On the previous DAISI platform, our team performed a heat analysis on the electronics inside the Pelican case to determine how much internal heat was generated, and if it would affect the performance of the system. Our analysis determined that the laptop and motor controllers did not generate enough heat to warrant a cooling system for the Pelican case internals. However, this was all lab testing inside an air-conditioned room, not outside in the heat. What was overlooked was the ambient heat of the sun directly on the black Pelican case, cooking the internal systems. To combat this problem, a sun prevention system was implemented by covering the Pelican case in aluminum tape to reflect the sun and prevent the box from heating up.

This was an inelegant solution, and so for the DAISI-C platform a new sun prevention device was needed. This new sun prevention device needed to not only reflect the heat from the sun, but also be weather resistant and lightweight. To determine what material would be the best for this, our team ran several materials through a design matrix, seen in Table 3, to determine what would be the most optimal material. From this analysis, our team chose to use a plywood cover that has been sealed for increased weather proofing as the sun prevention device cover material.

In addition to just being a cover, the sun prevention device also has to be able to swing up to expose the Pelican case for accessibility to change batteries or access the computer. In addition, the LED light panel that was previously attached directly to the Pelican case has been moved to top of the sun prevention device for easier visibility of the panel. These additional designs change some of the weightings in the design matrix compared to the structural base decision matrix.

Table 3: Material Decision Matrix for Sun Cover

Material	Material Cost	Ease of Manufacturing	Heat Rejection	Weather Proofing	Weight	Visual Appeal	Final Score
Sealed Plywood	9	10	10	9	8	10	56
Fiberglass	5	2	10	10	9	10	46
Marine Board	3	8	10	10	2	10	43
Plexiglass	7	7	7	7	8	9	45
Nomex Core Carbon Fiber	1	3	6	6	10	10	36
Aluminum	4	9	8	8	3	6	38
Plastic	7	10	10	10	10	2	49

2.3 New Circuit Board and LED Light Controller

In the previous system, the microcontroller system used to interface with the motors was updated from an Arduino Mega based system to an Mbed based system in order to run the new LED light panel indicator system. However, this board failed before the 2018 competition due to an unforeseen issue: the LED driver broke the serial communications with the motors. This was a hardware issue stemming from the LED driver code running software blocking operations that would interrupt serial commands to the motors and prevent the encoder feedback from being properly reported to the computer. This issue was resolved on the new control board used in the DAISI-C platform by using a separate Mbed for the LED light panel. This is a similar setup used in our A-REX vehicle entered in the Self-Drive competition.

The A-REX vehicle used in the Self-Drive competition has one Mbed in control of the drive-by-wire system and a separated Mbed running the multiple LED panels of different sizes. By using the same separated setup as the A-REX vehicle, the DAISI-C microcontroller can run a similar base code for controlling the LED light panels while keeping the motor control code separate. A shared code base allows for a unified code base across both platforms, allowing for easier development due to code simplicity and sharing.

3. Mechanical Design

3.1 Vehicle Structure

The chassis of DAISI-C was designed to best make use of the minimum size requirements. The base was a simple rectangular design without corners on the front to allow for a tighter turning radius and maximum efficiency in placement of the components on the frame to prevent hanging off the edges. By moving the sensor pole to the center of the vehicle, the GPS data is more accurate for calculations and mapping in the local frame because it is closer to the center of turning and mass of DAISI-C. Moving the payload to the back and rotating the electronics case made the vehicle much more accessible to a human operator working on the platform, allowing for easier assembly and disassembly in the field. In addition, the entire frame is constructed of carbon fiber for a very light, but strong and rigid base.

In order to protect the sensitive electronics, a waterproof IP65 rated Pelican Air Case was utilized in order to protect these electronics in addition to providing a means for the electronics to be modular and easily transportable. The electronic connections are passed through a connection panel which utilizes IP65 rated connectors in order to allow sensor communication with the internal laptop while allowing for the system to remain waterproof. When combined, the overall base system is designed to be modular and allow for ease of assembly, disassembly, and transport. The system frame design can be seen in Figure 2.

Figure 2: DAISI-C Base Configuration

The sensor pole, seen in Figure 3, is made of 1" square carbon fiber tubing mounted upright from the base of the frame. Carbon fiber was chosen for its rigidity, durability, and lightweight properties. The sensor pole holds the Ion Action Cam, Hemisphere GPS, safety lights, emergency stop button, and Ubiquiti Omni-Directional Antenna. The wires for the components are fastened to the sensor pole to allow for quick swapping of cameras or light options. The components are mounted using 3D printed friction mounts designed to allow for secure attachment to the sensor pole, while not disturbing the structural integrity of the carbon fiber, while providing the highest amount of stability for the sensors.

Figure 3: Sensor pole with close-up of 3D printed mounts

The motor assembly consists of a pair of 24V Quicksilver motors and OEM NEMA 23 Series gearheads connected to 12 ½" diameter Skyway tires. The motors are mounted directly to the frame to allow for ease of access while improving stability. The motors generate the 20 in-lb. of torque needed to reach the maximum 5MPH speed limit, while keeping traction even when going over the ramps.

