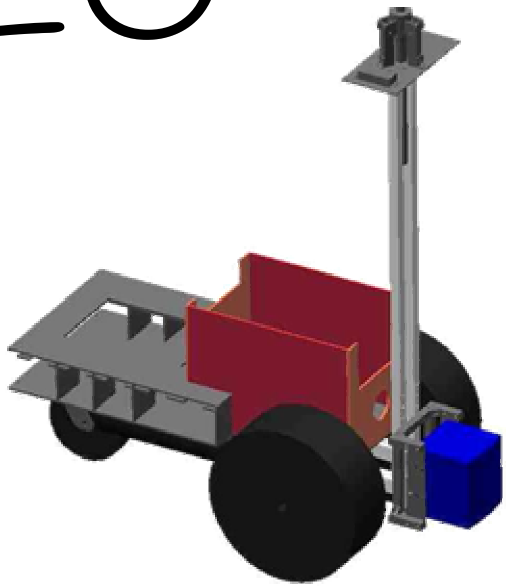
The Autonomous Vehicle Team of Virginia Tech Presents

ZIEG



A new autonomous vehicle, created by:

Michael Avitabile
Merritt Draney
Matthew Good
Sudhir Gopinath
John Hodge
Charles Lamb
Anthony Lee
Michael Roop

I hereby certify that Zieg is a new autonomous vehicle that has been designed, constructed and tested by students of mechanical, electrical and computer engineering. The team consists of members who will receive six credit hours of senior design in mechanical engineering, as well as undergraduate and graduate student volunteer members.

Signed: Date:

Dr. Charles F. Reinholtz,
Faculty Advisor

The Autonomous Vehicle Team of Virginia Tech has successfully designed and constructed Zieg to compete in the 11th Annual Intelligent Ground Vehicle Competition. Zieg is an all-weather, three-wheel, differentially driven vehicle designed and equipped to compete in all four events of the competition.

Design Process

The team closely followed a structured engineering design process while designing Zieg. The design process, diagrammed in Figure 1, was employed to ensure that all of the team's goals were met and that all of the possible design alternatives were examined. To begin the design process, the team developed the following mission statement: "To design and build a commercially marketable autonomous vehicle to successfully compete in all events of the IGVC." This simple statement served as a reminder of the goals of the team throughout the remainder of the design process.

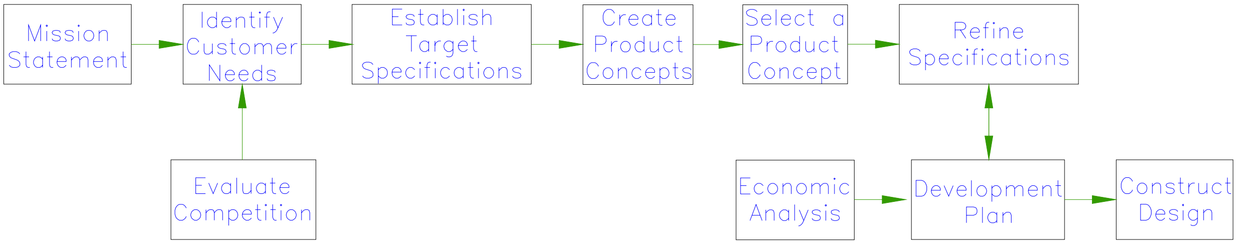


Figure 1. The engineering design process was closely followed during the design of Zieg.

The team next identified the customers that it would be serving along with their needs. The IGVC judges, team sponsors and faculty advisor were determined to be the most important customers. Other important customers included Virginia Tech and the team itself. These needs of the IGVC judges are well defined in the competition rules. Zieg should satisfy the judges as customers by its successful competition in all the IGVC events. The team sponsors want mostly to contribute to the education of engineering students and to help advertise their products or services. The needs of the faculty advisor are focused mainly on the education of the students involved. As a customer, the advisor will be satisfied by the demonstrations of engineering principles, hard work, and creative thinking by the team.

Several months of planning, research and conceptualization were the next step in the design process. The team read about and examined vehicles that had been successful in previous competitions and identified their strengths and weaknesses. They also sought the advice of experts in control theory, computer vision, and computer programming to help guide them in these fields. The team established lists of features, capabilities, and other considerations that they wanted to employ, including safety features, ease of repair, transportability, and adaptability. Construction of the vehicle began when the team had finalized its concept of Zieg.

Hardware

The equipment used in Zieg was carefully selected to give the vehicle the best combination of intelligence, strength, and size.

