Automated Designated Driver (ADD)

Calvin College
ENGR 340

Senior Design Team 3
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1. Executive Summary

The purpose of this project was to design and construct an autonomous vehicle for entry into the Intelligent Ground Vehicle Competition (IGVC). To perform well in this competition the vehicle must be able to navigate an obstacle course in a prescribed time limit. It must also be able to navigate itself from GPS point to GPS point with minimal obstacles in the way. The vehicle will be designed to represent a real-life truck.

2. Introduction

The purpose of this project was to design and construct an autonomous vehicle for entry into the Intelligent Ground Vehicle Competition (IGVC). This competition is run every summer by the Association for Unmanned Vehicle Systems International (AUVSI). The IGVC is tailored specifically so that an entry into the competition is a suitable amount of work to serve as an undergraduate engineering capstone design project, such as Senior Design at Calvin.

There are three competitions within the IGVC: obstacle avoidance, navigation, and design.

In the obstacle avoidance competition, the vehicle has to travel through an environment which is not entirely dissimilar from that of unoccupied roadway. There will be dashed white and yellow lines on either side of the vehicle, serving as boundaries that must not be crossed. In the area between the sets of lines there will be obstacles which the vehicle must avoid. These obstacles will consist of 5-gallon white pails, full-size orange and white construction drums, cones, pedestals, and barricades (like “Road Closed” signs). The course will also contain potholes and simulated potholes (white circles two feet in diameter), which must also be avoided. Points are given for crossing a line, making contact with an obstacle, or hitting a pothole. The team’s score is based on the amount of time required to finish the course, adjusted for the number of points received (one second added to time for each point received). The team with the lowest adjusted time will be the winner of the obstacle avoidance competition. If no team completes the course, the score will be the distance traveled, adjusted by the number of points received (one foot subtracted for each point received). The team with the longest adjusted distance will be the winner of the obstacle avoidance competition.

In the navigation challenge, the vehicle has to travel through eight waypoints, determined by the IGVC administration. The waypoints will be given both as GPS points and as coordinates on a Cartesian plane (an x-y grid). This competition takes place in an open field, so the vehicle does not have to stay between lines as in the obstacle avoidance competition. The vehicle has to begin and end at the same point, which is a ninth predetermined point. There will also be obstacles on the field, placed so that they must be avoided in order to pass through all of the waypoints. The vehicle will have six minutes to
complete the challenge. The team that passes through the most waypoints in the six minute time period will be the winner of the navigation challenge. If multiple teams reach the same number of waypoints (that number being the most reached out of all the teams), the team doing so in the shortest amount of time will be the winner of the navigation challenge.

The design competition is the simplest. Each team will give an oral presentation at the competition, and their presentation, along with their design report and an examination of the vehicle, will be evaluated by a panel of expert judges, and scored according to a rather lengthy list of criteria. The team receiving the highest score will be the winner of the design competition.

To participate in this competition, the vehicle contains computing, GPS, and power equipment, in addition to a digital compass, motor controller, and motors. This design report details how each of these components was implemented and integrated into the vehicle, and how the software ties it all together.

3. Terms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>3-D</td>
<td>Three Dimensional</td>
</tr>
<tr>
<td>ADD</td>
<td>Automated Designated Driver (Team 3)</td>
</tr>
<tr>
<td>ADC</td>
<td>Analog to Digital Converter</td>
</tr>
<tr>
<td>AMD</td>
<td>Advanced Micro Devices</td>
</tr>
<tr>
<td>ATA</td>
<td>Advanced Technology Attachment</td>
</tr>
<tr>
<td>AUVSI</td>
<td>Association for Unmanned Vehicle Systems International</td>
</tr>
<tr>
<td>CRT</td>
<td>Cathode Ray Tube</td>
</tr>
<tr>
<td>DARPA</td>
<td>Defense Advanced Research Projects Agency</td>
</tr>
<tr>
<td>DDR</td>
<td>Double Data Rate</td>
</tr>
<tr>
<td>DGPS</td>
<td>Differential Global Positioning System</td>
</tr>
<tr>
<td>DoD</td>
<td>Department of Defense</td>
</tr>
<tr>
<td>EMF</td>
<td>Electromagnetic Field</td>
</tr>
<tr>
<td>E-stop</td>
<td>Emergency Stop</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>HP</td>
<td>Horse Power</td>
</tr>
<tr>
<td>HSL</td>
<td>Hue Saturation Light</td>
</tr>
<tr>
<td>IDE</td>
<td>Integrated Drive Electronics</td>
</tr>
<tr>
<td>IEEE 1394</td>
<td>Institute of Electrical and Electronics Engineers Firewire specification</td>
</tr>
<tr>
<td>IGVC</td>
<td>Intelligent Ground Vehicle Competition</td>
</tr>
<tr>
<td>IR</td>
<td>Infrared</td>
</tr>
<tr>
<td>I/O</td>
<td>Input/output</td>
</tr>
<tr>
<td>JTAG</td>
<td>Joint Test Action Group</td>
</tr>
<tr>
<td>LCD</td>
<td>Liquid Crystal Display</td>
</tr>
<tr>
<td>LED</td>
<td>Light Emitting Diode</td>
</tr>
<tr>
<td>MIG</td>
<td>Metal Inert Gas</td>
</tr>
<tr>
<td>NMEA</td>
<td>National Marine Electronics Association</td>
</tr>
<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer</td>
</tr>
<tr>
<td>OS</td>
<td>Operating System</td>
</tr>
<tr>
<td>OSMC</td>
<td>Open Source Motor Controller</td>
</tr>
</tbody>
</table>
4. **Intelligent Ground Vehicle Competition (IGVC)**

The AUVSI, which is the world’s largest non-profit organization dedicated solely to the research and advancement of unmanned systems, sponsors many autonomous contests each year. One of these contests, dedicated to autonomous ground travel, is the IGVC. This competition, held each June, is currently in its thirteenth running year. It is a small competition designed to fit very well in a senior capstone course.

The competition consists of three smaller, yet interrelated, competitions: obstacle avoidance, design, and navigation. The overall performance of a team is based on the weighted performance of these three competitions. The winner of each individual competition as well as the overall competition winner is recognized and given a cash award for each victory.

In the Autonomous Challenge (obstacle avoidance) competition, a fully autonomous unmanned ground robotic vehicle must negotiate around an outdoor obstacle course under a prescribed time. The vehicle must stay within the 5 mph speed limit, while avoiding the obstacles on the track. This obstacle course may have natural or artificial gradients, a real or simulated sand pit (simulated sand being a light beige canvas tarp covering the full ten-foot width of the track), real or simulated potholes (real potholes are circles, two feet in diameter and two inches deep, and simulated potholes are white circles, also two
feet in diameter), and randomly placed course obstacles. These randomly placed course obstacles consist of 5-gallon white pails and full-size orange and white construction drums such as are used on roadways and highways.

In the Vehicle Design competition, the final design of the vehicle is judged to determine the quality of the vehicle. Design judging will be by a panel of expert judges and will be conducted separate from and without regard to vehicle performance on the test course. Judging will be based on a written report, an oral presentation, and examination of the vehicle. Due to the brevity of these reports in comparison to the requirements of Senior Design, this section of the competition should be easy to prepare.

In the Navigation competition, the vehicle is to autonomously travel from a starting point to a number of target destinations (waypoints or landmarks) and return to home base, given only a map showing the coordinates of those targets. Coordinates of the waypoints will be given in latitude and longitude as well as in meters on an x-y grid.

In both the Autonomous Challenge and Navigation competitions, the vehicle is required to carry a payload provided by the IGVC. The payload weighs 20 pounds, and has approximately the same dimensions as a cinder block (8”x8”x18”). The payload contains a camera which must be facing forward and will transmit streaming audio and video to the IGVC committee during the Competition. The streaming audio and video will also be displayed in the team tent. The payload has to be carried on the top of the vehicle, which means that the payload may be lower than cameras or other sensors, but must sit atop the main body of the vehicle.

5. Design Norms

During a project or design, a team or individual must take into consideration the applicable design norms. The design norms that directly correspond to the ADD project include cultural appropriateness, transparency, stewardship, integrity, caring and trust.

The first design norm is cultural appropriateness. This design norm deals primarily with the ability of the automated vehicle to fit into the culture in which it will be used (United States of America.) Currently the U.S. car industry is beginning to create cars that apply a greater level of automation and modern engineering breakthroughs, such as putting proximity sensors on cars so they stop before backing into an obstruction. The automated car that ADD has designed implements this same technology as well as expands the scope to include steering around obstacles. The prototype has been built to resemble a car in order for it to appeal to the American people.

This design has also been made transparent as possible and documentation has been written for the main section and the subsections explaining the responsibility of each component. The
documentation written for the whole design accurately and reliably indicate, to any future teams or users, what the car does and how it will respond. Furthermore, a simplified user’s manual and its accompanying software have been produced to help others understand how to operate the vehicle without understanding its inner workings. This considerable amount of documentation gives any future teams entering the IGVC the ability to use and expand on the design. It also serves as a safety feature. For instance, when disassembly of the car is necessary, the disassembly person(s) can look at the documentation and avoid being injured in the process. Errors during execution of the team’s software can be analyzed by viewing log files, files that attempt to contain pertinent information pointing to the error. This debugging software is able to store information on some medium that can be removed and then further processed.

The design team has tried to eliminate excess strain on the environment and thus be good stewards. One method was by being frugal with the resources the team used. A major problem in the world today is the inefficient gas engines used in modern cars. ADD took this into consideration when choosing the motors to be implemented. Since the vehicle has much lower standards than major vehicles today, the motors chosen for the automated car were two DC electric motors. With electric motors, the vehicle does not burn fuels that are corrupting the ozone layer. ADD also included many previously used components instead of buying all new parts. This is beneficial to the environment because computers and other sensors are not very recyclable and their reuse decreases the amount of unnecessary non-biodegradable materials in landfills.

