ZERO

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1 INTRODUCTION

Zero is an Autonomous, differentially-steered, vehicle used for intelligent navigation. The name Zero a reference to both the zero-turn-radius inherent in most differentially driven vehicles, and to the circular planform shape (the shape viewed from above). This shape is part of Zero's innovative design. It allows the vehicle to make zero-radius turns in close proximity to objects without the concern that an extending nose or tail will clip the object. The shape also eliminates sharp corners and is hence a safety feature. Zero's design incorporates novel mechanical, software, and electrical systems features, with an emphasis on testability, and maintainability. The software algorithms from its predecessor, Alvin, have been modified, supported with additional algorithms and optimized to handle the challenges of the basic and advance courses. This report outlines the development of these systems and the methods used to integrate them

No need for caps

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2 DESIGN PROCESS

The development of Zero uses a seven-step design process that began with determining the problem presented by the competition. For the IGVC competition, the problem is to develop a robot that can successfully navigate through an obstacle course and a series of waypoints, while reacting from visual cues from painted lanes and colored flags. The customers are the IGVC competition judges, the professors, and future team members. With those customers in mind, new specifications were developed to meet the new competition standards, and also to improve upon the previous year's platform. The customers' requirements, functional requirements, preferences, and comparisons with competitors were identified using a House of Quality (HoQ) (Table 1).

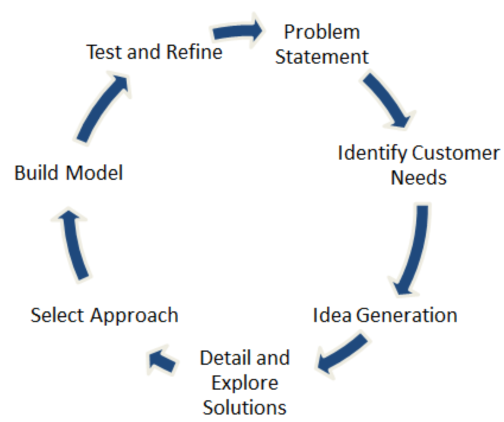

Figure 1: Design Methodology

Zero's HoQ (Table 1) shows a desire for accessibility and simplicity. Chassis A has a circular shape, Chassis B has a dome shape, and Chassis C uses a trailer hitch. Other characteristics were selected due to the emphasis of Zero targeting no down time which means that options such as running with continuous power (Hot Swappable Batteries) and quick repairs (Tool Compartment Shelf) were considered.

Table 2: House of Quality

Engineering requirements	Chassis A	Chassis B	Chassis C	Hot Swappable Batteries	Tool Shelf	Laptop Lift System	Tubes for Wires	Shelves	Caster Wheel	Middle Joint
Competition size	4	4	4	N/a	N/a	N/a	N/a	N/a	N/a	N/a
Accessibility	4	4	5	3	3	5	1	4	N/a	N/a
Testability	3	3	3	5	5	4	N/a	2	N/a	N/a
LRF Visibility	5	5	5	N/a	N/a	N/a	N/a	N/a	N/a	N/a
GoPro Visibility	5	4	4	N/a	N/a	N/a	N/a	N/a	N/a	N/a
Aesthetics	5	4	4	N/a	4	3	4	2	2	4
Weight	4	4	3	5	2	2	N/a	3	2	3
Payload	3	4	4	N/a	N/a	N/a	N/a	N/a	N/a	N/a
Internal Wiring	4	3	3	5	N/a	2	5	3	N/a	N/a
Waterproof	4	3	4	N/a	N/a	2	5	N/a	N/a	N/a
Cost	3	3	2	3	3	2	4	4	4	2
Score	44	41	41	21	17	20	19	18	8	9

Following the development of requirements for the HoQ, the design team focused on idea generation. The mechanical team members were tasked with developing and presenting their CAD designs. Each design was scored based on the HoQ selected criteria using a 1-5 scale and the design with the highest score was selected, as agreed upon by the team members.

This year's software went through the following changes in order of importance. The code in LabVIEW was redesigned to increase readability and code flow. With the redesign, it allowed for new software innovations. Zero has different course settings for switching between Basic or Advanced course or just a Testing setting. Zero can run with or with sensors with default dummy values in case of sensor failure.

2.1 Improvements

Below is a summary of major changes in this year's platform compared to Zero's predecessors. This year's design focused on improvement through simplification and ease of use. Each is discussed in more detail in its respective section.