3.2 Weather Proofing

Due to the location of the competition, rainy weather is unavoidable. In order to combat this issue, the vehicle was design and built in order to be waterproof, at least IP65 rated. This allows for testing in rainy conditions without additional changes needed to be made to the platform. This decreases the amount of downtime the system has to face during competition and allows for maximum efficiency when testing and making software changes. This is achieved through the combination of weatherproof devices, pelican case and connectors. This is also helpful for testing at home, as Florida is constantly raining as well.

3.3 Vehicle Cost

The cost of the vehicle can be split up into two different cost models, as seen in Table 2. The first model represents the raw cost of the platform if constructed brand new. The second model represents the cost to the team of the platform. Due to sponsorships and the reusability of various parts on the platform, the vehicle was of minimal cost to the team this year, with the only big expense being the new Nomex Core Carbon Fiber sheet. The final cost of the system was designed to be considerably lower than other possible designs used by competitors. This allowed for a versatile system in which sensors, and mechanical parts can be swapped at a low cost. Overall, this allows for a very low-cost system that is both versatile and efficient.

Table 4: Vehicle Cost

Item	Unit Cost ($)	Qty	Raw Cost ($)	Team Cost ($)
Laptop	$750	1	$750	$0
Wiring and Electrical	$150	1	$150	$150
Power Board	$200	1	$200	$200
ION Action Camera	$40	1	$40	$0
Digital Compass (IMU)	$1,350	1	$1,350	$0
LiPo Batteries (6s)	$45	3	$135	$0
Motors	$2,200	2	$4,400	$0
Wheels	$30	3	$90	$0
GPS	$3,000	1	$3,000	$0
LiDAR	$8,000	1	$8,000	$0
Transmitter	$255	1	$255	$0
Ubiquiti Network System	$380	1	$380	$0
Pelican Case	$200	1	$200	$0
Dragon Plate Nomex Carbon Fiber	$412	1	$412	$412
Dragon Plate Carbon Fiber Edge	$45	3	$136	$136
Stainless Panel Stud	$3	20	$44	$44
Total			**$19,522**	**$942**

4. Electrical Design

4.1 Overview

The central hub of DAISI-C's power system is a custom developed power board. Unregulated 24V power flows from the batteries to the power board, which can provide regulated 24V, 12V, 5V, and 3.3V to the sensors. The system overview is shown in Figure 4.

The electrical system is one of the more complex subsystems leading to a high number of potential failure points. For this reason, the team spent substantial time working to design and document the electrical system of DAISI-C before implementing it into the hardware. The DAISI-C team designed and manufactured a custom power distribution and control circuit board, which acts as the central hub for DAISI-C's power system. This minimized the risks that are associated with incorrect internal wiring.

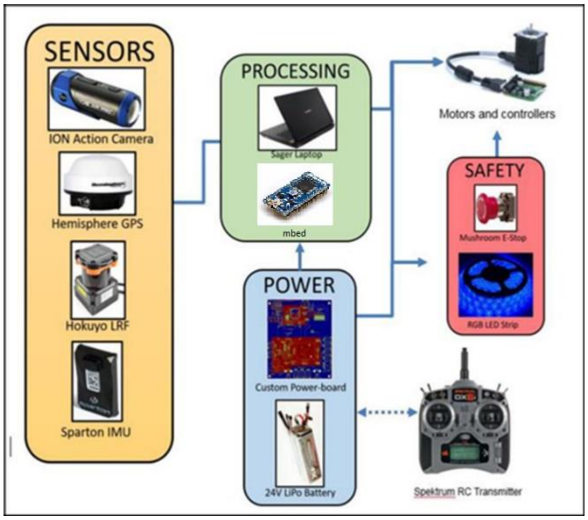

Figure 4: DAISI-C System Diagram

4.2 Power Distribution System

The custom printed circuit board provides all necessary operating voltages for each of DAISI-C's components. Unregulated 24V power flows from the batteries to the power board, which is then regulated and sent to the sensors. The power board can run the overall system for 1 to 1.5 hours on a 5Ah 6-cell LiPo battery. The overall runtime of the vehicle can be extended with a built-in hot swappable battery system that keeps the system running continuously. Each power connector for each of the components is protected by a fuse in the case of a power failure. The breakdown of which power rail each component in the system uses is broken down in Table 5.