ADD cares about disabled people. There are people living in the world that cannot currently drive because of disabilities. These people are hindered because it is hard for them to get from one place to the other. A current solution to this issue has been to outfit a car with equipment specially designed for a disabled person. However, such a car, which allows them to drive, is frequently very expensive and not as safe as other vehicles. Autonomous vehicles will allow these people to travel from place to place without help or public transportation.

ADD also cares about public safety. When autonomous ground travel becomes feasible on a grand scale, humans will not be in control of their car. This will reduce the number of traffic fatalities caused each year by human error. Drunk or careless drivers, road rage, and other potential roadway hazards could be avoided if humans were eliminated from the driving equation. On a smaller scale, the design team has made absolutely certain that all safety requirements of the project are met, and that no person or animal has been injured in the design, testing, or use of the product. The concept of humans not being in control of their vehicles does have downsides. Without any control, humans have limited ability to prevent crashes if the automated vehicle fails.

The documentation written and the implementation of the design is accurate because ADD has adhered to integrity design norm. The written documentation has not be exaggerated to make the design
look better, which could pose risks to any user or future designer. The project can only be successful and effectively impact the United States of America if the general public can view the project in its unbiased form. If the documentation is lacking and/or inaccurate the general public will reject the project. This rejection will cause the appearance of automated cars into mainstream markets of the United States of America to be delayed even further.

ADD wants the public and future users to be able to trust their design. With this in mind, ADD designed the prototype with reliability as a constant goal. Any unreliable sections are clearly apparent so that every individual will know all risks possible. The parts chosen for the prototype are also of as high of quality as is feasible, in order to ensure that they have the best chance of withstanding the off-road nature of the competition.

6. Project Management

6.1. Team Organization

ADD is a team project undertaken as part of an undergraduate engineering design-oriented capstone course. As such, most aspects of the course were designed to imitate practices found in industry. Reviews of designs are very common in industry and this course attempts to place students in a similar process. Senior Design teams were required to meet with an industrial consultant, an experienced engineer who had no direct affiliations with Calvin College’s engineering department (i.e. not a current faculty member), and thus was objective in analyzing student’s design work. ADD’s industrial consultant was Mr. Tim Theriault of Smiths Aerospace in Grand Rapids, MI. Each team met with its industrial consultant twice during the Senior Design course, once in the fall semester and once in the spring. The consultants were able to give practical advice to the teams that the professors may have been reluctant to give. In this way, their guidance often proved to be much broader than that provided by the professors. In addition to having industrial consultants, many teams also had mentors. ADD was no different in that respect. ADD’s mentors were John Washburn, Frank Saggio, and Jerry Jakeway, all of whom work at Smiths Aerospace (in fields closely related to navigation and guidance) and whose primary concern with ADD was providing insight to the navigation and control aspects of the project.

One part of the design that ADD did not have much experience in was the mechanical aspect of the vehicle. To overcome ADD’s shortcomings, the team sought the advice of Dave Ryskamp and Professor Ned Nielsen. Mr. Ryskamp was very helpful in giving practical advice on the feasibility of construction and modification of certain parts of the frame. He also gave feedback on the motors that were chosen by ADD. Professor Nielsen verified power calculations for the motors and gave advice on frame design.
The team also participated in informal weekly meetings with their mentors. Along with these meetings the team itself met once every two weeks for an informal meeting. During these meetings tasks were delegated, project status was discussed, and design decisions were made. Paul Bakker usually took minutes and transferred them to the team’s server. These meetings were largely informal and never had any set agenda. These meetings focused primarily on progress updates, testing schedule, and team discussions about future design proceedings.

\[\text{Figure 1 - Team Organization Chart}\]

### 6.2. Project Responsibilities

Even though team member roles were never formally defined for ADD, the members assumed roles based on their own strengths and preferences. Paul set up an off-campus server for the team’s electronic storage use, developed the project schedule in Microsoft Project, and was one of the primary software engineers for the project. Brian composed the weekly status reports, was a helper in the building
of the basic vehicle frame, and designed and manufactured the PCB. Matt performed the motor power analysis (size of the motors necessary for the vehicle to perform all of the desired tasks in the competition) and power consumption analysis (how much electric power the entire vehicle, including all of its subsystems, consumes), was the primary builder of the vehicle, and assisted with software development. Dan was the primary software developer for the project. Nate developed the basic system design (in block diagram form), and was the primary software engineers for the project. All team members were responsible for designing hardware for their sections, testing, and debugging.

6.3. Project Documentation Organization

Project documents were kept primarily in two locations: In the Team 3 folder on the Calvin College Engineering Department’s X: drive (the Senior Design Projects drive), and on the server that Paul set up off campus. This server was a revision control server based on Microsoft’s Sharepoint Services. This allowed documents to be saved and accessed from a secure (SSL) web-based interface. Check-in-check-out capability was enabled providing an efficient and safe means of editing documents. Access to the server was granted to anyone at the team’s discretion.

6.4. Project Timeline

The project timeline was created using Microsoft Project. Tasks for the completion of the vehicle as well as deliverables for the Senior Design course are included in the timeline. Hours for each task were estimated using ADD’s best judgment. Tasks were assigned based on each team member’s interests as well as the amount of work assigned.

Some of the problems with scheduling with the timeline also come from Microsoft Project. Microsoft project assumes that a set amount of time will be available each day for working on the project. Since the team members of ADD have other academic obligations they are not able to fully devote their time to this project. Therefore, some compromises have been made in setting up the timeline and working time for each day. A two hour working day has been set up for each weekday with three hours on the weekend. This comes to a total of 13 hours per week for each team member. With this work schedule each member was be tasked to spend about 500 hours on the project. And in fact that is how many hours each of the team members, Dan excluded, spent on the project.

7. System Design Process

7.1. Project Requirements

Project Requirements are in the appendix.
7.2. System Design

7.2.1. Vehicle

The team consisted of four electrical engineers and one computer science major. With that in mind, the mechanical design of the car was difficult for the team at first. The team would design a part of the truck and then build it. Then they would design the next part of the truck and build it. The reason that the mechanical aspect of the design was performed in this manner was to ensure that the mechanical creation of the vehicle did not hinder the vehicle’s testing with the software. The team used AutoCAD Inventor to develop a 3-D model of the vehicle as it was being built. Varying designs of each part of the vehicle were added to this 3-D model and the best design was chosen and then built.

The team designed the car by themselves, but the manufacturing was done with the help of Dave Ryskamp. Mr. Ryskamp did not rule the building of the car; he mostly gave the team instructions on the operation of machinery and then let the team do their own work. He was very influential in teaching members of the team how to work with various tools available in the metal shop.

7.2.1.1. Steering

7.2.1.1.1. Criteria

The majority of the time the vehicle must travel in a straight line. However the vehicle will also need to have the ability to turn left and right without any human intervention (such as a steering wheel). Without this capability obstacle avoidance would be impossibility. This steering must be completely controllable and as error free as possible to ensure proper system control. A key point to remember is that the IGVC is an obstacle course. This makes maneuverability a much needed commodity.

7.2.1.1.2. Alternatives

The first method of steering is a fly-by-wire steering method. The input required to create the turning effect for this method normally involves a joystick (implying human disturbances), but this can be adjusted to allow for computer input. This type of steering has been implemented before at Calvin College by a previous senior design team. The information about this steering from the previous design offers an advantage over other possible options. One disadvantage is translating control system outputs into joystick commands which can then be utilized. However, the main disadvantage is that one of the two remaining options for steering will still have to be used for propulsion of the vehicle.

A second method of steering is differential steering. This type of steering removes the steering column and changes a turning operation into simply speeding up one motor and slowing down the other. If a right turn is to be implemented, the right motor will decrease its speed while the left motor will
increase its speed. Many of the more advanced RC car models use this type of steering scheme because it allows for greater control with an almost zero turning radius. This type of steering will need a minimum of two motors (one on each side of the car) that are attached to either the front or rear wheels. Some of the other drawbacks with differential steering involve motor selection and horsepower. A vehicle that is implementing differential steering needs to have two motors that are of equal torque and horsepower curves or else the vehicle will drift while traveling in a straight line. This behavior is usually more pronounced in the reverse direction, and so is of little concern to the design team. Beyond that, each of the motors needs to have enough horsepower to move the vehicle by itself. This causes the motors for differential steering to be more expensive and to consume more power. Research into autonomous vehicle design revealed that in fact most small model autonomous vehicles are steered using differential techniques. The main reason for this is the simplicity of the control system and that it is not as prone to error caused by the off road conditions. In addition the turning radius provided by differential steering make it the primary choice for obstacle course navigation.

A third method of steering is to attach a servo motor to a standard steering column. The motor will turn the steering column in a similar method to that of a person turning a steering wheel. With this design the vehicle still requires two motors. The drive motor needs to have enough torque and horsepower to move the car, while the other motor can be significantly smaller due to the lower torque and horsepower demands. With this configuration the vehicle could be gas powered and governed to 5 mile per hour while turning is supplied by this servo motor. This would eliminate some of the power concerns of the vehicle. However with pollution concerns the design team would like to stay away from fossil fuels if at all possible. This method also has no real cost savings over the previous two. A gas powered engine with the required horsepower is more expensive than a single electric motor, and would require the design team to do a significant amount of mechanical design. Due to this lack of experience this design will take more time to implement than the previous two.

A fourth method which was briefly considered is tank steering. This system is basically a superset of differential steering with additional mechanical concerns. Though different with its own set of unique advantages and disadvantages, this combination of one steering method with undesirable mechanical design causes this method to be quickly thrown out.