- Mechanical:
    - Weight balancing

        - Weatherproofing
        - Accessibility
        - Optimized Payload Placement
        - Smaller chassis size
- Electrical: Redesign of system wiring and connections, redesigned safety stop system.
- Sensor Changes:
    - Single GoPro camera
    - One Hokuyo UTM-30LX-EW LRF
- Software:
    - Adjusted Code algorithms to new robot design
    - Increased code flow and readability
    - Course settings added for specific navigation settings
    - Default dummy values in case of sensor failure

2.2 Innovations

Tool Compartment Shelf

The design includes a tool shelf to store tools needed to maintain, adjust, or repair the robot. The tool shelf increases the duration of the vehicle's reliability on and off the field while integrating convenience and availability of tools for the customer.

Hot Swappable Batteries

Though Zero only needs one 24 Volt battery, it has two inputs for batteries. This feature allows for a fully charged battery to be plugged into Zero before removing the other battery, thus eliminating the need to power down the robot before switching batteries. To prevent the batteries from charging each while both plugged in, a current blocking diode is used. This only allows the current to flow into the circuit board and not into the other battery.

Minimalistic Sensor Use

Zero is capable of autonomous control even in the presence of sensor dropout. The code allows Zero to run using the available sensors while using substitute values for inactive or erroneous sensors. Although this approach limits the system capabilities, it enables Zero to still perform the tasks of any sensor that remains functional. The code can determine sensor activity if the sensor is powered and still receives a signal from the communication port (indicated by a green "<Name of Sensor> Online"). For example, if the GPS and compass were only available, then waypoint navigation is still active. Another example is if the GoPro camera is the only active sensor, Zero can avoid crossing the lines and obstacles.

2.3 Vehicle Cost

Table 2: Cost of all mechanical and electrical components

Zero Component	Retail Cost	Team Cost
Sensors & Electrical		
DELL Latitude Laptop Computer	$780.00	$0.00
Go Pro HD Hero Camera	$400.00	$133.00
Spartan GEDC-6 Digital Compass	$1350.00	$0.00
Torc SafeStop ES 220 Wireless E-Stop System	$2000.00	$0.00
Lipo 6 Cell Battery Packs	$60.00	$60.00
NovAtel Smart MR-10 GPS	$5000.00	$4500.00
Keyspan Serial to USB	$88.00	$88.00
Hokuyo UTM-30LX-EW	$6500.00	$5250.00
Custom Power Board	$140.00	$140.00
Wires & Mics.	$200.00	$200.00
Sensors & Electrical Subtotal:	**$16,518.00**	**$10,371.00**
Mechanical		
Quicksilver Motors	$2200.00	$1550.00
Caster Wheel	$15.00	$15.00
Skyway Wheels	$120.00	$60.00
Wooden Frame	$200.00	$200.00
PVC Pipe	$10.00	$10.00
Water Proof Cover	$50.00	$50.00
Mechanical Subtotal:	**$2,595.00**	**$1,885.00**
Total:	**$19,113.00**	**$12,256.00**

2.4 Team Composition

Table 3: Team Member list and each member's area of concentration for study

Areas Of Concentration							
Team Member	Academic Major	Mechanical	Software	Electrical	Document	CAD	Hours
Matt Greene (Mechanical Lead)	Mechanical Engineering	x		x	x	x	450
Marco Schoener (Software Lead)	Mechanical Engineering		x	x	x		450
Jesse Pierce	Aeronautical Science	x		x	x	x	300
Michael Miller	Software Engineering		x	x			350
Christopher Utt	Mechanical Engineering	x			x	x	250
Nicholas Middlebrooks	Mechanical Engineering		x	x			350
Melanie Lee	Mechanical Engineering	x				x	150
Yates Simpson	Mechanical Engineering	x			x		150

3 MECHANICAL

3.1 Vehicle Chassis

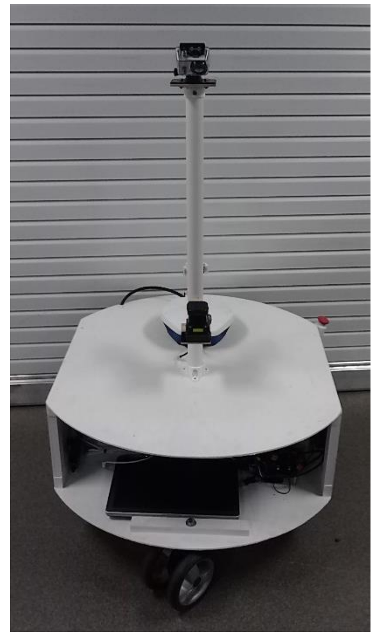

Figure 2: Photo of Zero

Zero's design focuses on being light weight, highly maneuverable, and compact. The frame is designed out of a recyclable natural composite plywood to reduce weight, cost and increase ease of manufacturing. As a result, the robot is composed of three logical components: motor assembly, frame, and vision mast. Each component is easily removed for individual maintenance while leaving the rest of the robot intact. In addition, the disassembly of Zero results in convenient transportation. Finally, Zero has a circular frame with the minimum required dimensions for the competition, making it possible to conduct zero radius turns without impacting obstacles and enabling the vehicle to easily fit through tight gaps, including doorways (Fig. 2).