Table 5: Sensor Power Ratings

Component	Power Consumption	Voltage Range	Operating Voltage	Sources
Sparton GEDC-6E IMU	0.32 W	3.3 V	3.3 V	Laptop via USB
Ion Action Cam	1.5 W	3 – 5 V	3.7 V	Battery Pack
Hemisphere A325 GPS	4.6 W	7 – 36 V	12 V	Power Board
Hokuyo UTM-30LX-EW	8 W	10.8 – 13.2 V	12 V	Power Board
Ubiquiti Rocket M5	8 W	24 V	24 V	Power Board
Quicksilver Motors	150 W	12 – 48 V	24 V	Power Board
Laptop	6 W	19V	19V	Laptop Battery

The power board has an extra connector for each voltage to allow for future expansion. The board also provides remote control function from an R/C transmitter, and both wired and wireless e-Stop capability. This all-in-one board is critical to the compact layout in DAISI-C.

4.3 Hot-Swap Capability

Thanks to the design of DAISI-C's electrical system, it is possible to swap out batteries during testing without having to re-initialize all of the hardware and software. This innovation was implemented in a previous version of the platform in order to reduce the downtime of the DAISI-C system during testing and competition runs.

4.4 Electronics Suite

4.4.1 Computer

The central point of sensor and communication integration is DAISI-C's onboard laptop with a Core i7 2.50 GHz processor, 8 GB RAM, and 250 GB solid state hard drive. The laptop runs a custom LabVIEW 2016 software package for hardware communication and implementation of the autonomy algorithms. The LabVIEW programming environment is a critical tool used to receive and organize data from the sensors and run all software algorithms in parallel. DAISI-C uses the following commercial off-the-shelf (COTS) sensors: a Hokuyo UTM-30LV-EW, a Hemisphere A325 GPS, a Sparton GEDC-6E IMU, and an Ion Action Camera.

4.4.2 LiDAR

The Hokuyo UTM-30LX-EW laser range finder scans for obstacles in a 270° planar sweep in .25° increments at 20 Hz. The maximum sensing range is 30 m, but DAISI-C limits detection of obstacles within 15 m. Resolution is 1 mm, and accuracy from 0.1-30m is ±50mm. Time-of-flight technology is used to calculate the distance to an object from the vehicle. This sensor scans in front of the vehicle and is used for obstacle detection and avoidance algorithms. The LIDAR data is transmitted to the laptop via Ethernet using TCP/IP protocols.

4.4.3 GPS

The Hemisphere A235 is a single unit GPS receiver and antenna that can gather GNSS and GLONASS L band signals and updates at 20 Hz. The uncorrected accuracy is typically between 1 to 2 m. However, the corrected accuracy with OmniStar HP brings the CEP down to around 0.1 m. GPS data is transmitted to the laptop via RS-232 and a serial-to-USB converter. Sensor fusion with the IMU takes place in the software for better positional accuracy.

4.4.4 Digital Compass IMU

The Sparton GEDC-6E Inertial Measurement Unit (IMU) is a 9-DOF system with an accelerometer, gyroscope, and magnetometer, which allows for highly accurate measurements of roll, pitch, and yaw. The accuracy in the heading is a 1° RMS accuracy at 0.1° resolution. The orientation data update at 20Hz and communicates over a RS-232 serial line with a built-in USB converter. Sensor fusion with the GPS takes place in software for better heading accuracy.

4.4.5 Digital Camera

The Ion Action Camera is an outdoor sport, consumer grade 12-megapixel digital camera with a wide 170° field of view lens. The camera is configured to output 720x480 standard definition video. This video is streamed to the computer with a digitizer and captured at 20Hz. The camera runs off its own battery power with a typical use time of 2.5 hours of continuous streaming.

4.4.6 LED Panel

The LED panel is an 8 x 32 LED pixel panel that allows the DAISI-C platform to show basic operating information at a glance. This system interfaces with the microcontroller on the power board to display any information passed to it in a simple format. Currently, it can display the state of the robot in RC, Autonomous, or Remote Operation mode, but has also been tested showing what waypoint it is the current goal heading.

4.5 Motor Interface

DAISI-C uses a new onboard Mbed-based microcontroller that is embedded inside the custom power board to relay commands to the motors. The microcontroller receives motor commands from both the laptop over the RS-232 serial interface and the radio controller, meaning DAISI-C can be controlled manually independent of a computer through the use of a RC controller.

4.6 Safety Devices

DAISI-C 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 a long restart time. E-Stop buttons are located both on the sensor pole and on the RC controller. In addition to the mechanical emergency stop system, an LED strip indicates to bystanders when the system is under autonomous or manual control.

In addition to the hardware E-Stop, the power board also has a software E-stop for the motors as a redundant system. Where 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 quicker restart time after being E-stopped compared to the hardware E-Stop. The RC controller emergency stop has a range of 0.25 miles, and when DAISI-C exits that range, it is automatically stopped.

5. Software Design

5.1 Overview

The software was developed in the National Instruments LabVIEW environment. As part of this software DAISI-C has an intuitive Graphical User Interface (GUI) to monitor, modify, and tune system functionality in real-time. The GUI helps verify real-time sensor statuses and path planning decisions for the current course. The flow of the code is organized for parallelized decisions that feed into a centralized trajectory planner. The highest priority for DAISI-C's trajectory planner can be seen in Figure 5.