7.2.1.3. **Decision**

The design team automatically ruled out the fly-by-wire steering method because implementation of two of the alternatives was deemed a waste of time. The servo motor connected to a steering column with gas propulsion met the design requirements, but the design of this type of steering is geared towards mechanical engineers. ADD had little experience in the design of this type of steering system and wanted
to avoid it. With this steering method small errors in design could have resulted in costly errors for the project as a whole. Tank steering was also rejected because it would have required an expansion of the differential steering technique.

The differential steering method uses primarily software to control the speed of the turn and the turning radius. This gave the ADD team an advantage since they were already familiar with writing software. This type of design also allowed the design team more flexibility in the turning radius of the vehicle. The maneuverability that this alternative provided made it the primary choice of the design team.

7.2.1.2. Vehicle Body

7.2.1.2.1. Criteria

The vehicle body is the material that will be used to cover the frame and any components inside. The design of this material can be helpful in making the vehicle resemble a car. The material is needed because the electronic parts inside of the frame need to be relatively shielded from varying weather conditions. The vehicle body will be designed to efficiently cover all of the components of the design that need to be covered. While covering the components, the body needs to be water resistant to prevent possible water damage to the sensitive electronic components. The vehicle’s body must also allow the users to have access to each component whether it is inside of the vehicle’s body or on the outside. The following alternatives assume that the design team will be building the vehicles body because it is not feasible to buy the custom body which would be needed.

7.2.1.2.2. Alternatives

The first method is to create the body so that it is completely detachable. If a part needs to be accessed then the body can be removed. This type of body makes the vehicle safer since people viewing the vehicle will not be able to easily access the inner components of the design. This type of body hinders the team members because they will need to spend extra time removing the entire body each time a single component needs to be accessed.

The second method is to create removable sections in the body. This method allows the team members to have quicker access times to the components that they need to access. Instead of having to remove the whole body of the vehicle, they only need to remove the smaller section that covers the components they need to access. The drawback of this system is that there are more seams that water can slip through to enter the vehicle. Therefore this method also needs a test to ensure that water will not be able to damage any components. If the test results show that water is seeping into the vehicle body then
the team will need to attach weather stripping around the seams to block the water from entering the frame.

A third method is to create sections of the body that are connected by hinges (similar to a door). This method will give the design team the fastest access time. The design team will not need to unscrew anything in order to lift the section. However, since these sections are so easily lifted the overall design of the vehicle decreases in safety since anyone passing by can lift the sections and possibly be injured by the components.

7.2.1.2.3. Decision

The design team decided that the best option presented above was to cover the frame with a permanent body and create areas that were firmly held in place by screws. The fixed body removable section design allowed the team quick access time to components while maintaining safety. The removable sections are areas that are cut out and re-attached with screws giving the team members access to each section of inner components. This will give the user quicker access to each component inside the car. The problem with a fully removable body is that if one device needs to be accessed the whole body must be removed. With removable panels the full body never needs to be removed and each component can be accessed. Having the sections be connected by hinges instead of screws decreases the safety of the car by too much and ADD does not want people to get injured.

The team then decided that since the body will have many seams they must test the amount of leakage water the seams allow. The design team will test the seams to determine if any water enters through the seams. The test will consist of the team members simulating a steady drizzle of water on the car. If the seams allow water to drip through during this test then weather stripping will be added around the seams to ensure that no water will continue entering the vehicle.

7.2.1.2.4. Implementation

Several components had to be securely mounted on the vehicle’s frame. These components were mounted on the frame as soon as the team decided the final part to be used. The devices created to mount these components on the frame were designed to specifically fit the device that was being mounted on the car. This made the vehicle less versatile, but allowed for a more elegant fit for each component.

The body of the vehicle was created out of 0.040 inch aluminum sheet metal. Aluminum was chosen because of its light weight and its ease of error correction (aluminum is easier to unbend). The body of the vehicle was designed to look like a truck. Wherever two pieces of sheet metal were connected they were riveted together and the seam was caulked. This caulking allowed the team to also be able to paint the vehicle without any visible seams. This also made the body of the vehicle water
resistant. The vehicle was able to tolerate a light drizzle for the competition without having the batteries or circuitry get damaged.

Inside the cab of the truck are several components that needed to be mounted. There is a switch box where all of the switches for various components were routed. There are two 12 volt car batteries, two 12 volt battery chargers, one smaller 12 volt battery, one motor controller, one inverter, one PCB, one wireless E-stop board, one computer, and one monitor. The digital compass is mounted on the top of the cab so that the EMF of the motors does not affect the heading determined by the compass. The compass is not the only component outside of the vehicle body; a roll bar was created just for mounting components.

The roll bar was created to mount the lights, camera, and GPS unit. Each of these devices had to be higher than the rest of the vehicle. The lights had to be visible from any angle to the onlookers. The camera needed to be mounted high to ensure that it gave the maximum viewing area available. The GPS unit is mounted at the highest point of the car so that its reception of satellite signals is not hindered by the rest of the vehicle. Some aspects of the mechanical design were implemented just to make the vehicle look more like an everyday truck.

There are a few designs on the vehicle that look cool, but serve a small purpose if any. The hood was installed to eliminate a safety concern by giving the team an easy access point to all of the switches that are mounted in the body of the vehicle. If the hood had not been installed the switches would have been mounted on the outside of the car. With the switches on the outside anyone could have accidentally turned off a component that is imperative to the operation of the car, while the car is moving. If a component is turned off the car’s behavior could become erratic and unpredictable. The sole purpose of the tailgate is to provide the vehicle with a more lifelike representation of a truck. The headlights serve the same purpose as the tailgate. The headlights were donated by Andy Wallner. The monitor was mounted inside of the car because the monitor could not get wet. The 17” Proview LCD Monitor provided increased visibility compared to the CRT monitor that was previously used. The monitor allowed the team to view what the program was doing while the vehicle ran, which increased testing productivity. The jacks that were installed beside the monitor were also necessary in order to allow the team to easily plug in and unplug devices such as keyboard, mouse, and joystick. These devices are good for loading the program, but at the competition they will not be used while the vehicle is moving. The extra USB connector allows the team to easily plug in a USB removable storage device and move the various output files from the computer program to a remote location.
7.2.1.3. Motors

Since the vehicle implemented differential steering there was a need for either two or four motors. The two-motor design must be a two-wheel-drive system. The four-motor design would have implemented four wheel drive. Given the cost constraints of the design project a four wheel drive system was ruled out as infeasible and only a two wheel drive system was considered.

7.2.1.3.1. Criteria

This type of system may be implemented with front wheel drive or rear wheel drive. The vehicle must be able to maintain speeds of nearly five miles per hour. The reader can see in the calculations below that the horsepower needed to maintain a steady five miles per hour up a 15% gradient is approximately 0.5 HP. The amount of horsepower needed to accelerate from zero miles per hour to five miles per hour on a flat surface is 0.7 HP. Due to the off-road nature of the obstacle course the design team used a safety factor of two or twice the amount needed when determining the rated HP of each motor. With this safety factor in place the amount of HP that the design team will implement is 1.5 HP because that value ensures that the motors will have an adequate amount of power for any unforeseen complications on the off road terrain.
Road Inclination

\[ B_{\text{incl.}} = \text{degrees from horizontal} \]

\[ V_i := 2.2352 \]

\[ g := 9.81 \]

\[ B_{\text{incl.}} := 8.53 \]

\[ M_{\text{Gr.Veh}} := \frac{250}{2.2} \quad M_{\text{Gr.Veh}} := 113.636 \]

\[ P_{\text{incl}} := M_{\text{Gr.Veh}} g V \sin \left( \frac{B_{\text{incl.}} \pi}{180} \right) \]

\[ P_{\text{incl}} = 369.593 \quad \text{Pincl := } \frac{P_{\text{incl}}}{746} \quad \text{Pincl = 369.593 HP} \]

Power required to accelerate

\[ V_{\text{ave}} = \text{average velocity} = \frac{1}{2} (V_2 + V_1) \]

\[ a = \text{acceleration} \quad \frac{m}{s^2} \]

\[ V_{\text{start}} := 0 \quad V_{\text{finish}} := 4.5 \]

\[ V_{\text{ave}} := \frac{1}{2} (V_{\text{finish}} + V_{\text{start}}) \quad V_{\text{ave}} = 2.25 \]

\[ a := 2 \]

\[ P_{\text{accel}} := V_{\text{ave}} M_{\text{Gr.Veh}} a \quad P_{\text{accel}} = 511.364 \]

\[ P_{\text{accel}} := \frac{P_{\text{accel}}}{746} \quad P_{\text{accel}} = 511.364 \text{ P} \]

Figure 2 - Horsepower Calculations

Another calculation was performed to determine the horsepower needed to ensure that the car can move at a speed of five miles per hour. Figure 3 shows that with a 10 inch wheel size the RPM must be approximately 168 for the car to travel at a speed of five miles per hour.

\[ \text{WheelDiam} := 10 \quad \pi := 3.14 \quad \text{RPM} := 168.15 \]

\[ \text{WheelDiam} \cdot \pi \cdot \text{RPM} \cdot \left( \frac{60}{1} \right) \cdot \left( \frac{1}{12} \right) \cdot \left( \frac{1}{5280} \right) = 5 \quad \text{mph} \]

Figure 3 - RPM to MPH Calculations
7.2.1.3.2. Alternatives

The first motor considered was a NPC-T64. This motor was capable of approximately 1 HP. It had a gearbox attached to it with a ratio of 20:1. The attached gearbox was a bonus because the team would save money by purchasing this type of motor. This motor cost $286. However, this motor did not give the desired horsepower. The next motor in same family was the NPC-T74. This motor delivered a maximum of 1.5HP, which met the design team’s requirements. The NPC-T74 also included a 20:1 gearbox. The maximum RPM produced by this motor was 248. This value was more then necessary to ensure that the car would maintain a speed of five miles per hour. The cost of the NPC-T74 was $291. The next motor/gearbox system considered was a motor that did not incorporate a gear box. A standard 1.5HP motor had an average cost of approximately $200. The gearbox that needed to be purchased in addition to the motor had an average cost of $125. This brought the cost of this motor to $325. The cost of these motors was not the only factor in the decision. If the motor was to purchased separately from the gearbox it was more likely to have higher inefficiencies between the gearbox and the output motor shaft.