3.1.1 Sensor Mast

The sensor mast is made of standard plumbing 2" PVC pipe, mounted upright to the base of the vehicle chassis. This material was chose due to durability and weight considerations. It is 3.5 ft. in height, and has an inner diameter of a quarter of an inch. Mounted to the pole are the GoPro Hero3 camera, GPS antenna and the Hokuyo UTM-30LX-EW laser range finder (LRF). The connections for these components to the system computer run through the inside of the mast, out the bottom of the base and loop back up through the base. This allows any water that gets into the pole to exit through the base of the robot and prevent it from entering the body of the robot.

3.1.2 Motor Assembly and Drivetrain

The motor assembly consists of a pair of 24 Volt Quicksilver motors and OEM NEMA 23 Series gearheads connected to two 12 ½" diameter Skyway tires. The aluminum clamps attached to the gearheads are fixed onto a wooden support which is mounted to the robot base. Supporting the motors in this way provides mounting security and prevents warping in the robot frame. The assembly is quickly removable with four quarter inch bolts for maintenance and storage.

3.1.3 Quick Service Tool Box

A tool box is placed inside Zero's chassis towards the back. The tool box contains, but is not limited to: Screwdrivers of various sizes, socket wrench with 1/4 head, and Pliers. This set of tools is sufficient to perform most servicing operations on the robot.

3.2 Waterproofing and Durability

Due to the wooden construction of Zero, waterproofing is paramount. In order to provide the pieces of Zero's chassis with a water tight fit, all external wires run through the sensor mast with wire glands (preventing water from getting into mast) and straight into Zero in order to plug into the computer and motherboard; there is also a small hole in the bottom of the mast to prevent water collection, if any, at the bottom of the mast. Zero also has internal, covered wheels to prevent incursion from any outside debris or moisture. These wheel covers are mounted inside of the robot using a rubber gasket between the covers and the bottom panel of Zero's cargo bay. Zero also has a waterproof covering that covers the entire chassis leaving the GPS and sensor mast exposed.

4 ELECTRICAL AND SENSING SYSTEMS

4.1 Power System and Battery Life

The central hub of Zero'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.

Table 4: Operating Voltage Chart for all the sensors and electrical components in Volts (V) and Watts (W).

Sensor Voltage Chart				
Sensor Name	**Power Consumption**	**Voltage Range**	**Operating Voltage**	**Source**
Novatel Smart MR-10 GPS	3.7W	9 – 36V	24V	Motherboard
Sparton Compass	0.32W	3.3V	3.3V	Laptop
Hokuyo UTM-30LX-EW	~8W	10.8 – 13.2V	12V	Motherboard
GoPro HERO	1.5W	3-5V	3.7V	Battery Pack
Quicksilver Motors	150W	12 – 48V	24V	Motherboard
TORC Robotics SafeStop	8W	10 – 40V	12V	Motherboard

The regulated 24 volts is distributed to each motor. The regulated 12 volts is sent to the GPS, SafeStop, LRF and LEDs. The regulated 3.3 volts is sent to the ambient light sensor and Sparton GEDC-6 compass. The regulated 5 volts is not be currently used but is available for testing future sensors and electrical system expansion. Each of these connectors has an individual fuse to avoid damage to the sensors.

4.2. Custom Power Distribution and Control Circuit

The electrical system is one of the more complex subsystems in a robot, and therefore had a high number of potential failure points. For this reason, the team spent substantial time working to design and document the electrical system of Zero before implementing it in hardware. The Zero team designed and manufactured a custom power distribution and control circuit board. The custom printed circuit board provides all necessary operating voltages for each of Zero's components. In addition, each voltage has an extra socket to allow for new components to be integrated in the future. 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 packaging layout in Zero.

4.3 Safety Systems

Zero incorporates the SafeStop emergency stop system from TORC Robotics. The SafeStops are located on Zero's chassis and on its controller. The controller Emergency Stop (E-Stop) has a range of 0.25 miles; and when the robot is out of that range, the robot enter "safe mode" and is automatically stopped. As implemented, the SafeStop system provides a pause mode and a "hard" emergency stop mode. The pause mode rapidly brings the vehicle to a controlled stop without cutting power. The "hard" emergency stop opens a relay, disengaging all power to the motherboard. There is also a mounted lighting on Zero indicates to bystanders when the system is under autonomous control.