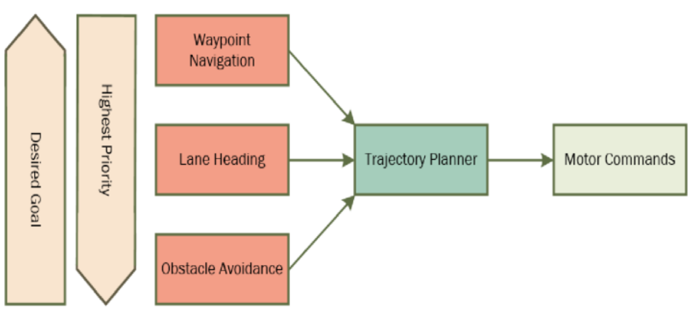

Figure 5: Software Priority

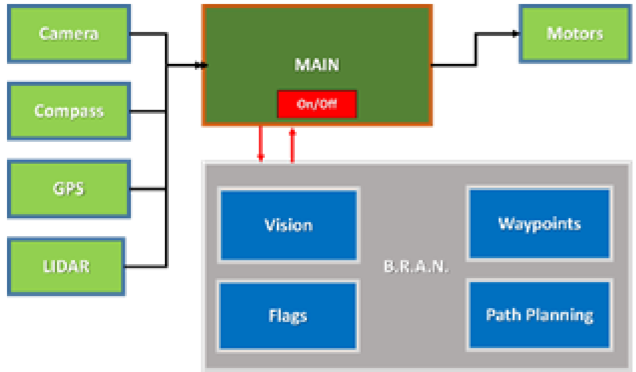

Figure 6: Software Flowchart

The software overview can be seen in Figure 6. The sensor modules feed the data into the MAIN program, which handles data queuing for any process to pull from. The sensor data is then fed in the Basic Robotic Autonomous Navigation (B.R.A.N.) module where the data is utilized by path-planning algorithms. The output of the path-planning is sent back into MAIN, where it is processed and sent out to the motors.

5.2 Obstacle Detection and Avoidance

DAISI-C's obstacle avoidance algorithm uses a LabVIEW function called "Advanced VFH" to create a new heading around obstacles. This function implements a use of a Vector Field Histogram (VFH) to determine location of obstacles. The Lidar data is passed into the Advanced VFH module, and when an object is detected within 2 meters of the robot, it is classified as an obstacle. The function uses the previous heading and the values of classified obstacles to output a new heading that avoids the obstacle field.

5.3 Software Strategy and Path Planning

5.3.1 Waypoint Navigation

The lowest priority for DAISI-C's trajectory planner is to follow the current waypoint location. This means that DAISI-C's final destination is the waypoint, but the lane heading and obstacle avoidance determine the actual path on how DAISI-C will reach the waypoint goal. The waypoint navigation algorithm calculates the angular difference and error to the waypoint by using the GPS's position data and the IMU's heading data. The navigation data is sent to the trajectory planner as the goal point for all navigation data.

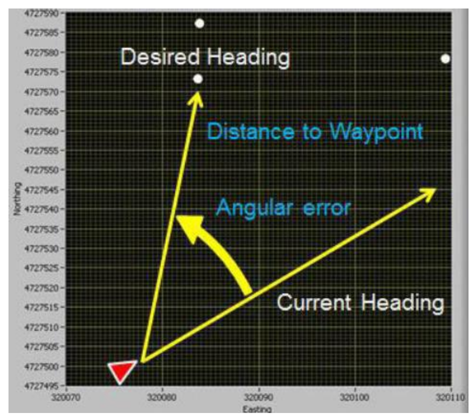

Figure 7: Waypoint Angular Error

5.3.2 Lane Following

Once the direction to the waypoint is determined, the next section of code implements Lane-Following. The Lane-Following flow diagram, shown in Figure 8, illustrates the primary steps in the line extraction algorithm. The algorithm's goal is to first prepare the image feed for image processing, then extract the location of the lanes. To prepare for image processing, irrelevant data such as the sky's horizon and the robot's frame are cropped out from the image. The image is also resampled at 360 X 180 resolution and blurred with a Gaussian filter to reduce processing time and blur out noise respectively from the image.