Drive System

The vehicle is driven by two Kollmorgen 24-Volt servo motors. Designed for military applications, these rugged motors are each capable of delivering 120 ft-lb of torque to the 16" wheels, through a 20:1 ratio right angle gearbox. The motors are powered by a pulse-width-modulated signal from servo amplifiers, made by Advance Motion Control. The amplifiers that we selected are capable of delivering a continuous current of 60 A. This is larger than Zieg is designed to use, but the team wanted a large factor of safety to help prevent the amplifier failures experienced by previous teams. The amplifiers receive their commands from a National Instruments motor control board, model PCI-7344. The motor control board interfaces with the computer via a PCI slot and it interfaces with the amplifiers through a breakout wiring board.

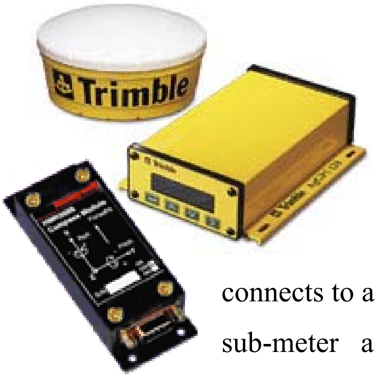
Computer

All of the vehicle's data processing, navigation, motor control and feedback occur in its on-board computer system. The computer is 24 VDC industrial PC custom made for the vehicle by Comprehensive Computer Solutions. The computer features an Intel Pentium IV processor with a clock speed of 2.4 GHz and 256 MB of RAM. The system is highly expandable due to its 7 PCI slots, 4 serial ports, and 3 USB ports. One of the PCI slots is populated with a motor control card, which gives a signal to the amplifiers. Another slot holds an image acquisition card, which interfaces with the camera and performs some of the image processing. Both the motor control board and the image acquisition card were supplied by National Instruments. Other useful features are a wireless ethernet connection, which allows a user to connect to the computer remotely, and a programmable gamepad that can be used to drive Zieg manually.

Sensor System

Zieg receives eternal data from four sensors: a camera, a laser range finder (LRF), a global positioning system (GPS), and a digital compass. All of these devices interface with the on-board computer to allow the vehicle to make navigation decisions.

The camera used on Zieg is a Sony 8mm camcorder, with a wide-angle lens attachment. The camera is critical for line detection in the Autonomous Challenge. It has as independent power supply and connects to the computer through an S-video cable to the image acquisition board. By connecting the camera using a standard S-video cable, the team is ensured that the camera can easily be replaced if it fails. The camera is mounted to the vehicle on an adjustable-height mast with a pan-and-tilt head.



Also mounted on the mast are the digital compass and the GPS antenna, the two devices that are most essential for the Navigation Challenge. The digital compass, Honeywell model HMR-3000, senses the heading, pitch, and roll of the vehicle. At this time, only the heading is used, although the other two axes may be used in the future. The GPS antenna connects to a Trimble Ag124 GPS receiver. When used alone, this system is capable of sub-meter accuracy. When used in conjunction with OmniSTAR worldwide differential GPS service, this the accuracy improves to a few centimeters, with less reliance on satellite signal. Both the digital compass and GPS connect to the computer through serial ports.

The forth sensor, which is used in every phase of competition, is the Sick Optics model LMS-100 laser range finder (LRF). It is mounted on the bottom-front of the vehicle and has an adjustable height and angle. The LRF uses a scanning laser to detect the distances to physical obstructions, an ability that has many applications in autonomous vehicles. It can be used for obstacle avoidance, critical in the Autonomous Challenge and Navigation Challenge, and to detect the closest object, which is used in the Follow-the-Leader Competition. The LRF's capabilities could also be used to help identify objects by their signature shape, or potentially even to detect painted lines, by using the spectral response. The computer receives data at a rate of 4 Hz from the LRF through a serial port.

Power System

Zieg is powered by ten 24-V DeWalt Nickel-Cadnium batteries, each capable of delivering, on average, 2.4 A-h. These batteries are separated into two groups. The six "component" batteries are used to power the amplifiers, motors, laser range finder, compass, and GPS. The four "PC" batteries are dedicated to powering the on-board computer. An overview of the power system is shown in Figure 2. These two power systems are isolated to prevent large motor currents and the accompanying voltage drop from affecting the computer. Current spikes could damage the power supply and current drops could cause the computer to shut down.