4.4 Improvement of Motor Interface

Zero's predecessor used an analog voltage line to command the Quicksilver A23H-5 motors. This design worked well except in the case where the motors were turned on before the R/C controller. In this case, the analog input of zero volts would command the motors to full reverse. To solve this, and for safety and interoperability with other software packages being developed at Embry-Riddle, the remote control solution and the command interface from the computer have been integrated into one microcontroller on Zero's custom power and control board. This board communicates with the motor controllers through an RS-232 serial line.

4.5 Sensor System and Integration

The central point of integration for all of Zero's sensors is a DELL Latitude Laptop with a Core i5 2.50 Ghz processor, 4 GB RAM, and 256 GB solid state hard drive. The LabVIEW programming environment is a critical tool used to receive and organize data from the sensors and run all software algorithms. Each sensor has a separate data acquisition block that is polled for current sensor readings.

Zero uses four commercial-off-the-shelf (COTS) sensors. Zero uses a Hokuyo UTM-30LX-EW, a NovAtel GPS system, a Spartan GDEC6 compass, and a GoPro HD Hero camera for perception. A comprehensive list of components is provided in Section 2.3, along with component costs. Each sensor is briefly described below.

LRF — Hokuyo UTM-30LX-EW laser range finder scans for obstacles in a 270° planar sweep in 1° increments at 20 Hz. The maximum sensing rage is 60 m, but Zero limits detection to 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 LRF collects angle and distance information of obstacles over the entire 270° plane and transmits this data to the laptop via Ethernet cables.

GPS — Novatel's SMART-MR10 receiver and antenna combines global positioning satellites with the OmniSTAR HP correctional service. Uncorrected accuracy is usually 1-2m CEP. Correction with OmniSTAR HP decreases the uncertainty to sub-decimeter range. The SPAN system integrates an IMU with a Kalman filter, so continuous inertial solutions can be output at up to 100 Hz. ZERO accesses the fused GPS-inertial solution at 20 Hz. GPS data is transmitted to the laptop via RS-232 and a serial-to-USB converter.

Digital Compass — The Sparton GEDC-6 digital compass for navigation is a six-axis accelerometer/magnetometer that measures heading, pitch, and roll information with 1° RMS accuracy at 0.1° resolution. ZERO accesses the orientation data at 20 Hz via RS-232 and a serial-to-USB converter. The pitch, roll and linear acceleration outputs of this sensor are currently ignored.

Digital Camera — The GoPro HD Hero is an outdoor sport, consumer grade 5 megapixel digital camera with a very wide 170° field of view lens. The GoPro on Zero is configured to output 720x480 standard definition video, which is streamed to the computer with a digitizer and captured at 20Hz. The GoPro camera runs off its own battery power with a typical use time of one hour continuous streaming.

5 SOFTWARE STRATEGY

5.1 Structure

Zero's software system was developed using National Instruments LabVIEW. LabVIEW was chosen because it provides an intuitive Graphical User Interface (GUI) which allows the user to easily monitor, modify, and debug software and easily handles sensor integration. The GUI is helpful in verifying that all of Zero's sensors and components are fully operational before the autonomous program is run.

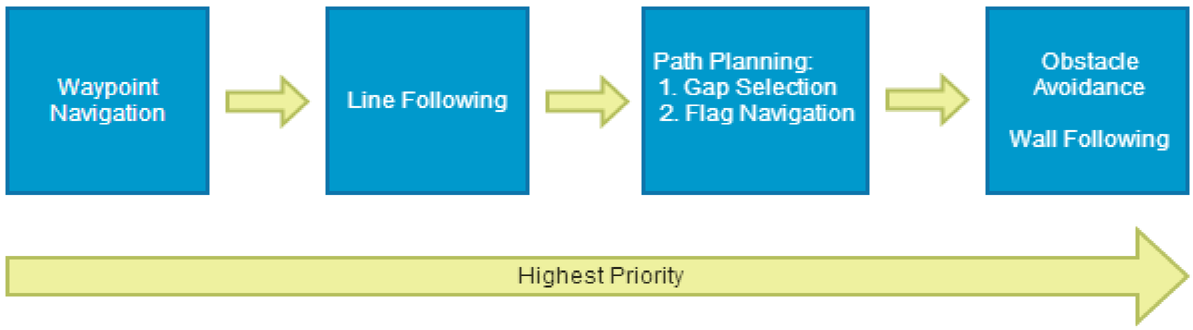

Figure 3: Flowchart of ZERO's Software Architecture

The code is broken into four major sequential steps, with each later process able to make use of and subsume the previous decision. The steps are waypoint navigation, line following, path planning, and obstacle avoidance (Fig. 3).