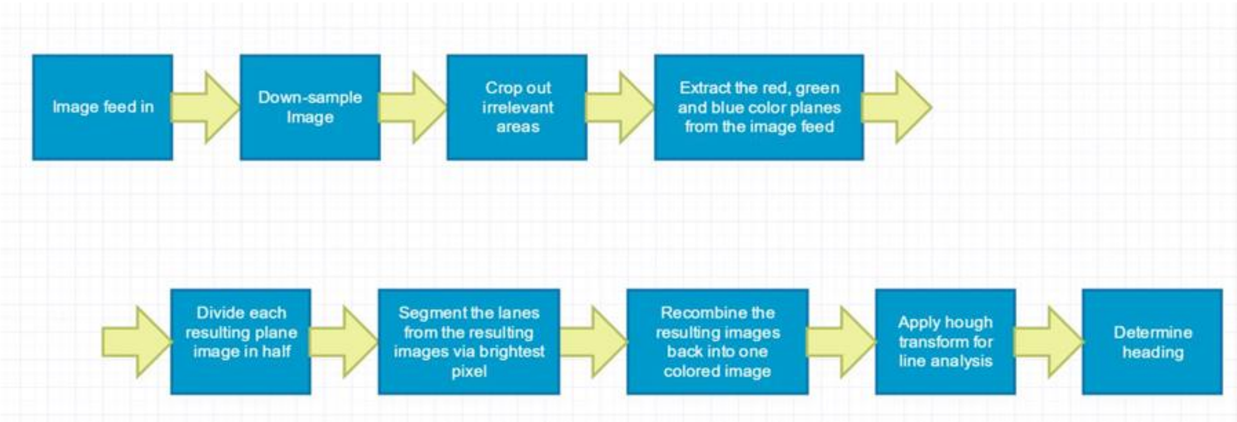

Figure 8: Lane-Following Flowchart

After preprocessing, lane segmentation takes place by extracting the three primary color planes, red, green and blue from the image feed. Each color plane image is divided in half for parallelized image processing, and a brightest pixel algorithm is applied to each divided image. The brightest pixel algorithm isolates the white pixels by scanning both horizontal and vertical axis of the image for the pixel(s) of highest value. The result is the segmented lanes within each color plane. To be robust to various lighting conditions, the results from the three primary color planes are combined into one final colored image as seen in Figure 9.

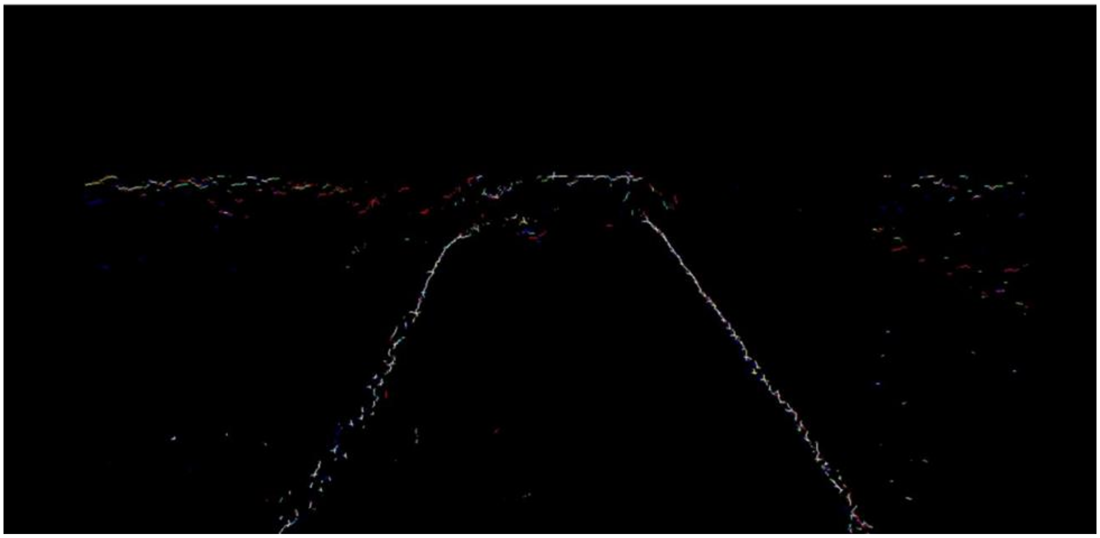

Figure 9: Segment the Image

After this, a Hough transform is used to find the best fit lines in each image half. It is possible that no line is detected in the image if no candidate receives a minimum number of "votes" in order to be considered a line. If lines do exist, they are categorized as horizontal or vertical, and compared with each other as parallel or intersecting. The last step is to recombine the half-images and draw an overlay on the location of the lanes as seen in Figure 10.