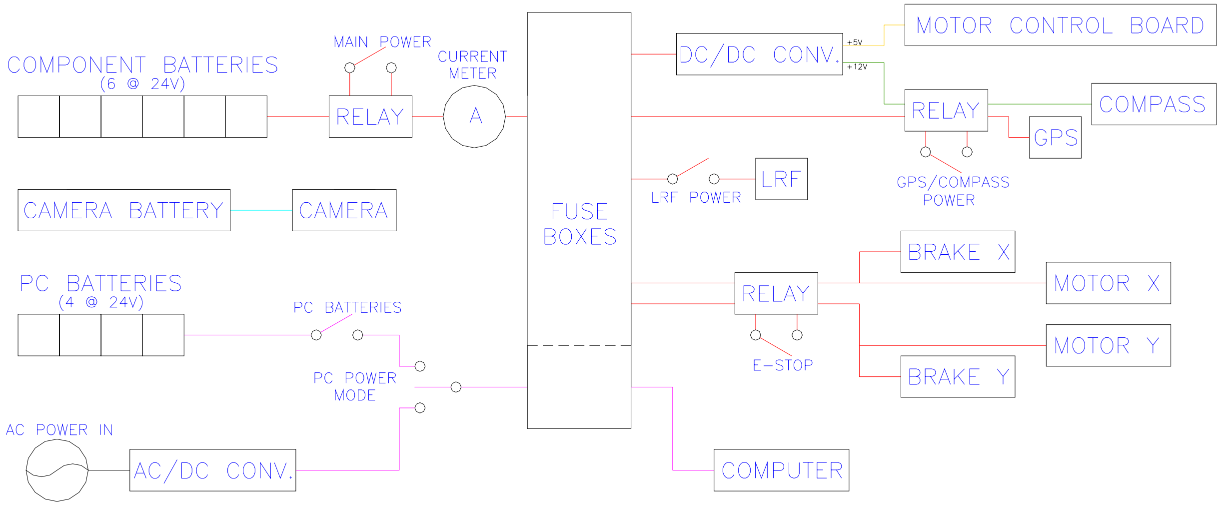


Figure 2. Component power and computer power are kept isolated in Zieg's power system.

When the vehicle is running at maximum current, the components draw approximately 28 A, which would give an expected run time of 30 minutes for the six component batteries. Because the motors do not draw their peek current at all times, a battery life of 45 minutes is typical. The computer typically draws 6 A from its four batteries, allowing the computer to run for 1.5 hours between battery changes.

Another important feature of Zieg's power system is the ability to "hot-swap" batteries on both busses. This is accomplished by using 3300 μF capacitors in parallel with the battery to prevent sparking, and diodes in series with each battery to prevent batteries from back-charging each other. The diodes also allow the individual battery voltages to be monitored. The batteries are monitored in two ways. The back panel features an analog voltage meter and an LED for each battery that turns off when the battery falls below the cut-off voltage. Batteries are also monitored in software, through the data acquisition board.

Several devices on Zieg require voltages other than 24 V. The motor control board and battery monitoring LEDs require 5 V, and the digital compass requires a voltage between 7 and 15 V. To meet these requirements, Zieg employs a DC-to-DC power supply, which converts a 24-V input into 5 V and 12 V supplies. The only component that is not powered by the 24-V batteries is the camera. It uses its own rechargeable battery. A subtle, but important, feature of Zieg is the use of independent power switches for each individual component. This allows the LRF, GPS, and compass to be turned off when not in use. This saves power when these components are not needed, such as when driving by remote control. Power to the digital compass and GPS is controlled by a single switch and relay because they are always used together.

Vehicle Costs

Zieg was built using donations from team sponsors, as well as funding from Virginia Tech and from prize money from previous IGVC competitions. Through these sponsorships, Zieg was built at a cost to the team of less than $1,800. Without donations, the material costs would have been close to $28,000. A breakdown of the component costs and donations is shown in Table 1.

Table 1. Equipment Cost Estimates for Zieg.