5.2 Waypoint Navigation

The first part of Zero's software structure consists of Waypoint Navigation. The GPS and compass provide Zero's current position and heading, respectively. With this information the angular error and the distance to the target waypoint can be calculated. Without the presence of any obstacles, independent PID control loops are used to control Zero's angular velocity and speed based on the angular error and distance to waypoint feedback as depicted in Fig. 4.

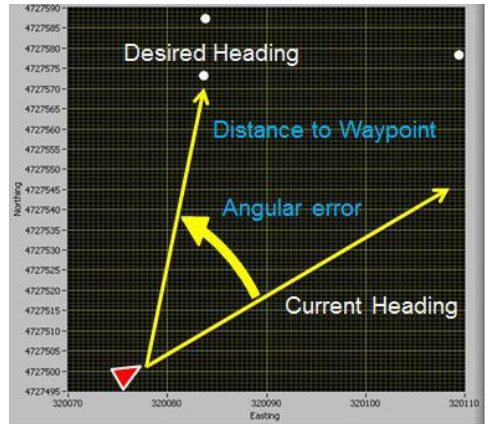

Figure 4: Waypoint Navigation graph of the robot's heading vs. the desired heading.

5.3 Line Following

Once the direction to the waypoint is determined, the next section of code implements line following. The line following flow diagram, shown in Fig. 5, illustrates the primary steps in the line extraction algorithm. First, box covers are placed at the top and bottom of the image to block out the horizon and vehicle, respectively, since both can have very bright pixels that can saturate the image and are not lines. Next, the image is down sampled from 720 x 480 to 160 x 120 to blur some noise and reduce processing time. A 2:1 plane threshold of blue and green filters is performed to obtain a grayscale image. The image is also split into a left and right half, since there are potentially two dominant lines in the image.

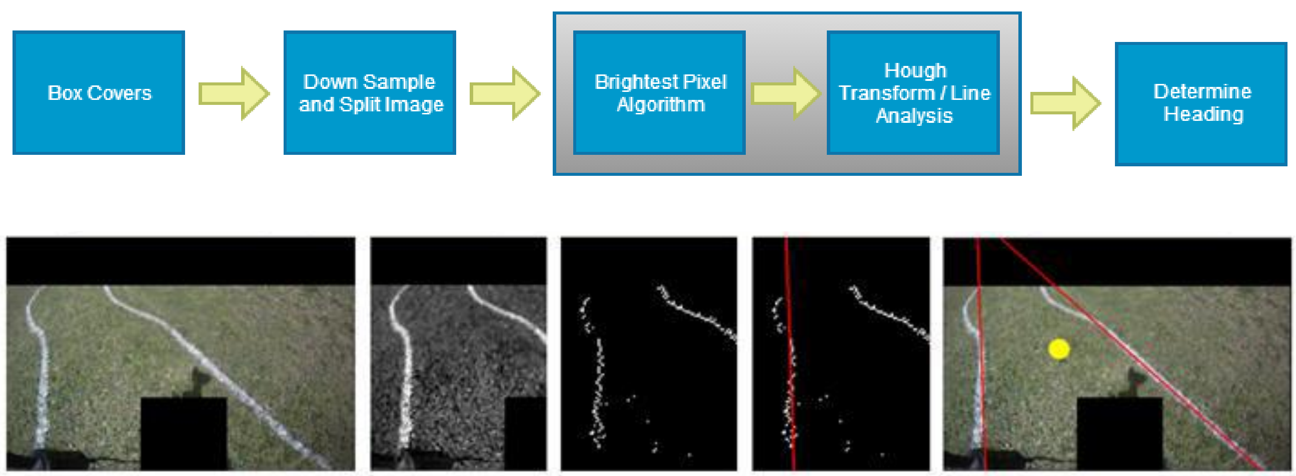

Figure 5: Line detection algorithm

A brightest pixel algorithm isolates the white pixels by scanning both horizontal and vertical lines for the pixel(s) of highest value. Then, a Hough transform uses a voting system to determine the slope and distance to the dominant line traced by the pixels of each half-image. 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 use a decision tree to select the heading given the possible combinations of lines in half-images. For example, if both images detect a line, the heading should be between them. If only one image contains a line, then the heading should be a few feet left or right of this line as appropriate to stay within the course.

5.4 Path Planning

Path planning uses the previous data from the waypoint navigation and line heading and adds one of two scenarios: Gap Selection and Flag Navigation.