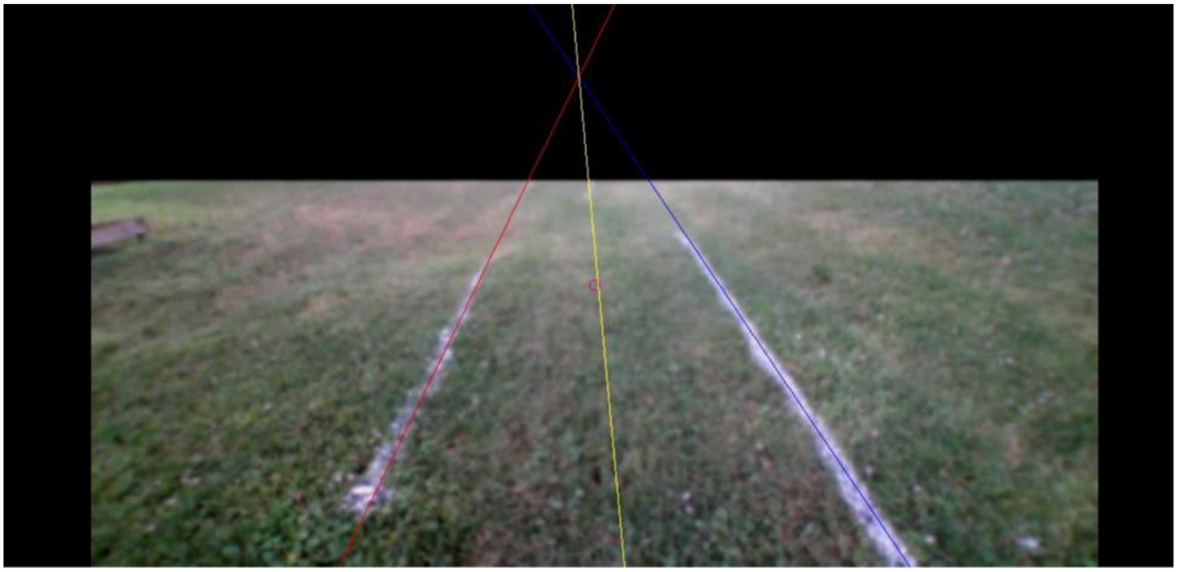

Figure 10: Identified Lane

A red line represents a line on the left, a blue line represents a line on the right. A decision tree is then used to select the heading given the possible combinations of lines as seen in Figure 8. A yellow line is then displayed in the image to represent this desired heading. For example, if two lines are detected, the heading should be between them. If only one line is detected, then the heading will be a few feet left or right of this line as appropriate to stay within the course. In addition, this algorithm works for both solid and dashed lines.

5.3.3 Pothole and Ramp Detection

The next stage in the vision processing is to identify the potholes and the ramp in the image. In both cases, the algorithm checks the image for a particular shape of a set area: a circle or a rectangle. If the circle criteria are met, the algorithm will identify this as a pothole; whereas, if a rectangle criterion is met, the algorithm will identify this as a ramp. When the ramp is detected, its entire visual appearance shines as bright as the surrounding lines due to its high spectral reflection. The ramp problem is solved by generating a blank strip down the center and using the edges of the ramp as a pseudo-lane. The pothole information is then passed to the Obstacle Avoidance algorithm to ensure the pothole is treated as an obstacle.

5.4 Map Generation

DAISI-C doesn't rely on previously generated maps, but instead works on a reactive system in the same style as how an autonomous car does. It has a local state of information plus the goal heading which it aims for. This is because the real world does not stay constant, such as construction and other moving vehicles, and is reflected in the IGVC competition because the judges can, and do, change the course between runs. However, all this information is not gone to waste, as it is logged and can be played back to understand how DAISI-C reacted to the environment in the MATLAB simulator.

The data logging system helps immensely with the testing and refining process by identifying problems that cannot be immediately noticed by vehicle performance inspection during a test. The output of the program is shown in Figure 11. The black rectangle represents the robot, while the blue represents obstacles, and the green circle is the target waypoint. The green semi-circle extending from the vehicle is the obstacle avoidance range, which will cause a reaction from the robot. The red dots show the vehicle's GPS trail. On the left-hand side are numerical values that can be customized to whatever the user wishes to see, including elapsed time, wheel speeds, and latency. Data can be fed into the system simulator from the data simulator to observe the output of the system, which is useful in determining software issues without needing to go outside and have a test run for each new change.