7.2.1.3.3. Decision

Due to the cost savings and reduction of inefficiencies the team decided to purchase the NPC – T74 motors. The design team considered a standard motor without an assembled gear box, but the motor and gear box cost was greater and the amount of time for the EE team members to design a gear box increased considerably.

7.2.1.3.4. Implementation

The Motors were mounted to the frame using two socket head cap screws and one L shaped piece of aluminum. The team removed the aluminum shafts from the drive wheels and replaced them with steel shafts. The shafts connected to the motor with four more socket head cap screws. The shafts were changed because the motor would shear the aluminum shaft at its peak torque. Even though the shafts were replaced one of the shafts continuously had problems. The first problem was that the wheel spun on the shaft and the set screws began digging grooves into the steel shaft. The solution to this problem was to drill a screw hole halfway through the shaft and then place a screw into it. This resolved the first problem. The second problem the team faced was that the shaft sheared and split apart. The solution to this problem was to add shims to the motor mount so that the motor output was level with the drive shaft. Once this problem was fixed the problems ceased to occur.
7.2.1.4. Wheels

Though it was possible to design the vehicle with only three wheels this solution would only have caused additional problems for the design team. Instead the design team proceeded with a more traditional four wheel design.

7.2.1.4.1. Criteria

Since the vehicle is differentially steered using two wheel driver, two of the wheels must be fixed to the frame and the other two wheels must be able to move freely. The wheel diameter is important because the vehicle must be able to drive over a 15% gradient without the middle of the car scraping the ground. The design team calculated that the wheel diameter must be greater then eight inches. Due to the differential steering of the vehicle the rear wheels need to be caster wheels that can swivel.

7.2.1.4.2. Alternatives

The type of wheel which fits with our needs is ordinary caster wheels. There are many caster wheels available today; however there are two main options for the design team to consider. The first option is for a caster wheel that has limited movement. The benefit of this option is that the wheels are more stable. Unfortunately, the drawback is that the vehicle has an increased turning radius. The full motion casters allow the car to turn at very sharp angles, but it decreases the vehicle’s stability.

7.2.1.4.3. Decision

Due to the nature of the events that the vehicle will compete in, a sharp turning radius was a major benefit. For example, if two waypoints are in opposite directions the car will arrive at the second way point faster if it can turn around quicker. The obstacle environment also dictates that the design must be agile. Therefore, the team decided to obtain full motion caster wheels to decrease the turning radius.

Two drive wheels were found at Calvin College that each have a ten inch diameter. These wheels also had a fixed mounting plate and encoders already attached. These two wheels fit perfectly with the criteria and were used by the team in order to save money.

7.2.1.4.4. Implementation

The drive wheels that were used for the vehicle were donated by Calvin College. They are ten inch wheels that are mainly used for pavement driving. They contained a C shaped mounting bracket that was welded together out of aluminum. The shaft went through two ball bearings which were attached to the mounting bracket. The shaft also went through a piece of aluminum tubing approximately one inch thick that allowed the shaft to fit securely on the inside of the wheel. Encoders were mounted directly to
the outside of the shaft. The distance from the ground to the top of the mounting apparatus is approximately twelve inches.

The rear wheels of the vehicle were caster wheels bought from Harbor Freight. This allowed the vehicle to have a greater turning radius. The caster wheels had a full 360 degree rotation for reverse driving capability. These wheels were also ten inches in diameter and the distance from the ground to the top of the mounting bracket was also twelve inches.

Both of the wheel apparatuses were bolted to the frame with four bolts so that the mounting device does not move. There was also an angular piece of aluminum that was connected to the C shaped mounting device for one wheel. This keeps the mounting device from bending when the angular velocity of the vehicle is relatively high.

7.2.1.5. Frame

7.2.1.5.1. Criteria

The design of the vehicle’s frame must be meet the dimensional constraints that are defined by the IGVC. The IGVC requires that the vehicle’s maximum dimensions are 9 feet long, 5 feet wide, and 6 feet high, with a minimum length of 3 feet. The design team constrained these requirements to a more reasonable value for the design. The frame must fit within these requirements and have adequate space to house all of the computing, sensing, and power equipment. Additionally, the frame must provide adequate support for the weight of the vehicle.

7.2.1.5.2. Alternatives

Several different possibilities were considered for the configuration of the vehicle. A car frame, go-kart frame, wheelchair and building a frame from scratch were all entered into a decision matrix.

<table>
<thead>
<tr>
<th>Table 1 - Frame Design Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criterion Weight Percent</td>
</tr>
<tr>
<td>Car frame</td>
</tr>
<tr>
<td>Go-kart frame</td>
</tr>
<tr>
<td>Wheelchair</td>
</tr>
<tr>
<td>Build from scratch</td>
</tr>
</tbody>
</table>

7.2.1.5.3. Decision

Using the above design matrix as a guide, ADD moved forward in the requisition of a go-kart frame, which was chosen over a vehicle built from scratch because a go-kart frame would require less time for the team to assemble. The idea of a car frame received a low score in the design matrix primarily
because most cars (and thus their frames) are larger (at least in width and length) than the maximum vehicle dimensions laid out in the IGVC rules, and because most car frames are considerably heavier than ADD’s desired frame weight. The idea of a wheelchair was discarded primarily because it would have been too small to fit all of the sensing, computing, power, and propulsion equipment necessary to compete in the IGVC. However, after receiving a go-kart frame free of charge from Formula K, and considering exactly what would have to be removed from the frame to make it usable as a vehicle base, ADD came to the conclusion that both time and vehicle weight could be saved by discarding the steel frame from Formula K and building a similar frame from scratch out of aluminum.

7.2.1.5.4. Implementation

The team’s original idea for the frame was to use one that was donated from Formula K, ltd. After further review of the donated frame, the team decided that the frame had many disadvantages. The frame was created out of steel, which is heavy and does not weld to aluminum. The team’s design of the frame did not match the frame that was donated. That meant that the team would have had to cut out most of the pieces of the donated frame except for the outside box and then start building the inside. Since all that was left was the outer box, the team decided that it would be faster to build their own frame out of a material of their choosing. Since the donated frame had more limitations than benefits the team decided to build their own frame.

The frame of the car was designed to be able to hold the components, the body, and at least one person. In this design, unused space was left in the middle of the frame. This ensured that another device could be added without drastically changing the vehicle’s center of mass. The metal that was used was square aluminum tubing. The reason that aluminum was chosen over steel was because it provided the vehicle with a lighter frame. The two inch aluminum tubing was used to ensure that the frame would support more than one person if two people decided to stand on the frame. The frame was MIG welded using the welder in the metal shop. MIG welding was chosen due to the lack of welding experience on the team. MIG welding is supposedly one of the easiest welding methods at Calvin College. Initially, the team still found it relatively difficult and time consuming to weld aluminum together. There are various places on the frame where wires are held in place using metal clips and other various types of clamps that the team designed and mounted. These clamps helped to cleanly route power wires from the front to the rear of the vehicle. Directly under the middle of the car there are two C shaped pieces of metal that are hinged and latched. These C shaped pieces of metal hold wires tight to the underside of the frame to keep them from dragging on the ground. Also attached to the frame were motors and wheel assemblies.
7.2.2. Navigation

The navigation component of the vehicle was of great importance. Navigation had the relatively simple task of determining the current location of the vehicle and where it was heading. It was used to get from one point to another, whether those be waypoints specified by the competition or virtual waypoints provided by some other component. The navigation component read information from the various sensors and applied any applicable filtering. It then was able to pass this information to other components which needed information about the state of the vehicle.

7.2.2.1. Overall

7.2.2.1.1. Criteria

The navigation system shall be able to provide information about the state of the vehicle’s position and movement. It shall be able to pass this information to other components of the vehicle.

7.2.2.1.2. Alternatives

Some alternatives for the navigation system are a GPS only system, a dead reckoning only system, or a combination of the two systems. Another set of alternatives can be obtained by using an inertial navigation system. Then the system could be composed of only the inertial system or combined with either the GPS system or the dead reckoning system.

7.2.2.1.3. Decision

The combination of GPS and dead reckoning was chosen by ADD as the most desirable solution for the navigation hardware. These two systems do have significant errors associated with each component, but they are different types of errors. The GPS system has a relatively constant error associated with the number of satellites and atmosphere. The dead reckoning system is very accurate initially but its accuracy decreases the longer it is used. When combined these errors are corrected by the other system and can therefore provide a more accurate navigational solution than a single component. The inertial navigation system would have provided greater accuracy than the dead reckoning system but unfortunately it was out of our budget. Therefore the combination of the GPS and dead reckoning systems was the option that ADD decided to pursue.

7.2.2.1.4. Implementation

The overall implementation of navigation consisted of the integration of a GPS receiver and dead reckoning via wheel encoders and a digital compass. The GPS receiver provided the position of the vehicle. Dead reckoning provided the position of the vehicle as well as the heading and speed. Compass
heading was used to correct the dead reckoning navigation of the vehicle. The GPS and the dead
reckoning solutions were then filtered to remove any glitches or steady state errors on their outputs. This
provided the design team with a very accurate position and heading measurement and much less drift in
the dead reckoning position as time progressed.

### 7.2.2.1.5. Testing and Integration

Testing of the overall navigation of the car is an ongoing process. Our testing has consisted of
placing waypoints in the middle of a parking lot and instructing the car to attempt to drive through the
waypoint. After the car was able to do this, the team added multiple waypoints and instructed the car to
proceed to each successively.