5.4.1 Gap Selection

Zero makes use of a long range optimal heading algorithm for gap identification and vehicle maneuvering. Although Zero's LRF system sees a 180° FOV of objects at up to 60 meters away, the obstacle avoidance algorithm only makes use of data points within a set 2 meter distance threshold of the vehicle. This results in somewhat clumsy paths that can be characterized as simply straight lines towards the next waypoint until an object is within 2 meters, at which point the vehicle will make a sudden left or right turn.
The path planning algorithm eliminates this sub-optimal behavior by making use of data within a range of 15 meters. The algorithm analyzes the obstacle data and segments objects so that any gap greater than the vehicle's tolerance width for passing through, about 1.5 meters, is marked as either a left-handed or right-handed opening. In Fig. 6, the small green circles represent left-handed openings and the red circles mark the right-sided ones. The green arrow shows the heading that the algorithm has determined leads to the optimal opening. With this algorithm, Zero can drive straight to the optimal opening instead of simply driving straight until it is in close proximity to an obstacle.
Given the limitations of the LRF, namely that it cannot see through objects, this technique provides improved behavior going towards unknown parts of the course, because even a mapping solution cannot map unknown parts of the course given the same sensors.

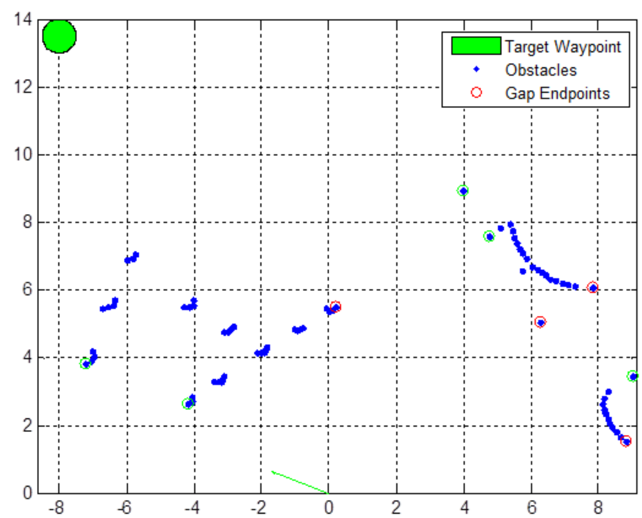

Figure 6: This is a screenshot of the obstacles (in blue) that the LRF sees and shows the openings it sees (in red circles).

5.4.2 Flag Detection

For the advanced course in the competition this year, blue and red flags are arranged in a complex row arrangement. The flag detection algorithm uses three simple steps (Fig. 7). First, it retains the same box covers as the line detection algorithm to block out parts of the image that are near the horizon or vehicle. Then it performs a mixed-plane threshold based on hue (color), RGB ratios, and HSL values to determine pixels that qualify as either blue or red. Finally, a particle filter is used to eliminate blobs that are too small or too large to possibly be flags. The results are overlain on the GUI so that the user can immediately see what has been detected as a flag and make adjustments as needed. This year, the field of view for detecting the flags is minimized to reduce the probability of detecting objects off the field.

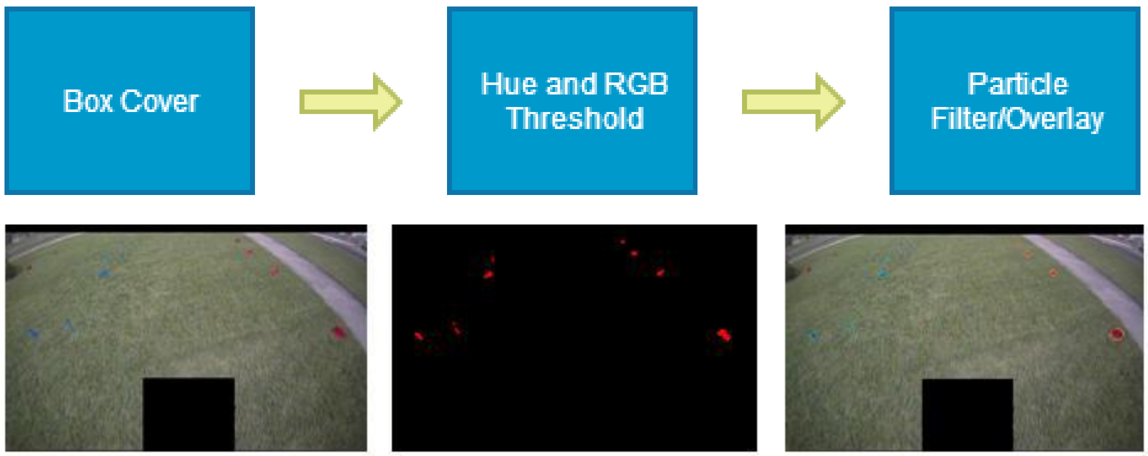

Figure 7: Screenshots of the Flag detection process.