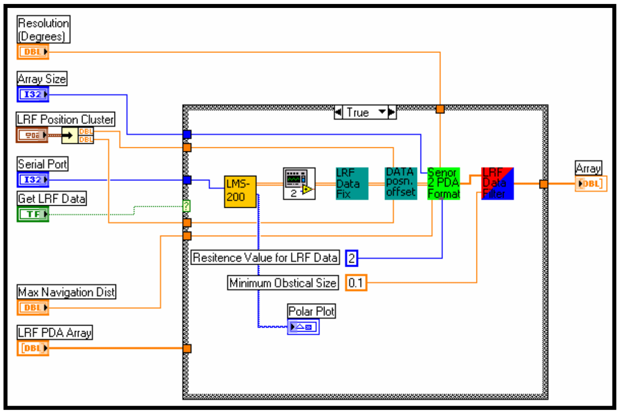
	Supplier	Quantity	Unit Price	Retail Cost	Cost toTeam
Sensors					
Camera, 8mm	Sony	1	$300	$300	$300
Laser Range Finder	Sick Optics	1	$3,400	$3,400	$0
Global Positioning System, AgGPS 124	Trimble	1	$2,995	$2,995	On Loan
Digital Compass, HMR-3000	Honeywell	1	$675	$675	$0
Electrical System					
24 V Battery	DeWalt	10	$110	$1,100	$0
Power Management Board	Team Built	1	$63	$63	$63
Battery Monitoring Board	Team Built	1	$47	$47	$37
Relay and Fusing System	Team Built	1	$97	$97	$97
Remote Control Board and Transmitter	Team Built, Tower Hobbies	1	$175	$175	$175
AC / DC Power Supply	Allied Electronics	1	$65	$65	$36
DC / DC Power Supply	Allied Electronics	1	$120	$120	$42
Misc. Wire, Connectors, Parts	Allied Electronics	1	$120	$120	$120
Drive System					
DC Servo Motor, 24 V	Kollmorgen	2	$3,990	$7,980	$0
DuraTRUE Gearbox, 90 deg, 20:1	Thomas Micron	2	$800	$1,600	$0
Encoder Plugs, MF3106F 18-1S	BEI Industrial Division	2	$30	$60	$60
Servo Amplifiers, PWM Output	Advanced Motion Control	2	$800	$1,600	$0
Wheel and Hub Assy., 16" x 4"	BF Goodrich / CT Farm & Country	2	$56	$112	$112
Caster Wheel, 8" Swivel	Trendlines	1	$23	$23	$23
Chassis					
Vehicle Frame	Team Built	1	$490	$490	$400
Sensor Mast	Team Built	1	$120	$120	$93
Fiberglass Shell	Team Built	1	$185	$185	$185
Computer					
Industrial Computer System	CCS-Industrial	1	$2,800	$2,800	$0
Motor Control Board, PCI-7344	National Instruments	1	$2,186	$2,186	$0
Image Acquisition Board, PCI-1411	National Instruments	1	$1,208	$1,208	$0
Wireless Internet Card	3-Com	1	$53	$53	$42
Gamepad	Thrustmaster	1	$30	$30	$30

Total Vehicle Cost	**$27,521**
Total Cost to Team	**$1,743**

Software Selection

Programming

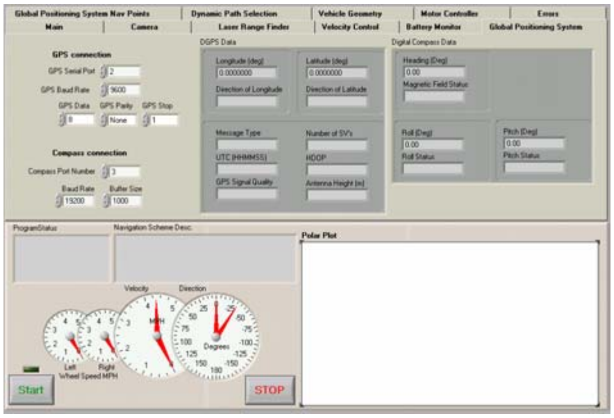
All of Zieg's software is written using National Instruments' LabVIEW 6.0. This programming package, according to National Instruments, is "a revolutionary graphical development environment with built-in functionality for data acquisition, instrument control, measurement analysis, and data presentation". Knowing that Zieg relies on data acquisition from many devices, the team wanted to choose a software package that could easily integrate all of Zieg's sensors and intelligence together. LabVIEW controls the interface to the sensors, the navigation, and the motor control. The interface can also be easily enhanced to include any possible input/output additions for increased functionality. Another advantage of using LabVIEW is that it is a graphical based language. The program's functionality is intuitively specified by assembling block diagrams. Every program is written as a flow chart of data between functions, such as the one in Figure 3. Each program also includes a front panel interface that displays the inputs and outputs of the program. Figure 4 shows a front panel with the GPS configuration data, as well as information on vehicle speed and heading. The use of a graphical interface should also make the software easier for future teams to understand and adapt.



Resitence Value for LRF Data 2

Minimum Obstical Size 0.1

Figure 3. This LabVIEW flowchart reads and formats LRF data.



GPS Serial Port 2
GPS Baud Rate 9600
GPS Data 8
GPS Parity None
GPS Stop 1
Compass Port Number 3
Baud Rate 19200
Buffer Size 1000
Longitude (deg) 0.0000000
Latitude (deg) 0.0000000
Heading (Deg) 0.00
Roll (Deg) 0.00
Pitch (Deg) 0.00

Figure 4. This LabVIEW front panel displays vehicle heading, speed, and device settings.