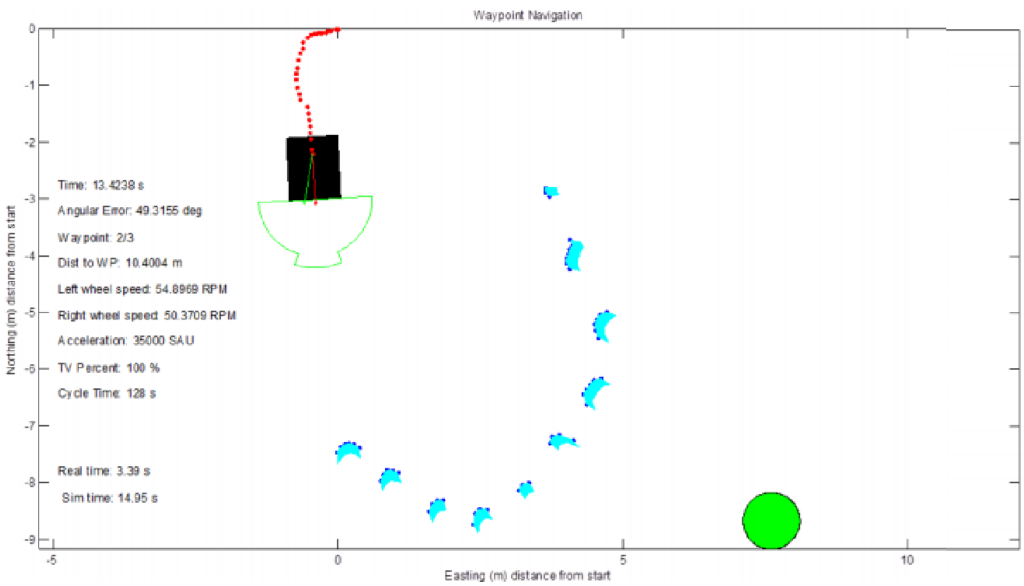

Figure 11: MATLAB System Simulator

5.5 Goal Selection and Path Generation

The trajectory planner is responsible for generating an appropriate heading for DAISI-C to follow based on all the information fed to it from the active algorithms. It is made up of two parts: the desired heading and the desired goal. The heading is selected based on available algorithm data from the software subsystem hierarchy seen in Figure 12.

The desired path goal uses a reverse priority order: waypoint navigation, lane heading, and then obstacle avoidance from the Advanced VFH. The goal heading is the next desired waypoint. The desired heading is the desired outcome from the algorithm.

Figure 12: Path Planning Flowchart

The waypoint navigation subsystem is the first step in finding the goal heading by initially finding the most direct route to the desired goal. Next the desired heading is updated with the input from the lane heading subsystem. This accounts for lanes up to five feet in front of DAISI-C to keep DAISI-C inside the course. Finally, the obstacle avoidance subsystem is used to prevent DAISI-C from hitting any obstacles. The combination of these algorithms will choose to find the heading to meet the priority heading criteria while attempting to converge to the goal heading.

5.6 Additional Feature: Modularity

The software integrates a messaging protocol structure which was developed by students within the Robotics Association of Embry-Riddle for the Maritime RobotX competition. This structure, referred to as “Minion Core”, allows the software to work as a system of modules, by passing data stored in “messages” across different computer processes. This allows LabVIEW to handle parallel-processing tasks more efficiently while retaining the ability to hot-swap sensors. This structure consists of individual modules that implement libraries consisting of publisher/subscriber protocols similar to JAUS. The modules can run parallel and communicate asynchronously.

6. Failure Modes and Resolutions

6.1 Vehicle Failure Modes and Resolutions

Although DAISI-C was designed for maximum rigidity and modularity, failures are always possible. To combat this possibility, a number of different failure modes have been identified, and resolutions have been put in place in order to minimize the negative results of any failure.

Mechanically, the vehicle continues to use a few hardware components and sensors from previous years. These components were thoroughly tested in order to ensure their integrity. In the event of a failure, the vehicles design and construction were focused around the concept of modularity. Due to this focus, components are easily removable and replaceable. Attached to the vehicle is an onboard toolbox which contains all the necessary tools to swap out any physical structure necessary.

In addition, if a sensor fails a replacement can be swapped with no software changes due to the health monitoring system in place. Some sensors tend to lose connection when connectors are jolted or other general software crashes. The software is constantly monitoring the sensor connections for any errors that may arise from communication protocol issues or disconnections and attempts to reset sensor connection. While the sensor is down, the previous set of data is retained for use until the senor is reconnected. This data then produces a trigger that allows the map to take over navigation until the newly installed sensor updates.

6.2 Failure Prevention Strategy

6.2.1 Health Monitoring

The software is only as durable as the communication with the sensors. Some sensors may lose connection if connectors are jolted and/or general communication crashes. The software is constantly monitoring the sensor connections for any errors that may arise from communication protocol issues or disconnections and attempts to reset sensor connection. During the reset, the algorithms send a dummy set of data, as if the course is free, and then uses the existing feedback data to aid in temporary travel. The dummy data sends a trigger to show that the map should take over until new sensor updates occur or if the approximated location has no new data.

6.2.2 Vision Processing

With vision-based algorithms, the toughest part of maintaining great results is dynamic lighting impeding the detection of white lines. The physical and solar interference affect the actual image quality due to washing out the scene. The most pertinent change is the change in sunlight: the direct sunlight versus a cloudy day can change mid-run and affect the amount of luminance on the ground. The software combats the chance in sunlight issue by preparing to find a very sunny set of lines on the ground. With the dead grass and flowers in the lanes, these objects could be considered as potholes or the ramp (based on size of patches) to help filter them appropriately (based on vision algorithms) and continue navigating accordingly.

7. Simulation

7.1 LabVIEW

To troubleshoot issues with software a simulator was created so that DAISI-C's GPS position and IMU heading could be manually controlled to observe how DAISI-C would react. This program allows software to be bench tested from the lab and the team can use it to troubleshoot issue that could typically only be seen when driving the system. Not only does this save team members' time in the troubleshooting phase of software development, this also prevents hardware modifications from delaying initial software tests. The simulator can only be used when the GPS and IMU are turned off, as manual control of the GPS position and IMU heading requires that those values aren't being overwritten by the sensors or their health monitoring system. Figure 13 shows the front panel of simulator.