5.5 Obstacle Avoidance

Zero's obstacle avoidance algorithm operates when the vehicle is within 2 meters of an obstacle. The LRF sensor provides angular position and distance information that enable the obstacle avoidance algorithm. The LRF's 180° field of view is broken into five zones: center, middle left/right and far left/right. Fig. 8 below shows the vehicle with the zones defined. The segmentation of these zones can be modified by the user but are currently set at: 0° (due right), 30°, 65°, 115°, 150°, and 180° (due left). A zone is considered occupied when an obstacle is within 2 meters. An occupied zone indicates to Zero the instruction to turn in the opposite direction.

While each zone is labeled as occupied or unoccupied, the algorithm continuously uses a decision tree to decide the path to avoid obstacles. The main check on the decision tree is to check if the center cone is occupied. If that cone is occupied, it goes on to check if the previous command was left or right. Next, the middle left or right, respectively, is checked to see if it is occupied. This decision tree continues on for all possible combinations of cones and objects.

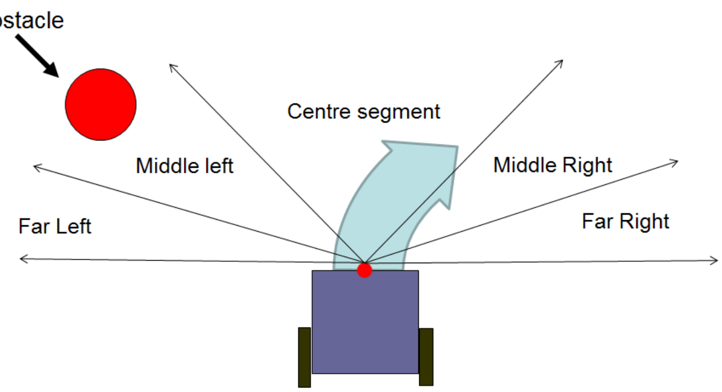

Figure 8: A diagram that shows the different obstacle detection zones that the LRF sees and controls obstacle avoidance.

5.6 Wall Following

The wall following algorithm activates if the following two criteria are met: The first waypoint is hit which turns off line detection and all three waypoints in the middle field are hit. The wall following algorithm uses the Hokuyo LRF thru the Gap Selection algorithm to detect obstacles and openings in the wall. When the waypoints are hit, Zero scans the wall and follows it to its opposite end while maintaining a distance between 1.2m to 1.6m. If an obstacle, or the wall, is less than 1.2m, it will move away from the wall and continue to follow the length until it finds the opening.

5.7 Complex Obstacles

There are two designated complex obstacles the system will experience at competition, switchbacks and dead ends. Zero's approach to each is briefly discussed below.

5.7.1 Switchbacks

A switchback occurs when the field requires the vehicle to successfully navigate through a zigzag like obstacle course. Zero handles switchbacks using the waypoint navigation and the five zone obstacle avoidance. The waypoint navigation knows the waypoint's location and uses the angular error to calculate the desired heading. Zero effectively avoids obstacles by using the five zone obstacle avoidance; the vehicle will recognize the minimum gap of five feet and be able to make it through without hitting any of the obstacles. Fig. 8 depicts Zero's desired path for a switchback situation.

5.7.2 Dead Ends

A dead end is a complex situation that requires Zero to use more than just the waypoint navigation and the five zone obstacle avoidance. With only these, Zero would continuously circle in the dead end. The dead end algorithm is broken down into three sections: recognizing the dead end, the action to take in order to get out of the dead end, and turning off the algorithm.

Zero recognizes the dead end by constantly checking to see if there is an obstacle in the three main zones for more than fifty percent of the time. This, in conjunction with any turn greater than 120°, will activate the dead end algorithm. The plan for getting out of the dead end is to identify the obstacles by using the gap planning algorithm to determine the desired direction and optimal path to navigate out of the dead end. The code will turn off when Zero moves a certain distance away from the dead end obstacles.

5.8 Matlab Data Log Simulator

The software also has a data logging system which outputs all sensor and algorithm information into a text file that can be imported into Matlab and replayed. The data logging system helps immensely with the test and refine process by identifying problems that cannot be immediately noticed by vehicle performance inspection during a test. The output of the program is shown in Fig. 10. 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.