Wireless Connection

Wireless Ethernet and PC Anywhere software provide the link of communication between the on-board computer and a remote operator terminal. This allows an operator to monitor and program the vehicle remotely. Three major advantages come out of using a remote terminal. The first is that the operator or programmer can observe the execution of the software in real-time, while the vehicle is running. This allows the programmer to pinpoint logical errors in the software without having to step through the program manually. The second advantage is that it eliminates the weight and space issues that are associated with having an on-board monitor and keyboard. While reducing the weight and space, power efficiency and battery life are increased and the vehicle is kept compact. The third advantage is that a programmer can work in a comfortable setting, perhaps finding a shady spot to avoid the common problem of bright sun washing out the monitor image. According to our customer feedback, this wireless technology should be a major advantage in commercial applications of the vehicle. Simply stated, an operator interface should not be necessary on a vehicle designed to function without an operator.

Intelligence

Zieg is controlled by a new navigation scheme we call the Dynamic Path Selection (DPS) system. As expected, the system works by gathering data from the input sensors (camera, LRF, GPS, and compass) and using the data to establish a heading and velocity. These values are then sent via the motor control board to the motors, and motor position feedback is received from encoders integrated into the motors.

Sensory Input

The use of the four sensors can be best be understood by looking at them in two pairs. The camera and laser range finder are “obstacle detectors” and the global positioning system and compass are “desired heading selectors”. The data received from the camera and LRF are converted into a single polar distance array. Each number in the array represents the distance to the nearest obstruction at a certain angle, in 2° increments, from +90° (left side of the vehicle) to -90° (right side of the vehicle). The data received from the GPS and compass are used to calculate the direction of the next desired location.

The LRF is used to detect distances to physical objects in front of the vehicle. A laser sweeps across the 180° field of view, in 1° increments, and reports the distance to the nearest obstruction at each angle. The data then go through a series of formatting algorithms, the result of which is a polar distance array with 2° resolution.

Generating a polar distance array from the camera is a more complicated task. The image acquisition card in the computer captures a static image from the camera. After thresholding, the resulting binary image goes through a shape analysis to find lines and potholes, and to eliminate sand traps. An array is calculated using transformation operators that give distances in the image from the camera to the detected lines and potholes, accounting for image distortion correction factors. An example of the steps of this process is shown in Figure 5. A single polar distance array is then created from the camera and LRF data by using the minimum distance at each angle, up to a maximum value of 10 m.

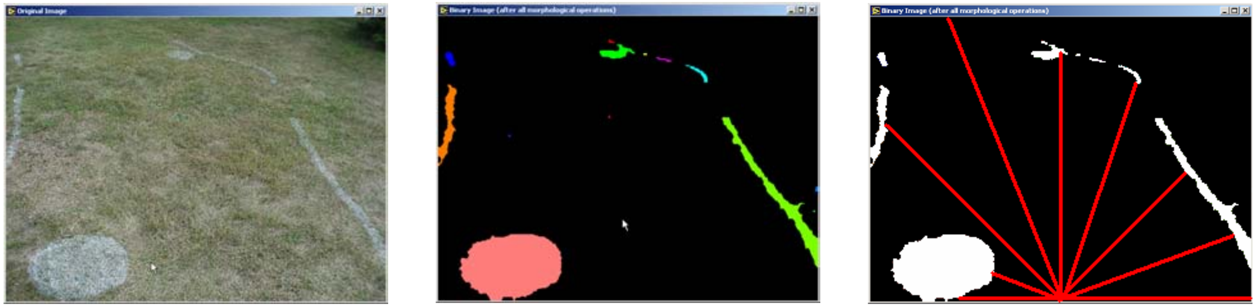


Figure 5. The original image (left) goes through a threshold and shape recognition process (center) and is evaluated to find the distances to obstructions (right).

The data from the GPS and compass are always used together. The GPS delivers a latitude and longitude that represent the vehicles current location. This location is then compared to a desired location to determine the desired heading. The compass is used to obtain the current heading. The difference between the current heading and desired heading gives a relative desired heading.

Navigation Schemes

Once the polar distance array has been generated, its values then go through a series of calculations to determine the best path and velocity. The algorithms that are used depend on the navigation scheme selected at the start of the run. Some schemes are used for competition events, and others are used for testing. For example, a scheme that seeks the closest object is a good way to test the LRF, while a scheme that tracks a single moving object could be used in the Follow-the-Leader competition. The output of every navigation scheme is a velocity and heading. The flow of data throughout the software can be seen in Figure 6.