The log files were examined at the end of each test to determine how well the vehicle did in
navigating the path of waypoints. The heading of the vehicle was compared to the heading received on
the digital compass during operation. This allowed the team to verify the heading that the software was
computing from the encoders and digital compass. The position of the vehicle was determined by
comparing the position computed by the software to the position received from the GPS receiver. An
external handheld GPS receiver was also used to verify the stationary positions. Using the distance to the
next waypoint and the heading of the vehicle during operation the team was able to evaluate the driving
performance of the vehicle.

With this testing the design team was able to verify the operation of the translational control
system, but had significant problems with the angular control system. After much testing and long hours
of looking at the log files produce, the design team was disappointed to discover that the error was
because the control system was only being updated at an inconsistent rate of 5-15 Hz. This was a big
problem since the control system required a much faster refresh rate. In order to fix this problem the
design team decided to switch to a new real time operating system. ADD is still in the process of porting
to this new OS, but the problem has effectively halted navigation testing for the time being.

### 7.2.2.2. GPS Receiver

A GPS receiver was used in the design to provide navigational information to the navigation
software.

#### 7.2.2.2.1. Criteria

The accuracy of the GPS receiver was of great concern. Many problems could have arisen due to
GPS inaccuracies. For instance, in the navigation part of the competition the vehicle may not reach the
waypoint if the GPS is very inaccurate. The refresh rate of the GPS receiver was also a parameter we
wanted to maximize. Most of the lower cost GPS receivers had a refresh rate of 1 Hz. ADD desired a
GPS with a higher refresh rate to offset the amount of interpolation done by the navigation software. Since ADD had written software that could interface with RS-232 the GPS receiver must be able to output in this format. Cost was also a great concern as ADD had a limited budget. Therefore, ADD desired that the cost of the GPS receiver be as low as possible while still meeting criteria mentioned above.

7.2.2.2. Alternatives

There are many possible options for GPS receivers. Many different companies produce models for use in automotive, marine, aviation, and other mobile applications. There are also GPS receivers specially designed for OEM applications. ADD decided that the OEM version would best suite the project. OEM GPS receivers typically do not have displays and are designed to be placed in a harsher environment (i.e. weather conditions). One downside of the OEM version was that testing was more difficult since the status of the GPS could not be easily determined from the device. However, this was not a significant issue for ADD due to the standard NMEA output provided by GPS receivers. ADD designed its software to this standard and used a GPS receiver with a display to test the software.

7.2.2.3. Decision

The Garmin GPS16-A was chosen by ADD. It met all of the criteria listed above and was within our estimated budget. It had a WAAS which allowed for an accuracy of up to 3 meters and had a refresh rate of 5 Hz. It was able to be connected to a computer by a USB or RS-232 (serial) connection.

<table>
<thead>
<tr>
<th>Table 2 - GPS Design Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criterion Weight Percent</td>
</tr>
<tr>
<td>Garinm OEM 16A</td>
</tr>
<tr>
<td>Novatel PropakLBplus</td>
</tr>
<tr>
<td>Garmin GPS 76</td>
</tr>
</tbody>
</table>

7.2.2.4. Implementation

The GPS receiver was placed on the top of the roll bar of the vehicle. This is the highest point of the vehicle and was chosen to give the receiver a clear view of the sky. The receiver was not mounted with any brackets, but instead the magnetic base of the receiver was used. Hand testing was used to verify the security of this mounting technique. The receiver was configured to refresh at a rate of 5 Hz and transfer only the minimum information used for determining the vehicle’s position. The receiver was connected to the PCB in order to provide power management features as well as surge protection.
(protection with a 1 amp fuse). Since the receiver is not in the same vertical plane as the wheels, the position that it provides is adjusted to this point in the navigation software.

7.2.2.2.5. Testing and Integration

The receiver’s positional drift was tested. The GPS receiver was placed in a location with a clear view of the sky and connected via a RS-232 connection to a computer. The receiver was powered on and positional data from the receiver was recorded for about 1.5 days. This data was then analyzed and an average drift per time period was determined. This drift was determined to be insignificant for the project and did not need to be addressed. The absolute accuracy of the receiver was never tested. The team decided that this was not really necessary as the team’s software could correct for any initial inaccuracies in the navigation challenge of the IGVC. Also the extra time and money needed to perform this type of test was decided to be unnecessary. The drift test verified the functionality of the receiver and its relational accuracy (accurate between measurements but possibly with some offset).

7.2.2.3. Compass

7.2.2.3.1. Criteria

The compass shall be digital. It shall have a heading error of no more than +/- 3 degrees and shall be able to output to a computer. The compass shall be weather tolerant so that it can be placed on any part of the vehicle. The compass shall be powered by a 12 volt unregulated or 5 volt regulated power source and shall not consume more than 1 amp during operation. The compass may be self calibrating and have a display. The refresh rate for the compass must be at least 5 Hz.

7.2.2.3.2. Alternatives

There are three compasses that meet the team’s criteria. The first compass that is considered is the KVH Autocomp 1000S. This compass is accurate within +/- 0.5 degrees. The Cost is $366, which is not terrible, but also not very good. This compass meets all of the criteria listed above.

The next compass is made by Honeywell. This compass has a built in gyroscope as well. The compass meets all of the criteria, but has extra features that the team will not use. With these added features also comes a high price. The price of this compass is over $600. The design team could not pay the extra money for features that they would not utilize.

The last compass that is considered is the KVH Azimuth 1000. This compass is the cheapest at around $200. It also meets all of the criteria listed above. Given that all of the compasses meet the criteria specified, it is safe to say that the team chose the compass with the lowest price to take some of the strain off of the budget.
7.2.2.3.3. Decision

The compasses that are listed above were entered into a design matrix that effectively determined which compass was best for the team. The design matrix includes the following criteria; accuracy, refresh rate, interface, cost, power, and enclosure type. Accuracy was one of the main concerns of the team. The more accurate the compass was the better results the team would have after implementing the compass. There are two main sections that excluded the Honeywell HMR3000. The cost and enclosure of this compass were much lower than for the KVH compasses. The Autocomp compass was beaten by the Azimuth 1000 compass primarily because of cost. The design team went with the KVH Azimuth 1000 compass because it provided them with all of the requirements and scored the best in the design matrix.

<table>
<thead>
<tr>
<th>Criterion Weight Percent</th>
<th>Accuracy</th>
<th>Refresh Rate</th>
<th>Interface</th>
<th>Cost</th>
<th>Power</th>
<th>Enclosure</th>
<th>Total Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>KVH Autocomp 1000S</td>
<td>9</td>
<td>5</td>
<td>8</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>5.7</td>
</tr>
<tr>
<td>Honeywell HRM3000</td>
<td>9</td>
<td>8</td>
<td>8</td>
<td>0</td>
<td>8</td>
<td>2</td>
<td>5.45</td>
</tr>
<tr>
<td>KVH Azimuth 1000</td>
<td>7</td>
<td>5</td>
<td>8</td>
<td>8</td>
<td>6</td>
<td>8</td>
<td>6</td>
</tr>
</tbody>
</table>

7.2.2.3.4. Implementation

The compass was mounted on the top of the vehicle's body. The compass is used to determine the vehicle's initial heading on start up. It is also used to determine the current heading of the vehicle while the vehicle is driving. The heading that is sent to the computer, via a serial connection, is compared to the desired heading calculated by the software. This allows the control system to know how far off course the vehicle is.

7.2.2.3.5. Testing and Integration

One of the tests that were performed on the compass was verification that the compass was sending the correct information via the serial cables. This test was successful on the first try and no altering needed to be done.

After the team was sure that the compass was sending valid data they calibrated the compass by driving the car in a slow circle. It took the car two and a half minutes to complete a 360 degree turn. This calibrated the compass and allowed the team to continue testing.

The other test that was performed was to determine how the heading of the compass was affected by the EMF created by the motors. The vehicle was placed on a stand and the heading was read from the display on the compass. Then the motors were activated and the compass display was read once again. The result was that the compass heading changed by two degrees while the compass was inside of the vehicle.
vehicle body. When the compass was outside of the vehicle body the heading only changed one degree by the EMF.

7.2.2.4. Wheel Encoders

7.2.2.4.1. Criteria

The encoders shall be digital. It shall have 2-channel quadrature capability giving the ability to determine if the vehicle is moving forward or backwards. The encoder should be able to be powered by 12 volts. The encoder must be able to safely handle 300 RPM. It must also be directly connected to a shaft that is less than or equal to 5/8 of an inch. The enclosure must also be semi-water resistant.

7.2.2.4.2. Alternatives

The most obvious encoders that meet the team’s criteria are the encoders that were found on the wheels that Calvin donated. These encoders already fit the shafts that are on the wheels. They can be powered by any voltage from 5 to 24 volts. These encoders can handle ten times the speed that is in the team’s criteria.

The second option is the H25 incremental encoder. This encoder meets part of the criteria except that it does not easily mount to the shaft. Instead this encoder has a piece that sticks out as opposed to a hole that the original shaft would fit into. This encoder is also expensive.

The third encoder option is the HB6M Hollow Bore Optical Encoder. This encoder meets all of the requirements except that the power to the encoder needs to be a steady five volts instead of twelve. This is a slight problem, but it is one that can be overcome if the design matrix says that the other benefits outweigh the voltage supply.

7.2.2.4.3. Decision

The encoders that are listed above were put into a design matrix and calculations were done to ensure that the correct encoder would be chosen. The main problem with the H25 Incremental Encoder was that this encoder had too many additional features and it was over designed for ADD’s application. These additional features caused the price to be extremely excessive compared to the other encoders.

The HB6M Hollow Bore encoder met all of the criteria listed above except that the input power for this device is only five volts instead of twelve. This would have caused the design team to add a new power supply to the car to create this five volt power source.