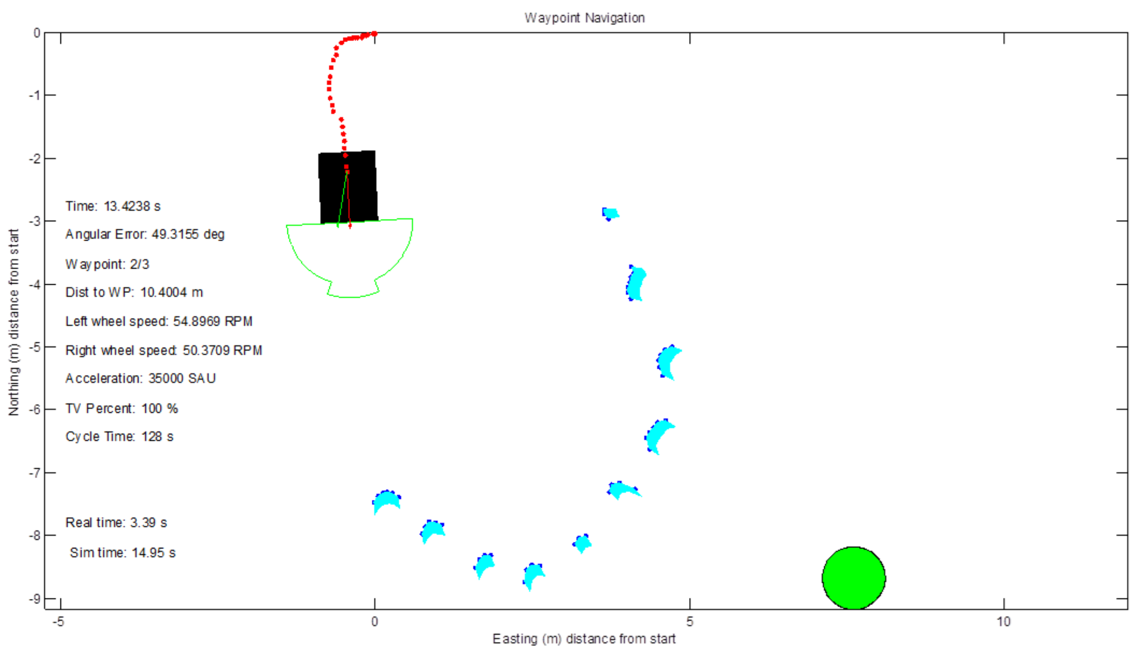

Figure 10: The screenshot depicts the robot (black) driving towards the waypoint (green), but it detect obstacles (blue) in its path to avoid.

6 COMMUNICATIONS

6.1 JAUS Protocol

The Joint Architecture for Unmanned Systems (JAUS) is an SAE standardized communication protocol that has been implemented on Zero. The Interoperability Profiles (IOPs) integrates JAUS's services to help it perform the four main IOPs: the Overarching IOP, the

Communication IOP, the Payloads IOP, and the Controls IOP. The attributes that spawn from these categories are the Platform Databus Attribute, the Transport Attribute, and the Mobility Attribute. This software requires a sequence structure, which creates a timeline of events. Zero incorporates the Core Operability attributes and Platform Management Attributes and the Navigation and Reporting Attribute group. The first event opens the port and UDP connection to the controlling unit by connecting to the Judge Testing Client (JTC) using a special team Subsystem ID (SSID). Zero then broadcasts a Query Identification every 5 seconds. Once the control unit responds, the next sequence is started.

The second event parses, sends and receives JAUS messages. Zero receives messages faster than it can process the messages. Even so, all of the messages are processed in the order of reception and placed into an event queue. Once the message is removed from the queue, the first action required is to determine the validity of the messages by checking the origination identity, as well as the sequence number to ensure messages being received only once. Once a message is determined to be valid, the message identity is determined and the remaining message data is handled appropriately. Responses are placed into another event queue, sequenced into a header and trailer, and sent to the control unit.

6.2 Latency (Reaction Times)

Zero's software code is able to run at about 9 Hz on an Intel i5 2.30 Ghz dual core processor and 4 GB RAM on Windows 7 (x64). The vision algorithms take about two-thirds of this processing time. Similar to Alvin, Zero can access sense data at 20 Hz or faster depending on the sensor, so the limiting factor is the speed of Zero's main algorithm process.

7 CONCLUSION

Zero is a successor to the reliable Alvin platform legacy, while implementing a safe, maintainable, accessible, protected integrated systems design that meets all of the requirements and challenges of the 2014 Intelligent Ground Vehicle Competition. Through extensive design, testing, and analysis, the vehicle includes new innovative features (i.e. Tool Shelf Compartment, Hot Swappable Batteries, and Minimalistic Sensor Use) and optimizes its previous hardware and software features for increased reliability in this year's competition as well as potential expansion to future competitions.

8 REFERENCES

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May 16, 2014

University of California, Santa Barbara
Graduate Admissions

Dear IGVC Judges,

I certify that the engineering design of Zero, as described in the accompanying report, has been significant and is equivalent to that required of a senior design project.

Sincerely,

Eric Joe Coyle
Assistant Professor of Mechanical Engineering
Embry-Riddle Aeronautical University

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