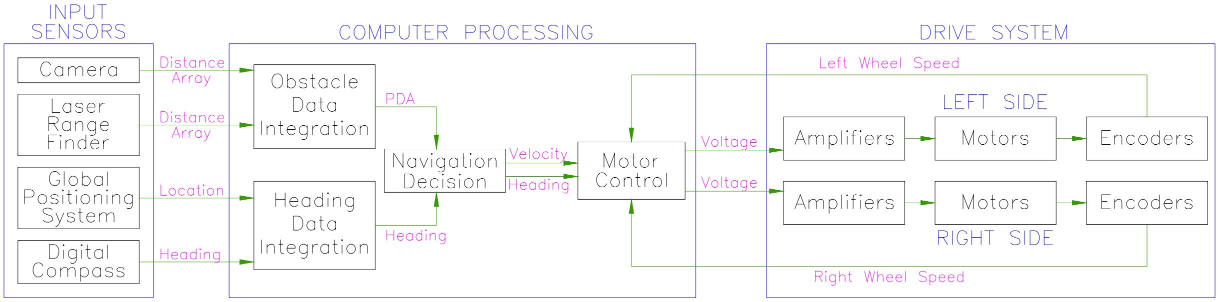


Figure 6. Zieg's software operates with input from sensors and output to the drive system.

Motor Control

The velocity and heading that are determined by the navigation process are passed into the motor control software. These values are then translated into rotational speeds of the left and right wheels, based on the wheel diameter and vehicle width. To accelerate or decelerate to these speeds, the software employs PID control loops and National Instruments motion software that is integrated into the LabVIEW programming language. The output of the software is a signal that is sent to the amplifiers. The board also receives feedback on the actual speed of the motors from the encoders. This feedback is used in control loops to determine if the voltages that the amplifiers are supplying are appropriate.

The motor control software features a setting for maximum speed, which can be set at the competition limit of 5 mph, or lower if desired. The gains for the PID loop can also be customized, tuning the vehicle for either smooth control or quick response.

Predicted Performance

Zieg was designed to meet the requirements of competition. It has a maximum velocity of 5 mph, limited software and controller constraints. It is capable of climbing a 20% incline at creep speed, and it can operate in any weather that might be seen in competition. The camera is aimed to have a 180° field of view at 3.3 m ahead. Lines and potholes should first be detected when they are about 3.0 m away. The vision software is capable of running at up to 8 Hz. The laser range finder has a much longer range. The device itself is capable of detecting obstacles at 30 m, but Zieg's software limits the detection to obstacles within 10 m. The LRF requires approximately 250 ms to make a complete scan. The navigation software is timed to run at 4 Hz, with LRF data being polled only on alternate cycles.

Competition Strategies

Zieg employs a different navigation scheme, uses a different set of sensors, and evaluates data in a different way to complete each event of the IGVC.

Autonomous Challenge

To navigate in the Autonomous Challenge, Zieg must be able to detect lines, potholes, and barrels, as well as avoid barrel traps, negotiate the incline and decline of a ramp, and pass through a sand trap. To accomplish these tasks, the vehicle relies on the camera and LRF for input data.

The basic principle behind the navigation scheme for the Autonomous Challenge is evaluating the course and finding paths where the vehicle can pass, unobstructed. A "clearance function" is generated, based on the minimum passage width of the vehicle and the desired navigation point. The maximum navigation point is set at 10 m, which is the practical range limit of the sensors. The clearance function represents the minimum width that is required for safe passage. The clearance function is compared to the polar distance array that is generated from the input sensors to find these passages.

The process is entirely numerical, but can be most easily conveyed in a graphical sense. The algorithm starts by overlaying plots of the aforementioned polar distance array and clearance function, centered at a 0° heading. If the clearance function fits under the polar distance array, then the vehicle has a clear path ahead, and it proceeds forward. If there is an obstruction ahead (whether it is a line, pothole, or barrel), then the clearance function is shifted to the left and right in small steps to find a clear path. The process stops when a path is found, thereby choosing the path that is closest to 0°. The process is diagrammed in Figure 7.

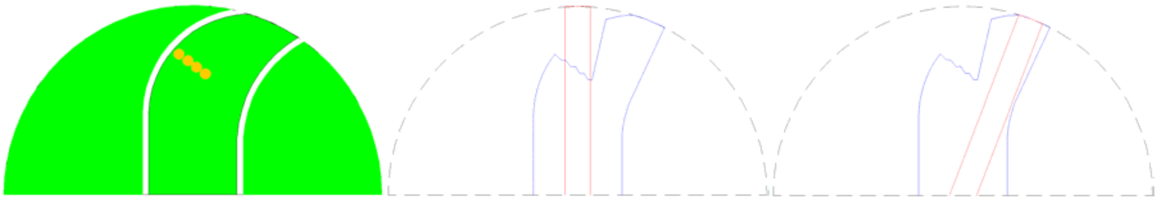


Figure 7. The course (left) is evaluated to generate a polar distance array (blue line). The clearance function (red line) does not fit under the distance array for a straight path (center). The navigation scheme chooses a path with a -20º turn (right).

In some cases, there will be no path that is clear over the entire navigation distance. When this occurs, the clearance function is truncated to a closer navigation point, and the paths are evaluated again in the same manner.