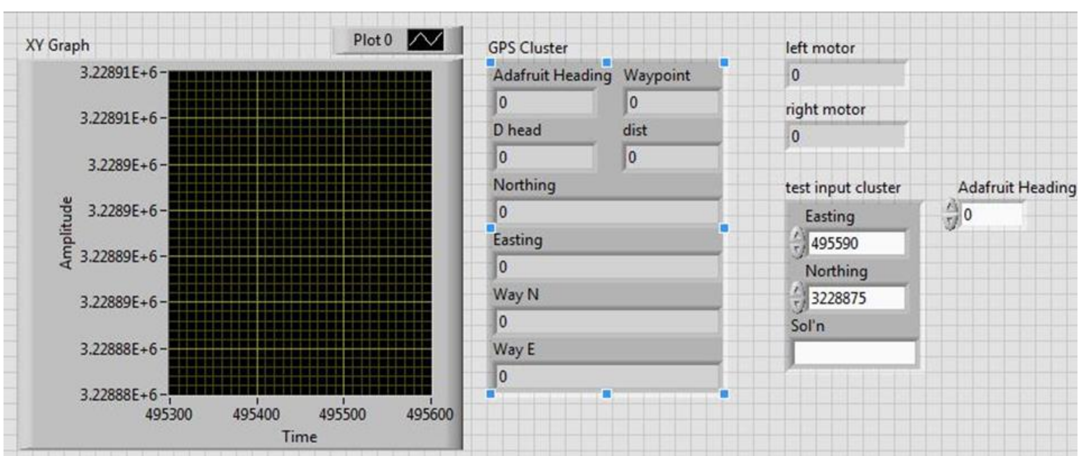

Figure 13: LabVIEW Data Simulator Interface

8. Performance Testing

DAISI-C was tested in an outside environment that was similar to the IGVC competition layout. The white lines painted on the grass with orange traffic barrels placed throughout made for a great place to test DAISI-C in a pseudo- competition environment.

Before the outdoor test could be conducted, each subsystem had to pass a quality assurance check to make sure the systems were still working. Each of the sensors, being reused from last year, were checked in the lab to ensure the cables still had a good connection for both power and data.

Before physically making the new frame, it was first created as a CATIA model, where the stresses and strains on the frame could be measured and adjusted before making the first prototype. This was harder to perform on the DAISI-C platform compared to the previous systems, as composites can't be modeled traditionally in CAD programs. To do this testing, our team used a sample sheet of the Nomex Core Carbon Fiber and loaded it to 150 lbs. (over three times the weight of the DAISI-C platform) for a traditional load test. The sheet did not show any signs of fracture or delamination during or after the test.

The subsystem tests were performed before each time DAISI-C was tested outside to ensure no problems had arisen between test, allowing for problem-free software tests. As each software algorithm was tested, from waypoint to obstacle avoidance, a remote E-Stop operated by a secondary team member was always prepared to shutdown the system in the case of any problem.

9. Conclusion

DAISI-C is a fully autonomous robotic vehicle designed, manufactured, and tested by engineering students at ERAU. The DAISI-C team gave special attention to both the requirements of the IGVC competition and the requirements set forth by their professors and peers. DAISI-C accomplishes the team's goals of creating a lightweight, safe, maintainable, and accessible robot with in a modular design. DAISI-C will be completely fine-tuned and ready for the summer 2019 IGVC competition. The team feels confident that DAISI-C will not only be capable of completing both the basic and advanced practical course, but that it will also impress the judges with its intelligent and innovative design.

10. References

[1] IGVC Rules committee, "IGVC Rules 2018," http://www.igvc.org/2018IGVCRules.pdf (accessed on March 15, 2018).

[2] Bacha, Andrew R. "Line Detection and Lane Following for an Autonomous Mobile Robot." Thesis. Virginia Polytechnic Institute, 2005. Print.

[3] Schoener, M., Middlebrooks, N., and others, "Embry-Riddle Aeronautical University – DOLLE," http://www.igvc.org/design/2017/3.pdf. Annual Report. Embry-Riddle Aeronautical University, 2017. Web.

[4] Schoener, M., Middlebrooks, N., and others, "Embry-Riddle Aeronautical University – Ozone," http://www.igvc.org/design/2016/17.pdf. Annual Report. Embry-Riddle Aeronautical University, 2016. Web.

[5] Schoener, M., Middlebrooks, N., and others, "Embry-Riddle Aeronautical University – Zero," http://www.igvc.org/design/2015/7.pdf. Annual Report. Embry-Riddle Aeronautical University, 2015. Web.

[6] Schoener, M., Middlebrooks, N., and others, "Embry-Riddle Aeronautical University – DAISI," http://www.igvc.org/design/2018/4.pdf. Annual Report. Embry-Riddle Aeronautical University, 2018. Web.