The Hohner Series 07 encoder scored higher than the other encoders because it met all of the team’s requirements. It was consistent throughout as being a relatively reliable and effective encoder without having too much overkill. The one factor that really boosted this encoder was that it was donated.
It gave the encoder more cushion on the design matrix when it was lacking compared to some of the other encoders.

<table>
<thead>
<tr>
<th>Table 4 - Encoder Design Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Criterion Weight Percent</strong></td>
</tr>
<tr>
<td>-------------------------------</td>
</tr>
<tr>
<td>Hohner Series 07 I.H.S.E.</td>
</tr>
<tr>
<td>H25 Incremental Encoder</td>
</tr>
<tr>
<td>HB6M Hollow Bore O.E.</td>
</tr>
</tbody>
</table>

7.2.2.4.4. Implementation

The encoders were attached directly to the drive shaft of each wheel. The shafts were taken off the wheels and a section of the shaft was lathed down to be 3/8 of an inch in order for the encoder to shaft connection to be tight. Setscrews were placed in the appropriate spots to hold the encoder to the shaft correctly. Both of the encoders were connected to the motor controller via a custom made cable. The wires from both encoders met in the middle of the car and then were enclosed in the same casing with one 8 pin RJ45 connector which was then inserted into the optical encoder device on the motor controller.

7.2.2.4.5. Testing and Integration

In order to test the encoders the team turned the encoders in each direction to be sure that the ticks were changing accurately in both directions. The team attempted to turn the encoder to receive one tick, but was never successful since the turn to produce one tick is very small. Once the team determined that the encoders were working correctly, the team attached them to the shafts of the wheels and put the vehicle on blocks to determine if the encoders still worked while being connected to the vehicle. They performed successfully.

7.2.3. Obstacle Detection

7.2.3.1. Criteria

This subsystem must be able to use information from hardware about the outside environment to extract obstacle patterns. The obstacle detection design must be able to observe and locate obstacles specified by the IGVC. It must also be able to perform a similar operation with traffic lines. In addition to traditional obstacles, the IGVC will place simulated obstacles in the path of the vehicle. These simulated obstacles are usually painted markings on the ground with no obstacle body. This forces the design team to only consider alternatives with the presence of a visual recognition system. The extent of the visual recognition is the subject of the following alternatives.
7.2.3.2. Alternatives

One camera would save the design team some money and would still be able to detect obstacles. One camera could be used to detect all the obstacles of the course. This system would cost less and require less processing power. With this option, however, it is very difficult to establish object position to some reasonable degree if the object’s size is variable. Various photographic transforms could be used to reduce this type of error, but doing so would be difficult from a programming side of view. However, since all the obstacles in the IGVC have a static size the single camera option will need testing to determine its feasibility.

Two cameras would allow for the same amount of obstacle recognition, but with some additional advantages/disadvantages. With two cameras the position of the obstacles can now be established with relative certainty without correcting transformations. However, the software for stereo vision could be too complicated for the scope of this project. The team’s computer science major will determine the feasibility of this option. Also this option would cost more, but the cost of a single camera is relatively insignificant with regards to the rest of the projects components.

Any number of cameras combined with some type of proximity sensors is a third option for the design team. This option would provide a back up to the cameras in case an obstacle goes unseen by the visual recognition programmer. Using these additional sensors has its perks because not every possible obstacle can be programmed into obstacle recognition. For example, without additional sensors the software would have difficulty distinguishing a wall or a solid object painted like grass. These additional sensors would provide a means to pick up and avoid these obstacles, but at additional monetary costs.

7.2.3.3. Decision

The decision was to use a single camera for obstacle detection. This decision was made after consulting with Professor Harry Plantinga about the feasibility of stereographic depth positioning. Currently there is no good way to extract the depth of objects from a pair of stereo images very well. The results of this would be inaccurate due to factors such as the edges between the pictures not completely matching and the difficulty to accurately match up one of the pictures to another edge of the other picture to correspond to the same object. Other easier and more accurate methods suggested was to base the depth upon the base position, size of object, and the size differential as the vehicle moves. These are all possible options for the team’s project and the base position was implemented. The size option would be a bit tricky to implement since ADD found out there are many different construction obstacles now to avoid and they are not all the same size. This would mean ADD would have to first try to figure out what kind of obstacle it is first before relying on size. The size differential option would be a good algorithm to implement, however once again this requires matching up an obstacle from one frame to an obstacle
from another frame which is difficult to do reliably. The base method is quite accurate and easy to implement so that option was chosen. Also another option that Plantinga offered was to mount a projector to the vehicle that would project a horizontal line in the viewing area and then could read how that line lies on different obstacles to calculate the depth. This would be an accurate way of finding depth, however projectors are expensive and also the car will be running outside which would lead to jittering of the projector image.

7.2.3.4. Implementation

The implementation of the obstacle detection consists of many different filters, and then processing that image for blocks. Main parts of the filtering consists of first passing the image through different sets of general image manipulation filters to prep the image, then passing it through the color filter that lets only certain colors pass through, then that image is filtered to reduce noise.

There are many first stage filters that were implemented that could be used in any sort of order. One good filter to perform in the initial stages is the normalize brightness filter. This filter will ensure that the full range of brightness’s are utilized. This is done by stretching the current values to fill up the full range. This is useful when the camera is being washed out or blackened. The camera driver brightness adjustment should be set correctly, however, in such a way that this filter should not be needed as long as that setting stays correct. Another filter is the equalize brightness, which is different from normalize brightness. Equalize separates the picture into fixed size squares and each square is forced to have certain average brightness. This does have the drawback that white and black areas become gray. This is useful though because it does a good job of normalizing the colors so that the color filter can work better. Another filter is the normalize RGB. This filter tries to compensate for different lighting environments by considering each of the RGB channels independently by having a reference point of pure red, green, and blue at a certain position of the camera field of view. These values are read in and then the rest of the picture is biased towards the channel that shows up the worst. Another filter is the exaggerate filter. This filter detects any differences among the RGB channels of a color and exaggerates this difference. This is a useful filter in that it can make orange look more orange. This must be used with some caution as it can modify the picture significantly. Another filter is the transform filter which arbitrarily changes the values of the RGB channels. A drawn graph can be used as the input in which the x axis is the current value and the y value is the value to change it too. For example, the negative slope would invert all the colors. A more useful function is to have an exponential type curve that would change the gamma values which would be useful.

The main filter which only allows certain colors to pass through has a simple basis in that it simply goes through each pixel of the picture and looks up that pixel in a table to see if it is allowed to go
through, if not it is replaced with black. This simple approach makes it very efficient which is greatly
needed since some other methods of mathematical equations would be very CPU intensive. The way that
this lookup table is made possible is by having a set of pictures that contain all the possible colors and the
unwanted colors are simply blacked out. From these pictures the lookup table is populated and because
very customizable by using the human eye which can catch minor color differences. Along with that
method of filling the table is also a parameterized input of HSL values. HSL is a different color space
than RGB and is much more related to how we humans perceive color. HSL stands for hue saturation
lightness. Hue is what color it appears to be, saturation is how much of that color it contains, or the
pureness of the color, and lightness is the lightness or darkness of the color. These values are
incorporated into the GUI so that they are easily adjusted and when they change it updates the lookup
table. Since these input parameters are in HSL they must be converted to RGB which the lookup is in and
this allows the expensive color space conversion to only happen when the filter needs to be changed
instead of every frame.

There must be filtering after the color removal since there will be extra noise that should be taken
out. This is accomplished by shrouding in the black to eliminate most all the noise. This is done by
setting a colored pixel black if a certain threshold of its neighbors is currently black. This filter is of
utmost significance for the later object detection to work.

The object detection could easily consume a lot of CPU so an efficient algorithm here is a
requirement. This detection fits either blocks or line segments to the input image. The algorithm
implemented is a single pass scan line algorithm which makes it very efficient. The algorithm basically
scans from bottom left to top right and builds up a list of current objects. If a pixel is within a certain
range of an established object it is combined to that object. When the current scan line does not add
anything to the object it is seen as finished. Also, if the object is too tall it is also considered finished.
This is needed because without this check the block would grow over the entire length of a curve and the
block would then be seen as a straight line then. Limiting the height of the block eliminates this with the
curved line then being composed of several line segments. Another requirement of the competition is to
connect dashed lines. This is done with some filtering which connects line segments if they are close
enough to each other and have similar angles. These values can easily be changed within the GUI so that
it can be optimized to connect the dashed lines that are present on their course.

7.2.3.4.1. Testing and Integration

Testing of the object recognition was done throughout the development of the code. When first
developing the video filters ADD used still images which were taken from previous years of the
competition. This proved to be useful in that it showed that the filters were able to correctly filter
previous years competitions. The majority of testing with the obstacle detection consisted of holding the video camera up to a sheet of paper with obstacles drawn on it. This also proved that the calibration software was very effective in that it could easily calibrate the filters to process a variety of colors. This would need to be done at the actual competition due to varying colors of the specific course.

The integration of the object detection code was simple because the only other part of code that needs to know about the obstacles is the obstacle avoidance, which is incorporated with the class that contains all the recorded obstacles.

Tests were performed on the tuning of the video filters when integrated with the vehicle. This emphasized even more the agility of the calibration. In order for the filters to be optimally calibrated for the current environment the settings were so tight that from day to day with slightly different environments completely different results of the filters occurred. At the competition this must be taken into account depending on whether it is cloudy or not. This could change the brightness and could cause unexpected results. The calibration is easy enough to do right before each run so it can be calibrated for a very short time period.

7.2.4. **Electronic Components**

7.2.4.1. **Cameras**

7.2.4.1.1. **Criteria**

The cameras implemented in the design must be the exact same brand and model because the images that are going to be compared need to be in the exact same format. This will ensure that the software that is comparing these pictures is not hindered by varying formats. The images also need to have the same resolution and color saturation. The team’s goal is to update the position grid twice a second, meaning that the cameras should refresh at a minimum of 15Hz. This will allow most of the 0.5 second latency to come from the actual computing and not from the camera. The cameras should have a wide angle lens, which will allow for a wide view of the obstacles in front of the vehicle. The cameras also need a minimum resolution of 320x240, but 640x480 is desired.