When Zieg cannot find a clear path in any direction, and the clearance function has been truncated down to the specified stopping distance, or an obstruction is detected in the "buffer zone", the vehicle considers itself trapped. It then executes a routine where it backs up 2 m, and evaluates the course again, with the previously selected path eliminated.

The Dynamic Path Selection system was designed to handle all of the difficulties of the Autonomous Challenge. If Zieg approaches a barrel trap straight on, it can be expected to take the correct way around it. The vehicle may choose the wrong path if the barrel trap is approached at an angle, or if the trap is on a curve, but Zieg's back-up routine should free it from the trap. Sand traps are eliminated by the shape recognition algorithms in the vision software. Ramps will be navigated like any other part of the course. The vehicle has been tested on a ramp that similar to the ramps found in the competition, as well as hills of various inclines. Based on its ability to handle all of the obstacles, the team expects that Zieg will fully complete the Autonomous Challenge.

Navigation Challenge

To complete the navigation challenge, Zieg relies on the data received from the GPS and compass to determine the optimum heading, and on the LRF to find a clear path to its destinations. This process starts by retrieving the current location of the vehicle from the GPS and current heading from the digital compass. Zieg then determines the absolute angle to the first target destination. The difference between the heading angle and target angle becomes the desired turning angle, as is shown in Figure 8. The vehicle then proceeds in a manner similar to the Autonomous Challenge, by evaluating a polar distance array generated by the LRF data. The evaluation starts at the desired turning angle and deviates left and right, instead of starting at 0°, as it does in the Autonomous Challenge. The velocity at which the vehicle proceeds is dependant on the distance to the target location.

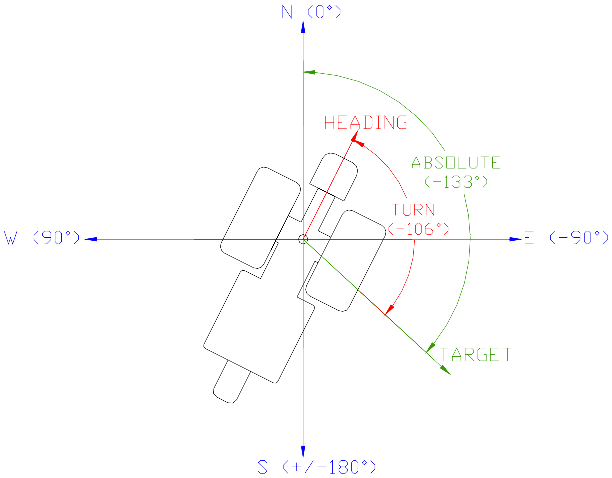


Figure 8. Compass and GPS are used together to find turning angle.

When Zieg believes that it has achieved the desired location within the specified margin of error, it stops for five seconds to determine if the target location has in fact been achieved. This stopping is helpful because the GPS is more accurate when several stationary readings can be averaged together. The vehicle should be able to navigate within 0.5 m of the target locations. When a target location has been achieved, it is removed from the list of locations, and the next location becomes the target.

Follow-the-Leader

Zieg navigates the Follow-the-Leader competition by using the laser range finder to track the closest moving object. When this object is found, the navigation software forms a narrow search area around it. By narrowing the search area, obstacles that do not threaten to block the vehicle's path are ignored, allowing the

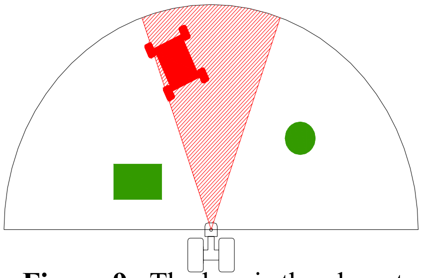


Figure 9. The box is the closest object but is ignored because it is not in the search area.

software to run faster. This is shown in Figure 9. If an obstacle does appear in the search area, Zieg will determine which object is moving, and will continue tracking it. If the leader leaves the search area, the vehicle will widen the search area until a moving object is found.

The velocity at which Zieg follows is proportional to the distance from the object that it is tracking. The velocity will be zero when the object is within the “stopping distance” and will be maximum speed when the object is beyond the “full speed distance”. This velocity variation will ensure that the leader remains within an acceptable distance range.

Safety

In the design and construction of Zieg, safety was always a primary concern. The team implemented several safety features into the vehicle, including a fail-safe emergency stop system, wiring standards, and fusing. The brakes on Zieg are fail-safe because they require power to remain disengaged, which means that the brakes will stop the vehicle if power to them is stopped for any reason.

Emergency Stop

There are three ways to stop Zieg in an emergency. The first is the red e-stop button, which is mounted on the rear of the shell. Pressing this button activates the e-stop relay which cuts power to the amplifiers and motors, engages the brakes, and changes the running lights from green to red. After the power is cut, the motors ramp down by drawing voltage from a 3300 µF capacitor which is in parallel with each amplifier. Theoretically, the 0.95 J stored in this capacitor should power the motors for only 0.05 s (assuming a 20% PWM), but testing has shown the charge lasting nearly 0.5 s. When the capacitor is drained, the brakes engage and the vehicle comes to a complete stop in less than one second. The “worst case scenario” for the emergency stop would be where the vehicle is traveling at its top speed of 5 mph with the motors drawing no current. The brakes alone would drain the capacitors before the vehicle had traveled one foot.

For added safety during testing, the switch box that houses the e-stop button can be dismounted from the vehicle and carried by a team member who follows the vehicle. To permit this, a serial extension cable of any length can be added between the vehicle and the switch box. An additional safety feature is that the emergency stop will engage itself any time the switch box is unplugged from the vehicle.

The emergency stop system will also be engaged any time that the vehicle is not receiving a signal from the remote control unit. This feature functions in two important ways. Zieg can be stopped at any time by switching off the remote control unit. An emergency stop of this nature is critical for safety, because it allows the operator to quickly bring the vehicle to a stop whenever needed. The vehicle will also stop when it gets out of range of the remote control. Stopping the vehicle when it is not receiving a useable signal is important to prevent erratic behavior when out of the signal range. The remote emergency stop feature can be disabled via a switch on the back panel, so that the vehicle can function without a remote control.

A third way to stop the vehicle is to issue a motor halt command over the wireless internet connection. This method will not engage the motor brakes, but rather it instructs the motors to have a velocity of zero. The motor controls will actively apply power to keep the wheels from turning. An advantage of emergency stopping via the motor control is that there is no encoder error accrual, which is a potential problem with other methods. The wireless connection is not fail-safe, and therefore the other emergency stop methods are required.

Electrical Safety

To ensure the safety of those who work with Zieg, and to protect the vehicle's sensitive electronics, electrical wiring standards and a fusing system were implemented. The wiring standards ensure that wires are all clearly labeled and that no wire carries more current than it can safely handle.

Short circuits can be caused by unsecured connections, metallic tools, and loose hardware. To protect against these types of shorts, all critical devices are fused at the power source. The fuses are housed in two fuse boxes, each of which features a row of fuse-fail indicators. When a switch on the box is pressed, each light will turn on to indicate a good fuse, and will remain off to indicate a blown fuse. Both fuse boxes feature a label that states which devices connect to which fuse position, and the appropriate fuse rating for each.

Team Organization

Eight students contributed to the design and construction of Zieg over the year-long design process. Rather than dividing all work into an organization of sub-teams, the team members decided to work together, with each member focusing on their strengths but remaining involved in all aspects of design.

The team worked on the vehicle for a total of over 3,500 hours over a nine-month period, as shown in Table 2.

Table 2. Team Organization

Name	Focus	Major, Year	Status	Hours
Mike Avitabile	Electrical	EE / CpE, Junior	Volunteer for Credit (3 hr)	660
Merritt Draney	Frame / Software	ME, Senior	Senior Design Credit (6 hr)	613
Matt Good	Frame / Software	ME, Graduate	Volunteer	252
Sudhir Gopinath	Software	ME, Graduate	Volunteer	180
John Hodge	Electrical / Report	ME, Senior	Senior Design Credit (6 hr)	705
Chip Lamb	Software / Electrical	ME, Senior	Senior Design Credit (6 hr)	724
Anthony Lee	Electrical	EE, Freshman	Volunteer	75
Mike Roop	Electrical	CpE, Senior	Volunteer for Credit (3 hr)	300
			Total Person-hours =	**3509**

Design Issues and Solutions

An important part of the design process is redesign when problems are found during testing. One problem that the team encountered was slow speeds over the wireless connection. After some investigation, it was determined that the processor was dedicating every available cycle to executing the LabVIEW software. When a short delay was added into the software, the wireless connection speed increased dramatically. Another problem was that the connections on the back of the computer were difficult to access. This problem was solved by mounting the computer at an angle, which gave more room between the computer and the sensor mast. A third problem that the team encountered was difficulty accessing the battery control box, which was mounted below the other electronics, between the battery racks. This issue was solved by extending the wires between the batteries and the box, and remounting the box on the shelf with other electronics. To allow for this, components that did not need to be as accessible were moved to below the shelf.

Conclusion

By following a structured design process, the team has created Zieg to succeed in the Intelligent Ground Vehicle Competition. The team has implemented features to solve problems encountered by previous vehicles and problems that were found during the design and testing of Zieg. After significant amounts of testing, the team is confident that Zieg will perform well in the competition.

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