7.2.4.1.2. **Alternatives**

Two analog video cameras can be used for this design. The refresh rate is above the required 15Hz. The analog camera has the capability of having a wide angle lens attached to it quite easily.

The major drawback of an analog camera is data that is being inputted to the system needs to be converted from analog signals to digital signals. This conversion process will create a time void between
when the pictures are taken and when the pictures are searched for possible obstacles. Therefore, the analog camera does not run in real time.

Two digital camcorders can also be used for this design. The refresh rate is above the required 15Hz at a standard 30Hz. The digital camcorder can also have a wide angle lens attached. The resolution of a digital camcorder can be set to 640x480. No conversion is necessary when dealing with the output signal from the camcorder because the output is already in a digital format that the filters can use.

The digital camcorder has its drawbacks too. The most significant drawback is the relatively high price. The digital camcorder also has many features that could make the setup and configuration of the camcorder more difficult.

Two web cameras can be used as well. The refresh rate of a web camera is 30 frames per second and the resolution is 640x480. Both these parameters exceed the specified requirements. The web camera is designed to be connected to a computer and thus viewed in real time. The web camera is also inexpensive when compared to the digital camcorder and the analog video cameras.

Web cameras do not have many additional features. An additional lens can not be attached to many of the current web cameras which limits the viewing width of the camera. The web camera also lacks additional features such as zooming capabilities and self contained memory units.

7.2.4.1.3. Decision

The design team decided that the analog video camera was not a viable option. The potential improvement in viewing area was not worth the extra cost when compared to digital cameras.

The digital camcorder and the web camera both met all of the requirements for the cameras. The drawbacks of a digital camcorder were more significant then those of the web camera. The digital camcorder was on average ten times more expensive than the web cameras. Due to the limited budget that the design team was given, the cost of the camera was a major factor in this decision. The benefits of the digital camcorder over the web cameras were small as well. The additional features, in particular the zoom capability, could have possibly caused additional problems with the accuracy of the two pictures. One of the requirements is that both cameras produce a picture with the exact same resolution and color saturations. If these features were adjustable then the two pictures could have possibly been different without the design team being aware of it.

Given the information above, the design team decided to utilize web cameras to take the pictures used to determine obstacles in the path of the vehicle. The web cameras chosen were Creative Web Cam NX Ultras. They cost the team fifty dollars a piece.
7.2.4.1.4. Implementation

Two webcams was the initial plan in that it would provide stereoscopic view of the obstacles so that the depth of the obstacles could be determined. After consulting with Professor Harry Plantinga, this idea was deemed ineffective. Finding depth from stereo images is a very hard problem and the accuracies of the algorithms are not very good at all. This is due to the difficulty in matching the part of one picture that corresponds to the same part in another picture. Other easier and more accurate methods suggested were to base the depth upon the base position, size of object, or the size differential when moving. These are all viable options for ADD’s project and the base position was implemented. The size option would have been a bit tricky to implement since we found out there are many different construction obstacles to avoid. They are not the same size so the software would have to first try to figure out what kind of obstacle it is first before relying on size. The size differential option would have been a good algorithm to implement, however once again this requires matching up an obstacle from one frame to an obstacle from another frame which is difficult to do reliably. The base method is quite accurate and easy to implement so that option was chosen. Also, another option that Plantinga offered was to mount a projector to the vehicle that would project a horizontal line in the viewing area. Then the software via the camera could read how that line lie on different obstacles to calculate the depth. This would have been an accurate way of finding depth, however projectors are expensive and also the car will be running outside on a grass field and thus would cause jittering of the projector picture and the objects. The results from this option would not have had the necessary results.

Since ADD had already purchased two webcams, the team started thinking what the second camera could be used for. Some ideas were to have the second camera pointed in back of the car so that when the vehicle backed up software could determine what was behind the vehicle. This idea became infeasible since when the vehicle starts backing up the caster wheels have to turn around. This causes the back of the vehicle to swing significantly. ADD therefore does not want to use reverse and instead hopes to always have enough room to make a sharp forward turn. Another idea for the second webcam was to have it mounted close to the ground looking directly in front of the tires. This could then act as a failsafe in that if the second camera detects some sort of obstacle right in front of the tires it could stop the vehicle or try to do a tight turn. This is still a feasible option, however not implemented due to time constraints of higher priority tasks. In the long run however it was still good that ADD purchased two cameras since one camera was mounted on the vehicle and the other camera was used for developing and testing off the vehicle.
7.2.4.1.5. Testing and Integration

Testing of the video was done throughout the development of the code. When first developing the video filters ADD first used still images which were taken from previous years of the competition. This proved to be useful in that it showed that the filters were able to correctly filter previous years competitions. The testing with the video camera primarily consisted of holding the video camera up to a sheet of paper with obstacles drawn on it. This also proved that the calibration software was very effective in that it could easily calibrate the filters to process a variety of colors. This would be needed to done at the actual competition due to varying colors of the specific course. Testing of path decision was also done by holding the video camera and drawing different courses on the sheet of paper and watching how the software instructed the vehicle to pass through the course.

Integration of the camera with the vehicle was pretty simple. The camera was mounted at the highest point of the vehicle so that it could get the best overhead view of the course. The camera was then pointed downward so that just a little bit of the vehicle’s hood showed up on the bottom of the picture. This was needed because one of the video filters requires looking at true red, green, and blue colors that can be mounted on the edge of the hood. The height of the camera lens and the vertical angle was then measured so that they could be put into the video filtering to correctly produce an overhead view from the perspective view of the camera.

Integration of the camera code with the rest of the code was also pretty simple in that the only thing that the cameras ever produce is a desired heading. This heading is written to the global heading variable which is then used by the navigation code. We were able to use the joystick to drive the vehicle and watch what path the camera was deciding.

Tests were performed on the tuning of the video filters when integrated with the vehicle. This emphasized even more the agility of the calibration. In order for the filters to be optimally calibrated for the current environment the settings were so tight that from day to day with slightly different environments completely different results of the filters occurred. At the competition this must be taken into account depending on whether it is cloudy or not. This could change the brightness and could cause unexpected results. The calibration is easy enough to do right before each run so it can be calibrated for a very short time period.

7.2.4.2. Proximity Sensors

7.2.4.2.1. Criteria

Proximity sensors may be used as secondary obstacle detection devices. The main sensor for obstacle avoidance is the cameras, but to increase the detection rate, ultrasonic sensors may be added to
work in parallel with the cameras. The proximity sensors should be placed on the front of the vehicle positioned so that they detect obstacles that hinder the current path of the vehicle. These sensors must be able to detect obstacles at a minimum distance of seven feet.

### 7.2.4.2.2. Alternatives

The first type of proximity sensor is a PIR sensor. This type of sensor is mainly used to detect warm bodied targets in motion. In order for a detection to occur, the target’s temperature must vary from its environment and the target must be in motion.

Another type of proximity sensor is an ultrasonic sensor. This sensor transmits a sound wave that is above 20 kHz (the maximum humans can hear). The receiver, which is normally included in the device, waits to receive the sound wave after it has reflected off of a target. With this sensor the greater the intensity of the sound waves entering the receiver the greater the voltage at the output. Using this analog output a distance can be determined by measuring the voltage on the output and performing simple calculations. Each ultrasonic sensor has its own conversion such as 1 volt/10 feet.

A laser range finder is another viable option for the design team. This sensor transmits a laser beam and if the laser is reflected back to the receiver then a distance is determinable. Otherwise, there is no obstacle in its path.

### 7.2.4.2.3. Decision

The design team’s decision was simplified due to budget issues. The laser range finder option could not be used because the team did not have enough money to purchase this device. The PIR sensor would not have worked for the given criteria of the project because the obstacles the car needed to avoid would not be moving. They would also be at a constant temperature with the environment around them. Therefore, the option that the design team would have implemented is the ultrasonic sensors. This type of sensor would have allowed the design team to detect the obstacles in the conditions of the competition. Although ultrasonic sensors are less expensive than the range finders, the design team was still unable to purchase these sensors. Therefore, the design team decided, after testing the obstacle detection via only one camera, that the ultrasonic sensors are not necessary.

### 7.2.4.2.4. Implementation

The design team looked carefully at these ultrasonic sensors and determined that they were not imperative for the detection of obstacles. There were two main problems with these sensors. One problem was the time needed to integrate these sensors. The software would have needed to be updated and possibly even more serial connectors added via PCI cards. This integration would have been very time consuming. Not only would the ultrasonic sensors have been a time consuming task for the team,
they also would have created increased strain on the team’s budget. The second main problem was the price of the ultrasonic sensors. In order to effectively implement the ultrasonic sensor system, multiple sensors, at a cost of more than $200 each, would have had to have been purchased. The total price for the ultrasonic sensor system would have been near $600. This was another major deterrent of the ultrasonic sensor system. The team put these sensors in the background from the beginning and decided that they would get obstacle detection working with the camera first. Then, if the design team had enough time, they would add the ultrasonic sensors to the obstacle detection system. However, these sensors were never added due to a lack of time.

7.2.4.3. Motor Controller

The electrical motors used on the vehicle needed some type of controller to regulate the speed of their operation. This was to be provided by a motor controller with a sufficient H-bridge. Many motor controllers exist, but because of their potential complexity some could be implemented more quickly than others. Also the functionality of different motor controllers varied significantly. Due to the importance of the controller, much time was spent looking into possible motor controller alternatives.

7.2.4.3.1. Criteria

The vehicle itself will be a skid steered design with electric motor propulsion. Most of the criteria for the motor controllers derive from this design decision. The electrical motors used on the vehicle will need some type of controller to regulate the speed of their operation. The DC motors selected are controlled by the amount and polarity of current being sent to them. During normal operation these motors draw around 25 amps with the occasional spike of about 80 amps. The motor controller will therefore need an H-bridge capable of surviving these conditions.

The control system, implemented on the computer of the vehicle, must also be able to communicate with the motor controller. The dead reckoning navigation of the system updates at a rate of 20 Hz and therefore this communication must be able to occur at a similar rate of 20 Hz. The process of this communication must be such that ADD is able to send the information without additional hardware considerations. Also it would be preferable to use a communication standard that is sent through wires, thus eliminating any possible illusion of improprieties on the part of the design team. During discussions with the teams mentors it was explained how the lag of the motors causes a pole in the plant of the control system. In order to mitigate the possible instability of the system, it is necessary to implement an inner-loop. A speed controlled inner-loop is desirable since it is more responsive to the motors. Therefore, to stabilize the control system of the vehicle the motor controller must be able to support a speed controlled inner loop.
Motor controllers are very expensive and thus the choice of the motor controller is one of the major decisions of the project. The price of the motor controllers used in past competitions ranged anywhere from $100 to $3000. This was a significant concern of the design team and an internal goal was set at keeping the price of this system to less than $500 if at all possible. Many of the available motor controllers were eliminated because of this stipulation.

7.2.4.3.2. Alternatives

The communication alternatives were some of the first things to be considered with a motor controller. The team itself was strongly opinionated towards controlling the motor controller directly from the computer and this would have left the team with only one feasible option. The motor controllers with RS232 ports became a primary desire of the design team. Other computer based communication standards are available, but the cost of these did not justify their consideration. Cheaper options than this were available so the design team also had to consider them as possible solutions. These solutions would necessitate additional hardware and effort by the design team, but were simple to implement at relatively low cost. These other solutions provided communication abilities through more traditional methods such as RC or analog control.

The skid steering of the vehicle gave the design team two options when it came to motor controller configurations. Either it would be necessary to have a motor controller that could survive both motors at the same time, or two motor controllers that could both handle one motor at a time. The design team was concerned that this second configuration may not work with RC motor controllers due to interference, but some investigation revealed that this should not be too much of a problem.

The AX2550 is relatively expensive at $495 and that fact alone made it one of the least favorable options. The unit also had a lot of functionality which would not be used by the design team. This functionality also presented a problem to our team advisor, because he was concerned that the team was not efficiently balancing the make or buy decision. Nevertheless this piece of equipment had several qualities which made it stand out. First, it could communicate using an RS232 commands and it was able to control two motors at once. Additional it could handle 80 amps continuous and current spikes up to 120 amps per channel, and it could step the voltage supplied by a 12 volt battery to the required 24 volt. Also supported by this motor controller was PWM and battery regeneration. These abilities of the motor controller would alleviate some of the power concerns of the vehicle, and in effect would eliminate the need for an additional battery. Furthermore, the motor controller could be configured to support a speed controlled inner loop.

A self-designed and constructed option was also considered for some time. A hybrid of this option was also considered. Both of these options would allow the design team to have a motor controller
that fit all the necessary specifications of the design. The self-designed option was immediately discarded because creation of this option would encompass as much of the team’s time as the rest of the project. The only option of this type which then remained was the hybrid option.

This hybrid option would use a motor controller built for controlling smaller RC cars, and add hardware so that it could supply the necessary current to the motors. This option would take significantly less time than the other, but it was not without its shortcomings. Transistors that could carry the amount of current necessary were hard to find and very expensive. Along these same lines the safety of the design would be in question. Any mistake on the part of the design team could result in personal injury or the destruction of the motors.

The RC Victor series was the only RC/Analog variation that the design team considered in the final decision. This motor controller could control only one motor at the time, but had a significantly lower cost than the serially controlled options. Two of these could be used along with a RC mixer to provide the control of the separate motors. This final configuration would be around 10% cheaper than most of the other options. To implement this final configuration the design team would have to create additional hardware to communicate with the motor controllers, so the final price would probably be around $500. These motor controllers could more than support the necessary current at around 120 amps continuous with surge protection up to 300 amps. This level of safety margin was attractive, but the controllers lacked an inner loop control.

The OSMC motor controller is a build-it-yourself motor controller kit. This kit would save the design team money over buying a final product and would allow for some personal customizations. The final device would fit along with many of the specifications of the design team. The device could only communicate using RC or analog control, but because it was a build-it-yourself kit RS232 capabilities could be added with relative ease. The listing for the device claimed that it could more than handle the necessary current for operation. Much like the Victor series, this controller lacked inner loop control capability. Once again because it was a build-it-yourself kit with a little work this could also be implemented. The OSMC can control two motors at a price of $450. This price could move up or down depending on what additional hardware was added to the design. On the downside, the safety concerns which plagued the self design alternatives were present with this controller. If the design team was to make a mistake during construction the motor controller would be unsafe.

The Vantec CFDR controller was the only other controller with RS232 communication capabilities that was considered. The cost of this controller was much less than the others at only about $350. This reduction of cost did come with a sacrifice of functionality. The device could only support around 30 amps continuous with current surge protection up to 70 amps per channel. With some work the
design team could make sure that the motors did not break this threshold, but this would leave little of a safety margin. The controller also had no support for an inner loop control system.

### 7.2.4.3.3. Decision

The design team itself had a rough time making this decision. Much of this difficulty stemmed from the lack of experience that the team had with systems such as this. This difficulty made it almost impossible to write an appropriate design matrix. In order to make the final decision the team had to rely on its mentors along with additional sources to decide on the best option. The main question the design team wrestled with was whether or not an inner loop control system was truly necessary, and if so, was it worth the extra cost. Mr. Washburn expounded upon his previous explanation of why this feature could prove necessary and further cautioned that its deletion could cause many problems. He offered many examples of things that could go awry if this was not included, but he left the decision to the design team. This advice was supported by Professor Ribeiro and gave the design team enough information to write an appropriate design matrix.

<table>
<thead>
<tr>
<th>Table 5 - Motor Controller Design Matrix</th>
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</thead>
<tbody>
<tr>
<td><strong>Communication</strong></td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>Victor</td>
</tr>
<tr>
<td>CFDR</td>
</tr>
<tr>
<td>OSMC</td>
</tr>
<tr>
<td><strong>AX2550</strong></td>
</tr>
<tr>
<td>Self-Built</td>
</tr>
<tr>
<td>Hybrid Self-Built</td>
</tr>
</tbody>
</table>

### 7.2.4.3.4. Implementation

The implementation of the motor controller was pretty simple. By following the manual ADD was able to set up the motor controller and get some preliminary software for motor controller communication written fairly quickly.

### 7.2.4.3.5. Testing and Integration

Initial testing with motor controller communication was done with encoder count retrieval. Testing of this function was done by displaying the encoder counts while a member of the design team spun the wheels. Since most of the other motor controller functions work in a similar manner to this one it was relatively simple to build the rest of the functions using the proven encoder one as a template. The changing of the motor power was tested by suspending the front end of the vehicle and then sending motor power commands. After this testing was complete a program was written that simply drove the car...
forward a specified distance in meters. This test gave the design team valuable data for further design of the vehicle and ended up being used almost daily. With this program ADD was able to determine that the speed of the vehicle was directly proportional to the percentage of total motor power. This linearity was then used to translate desired velocity in metric units to motor power commands to be sent to the motor controller.

Additionally this program was used to troubleshoot the problem of the vehicle drifting sharply to the right. This drift was caused either by the inequalities of the drive motors or an offset center of gravity, but despite the cause software compensation was needed. The design team ran the vehicle using the forward test and measured the drift that resulted at different motor powers. Using this data the design team was able to discover that the amount of compensation needed for the right motor to be about 0.75% to 1.5% depending on the speed of the vehicle.

### 7.2.4.4. Power

#### 7.2.4.4.1. Criteria

The power system for the vehicle must provide sufficient power for multiple runs of the course. This involves the navigation and the obstacle avoidance course. The navigation course allows for 3 runs at a maximum of 7 minutes per run. The obstacle avoidance course allows for up to 9 runs with 5 minutes per run. This means that the vehicle could possibly be running for 60 minutes. From the calculations shown in Table 6, the current consumption of the components on the car is 54.20 Amps. From ADD’s design norms, the power system to be used should produce as little harmful emissions to the environment as possible. Also in order to enable testing of the vehicle, the power systems must be rechargeable in some way.

<table>
<thead>
<tr>
<th>Item</th>
<th>Number</th>
<th>Current (mA)</th>
<th>Total Current Consumption (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encoder</td>
<td>2</td>
<td>80</td>
<td>160</td>
</tr>
<tr>
<td>GPS</td>
<td>1</td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td>Camera</td>
<td>2</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>Digital compass</td>
<td>1</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Computer</td>
<td>1</td>
<td>2000</td>
<td>2000</td>
</tr>
<tr>
<td>Emergency stop remote</td>
<td>1</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Illumination</td>
<td>5</td>
<td>40</td>
<td>200</td>
</tr>
<tr>
<td>Motors</td>
<td>2</td>
<td>25000</td>
<td>50000</td>
</tr>
<tr>
<td>Motor controller</td>
<td>1</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>PCB</td>
<td>1</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>LCD Monitor</td>
<td>1</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td><strong>Total Current (A)</strong></td>
<td></td>
<td></td>
<td><strong>54.20</strong></td>
</tr>
</tbody>
</table>
7.2.4.4.2. Alternatives

Two possible solutions for the criteria stated above are a generator or battery. The generator uses some sort of gasoline engine to run an alternator that would power the vehicle. One benefit of the system is that lengthening the run time of the vehicle simply involves adding a larger fuel tank. One of the disadvantages of the generator is that it produces emissions that are harmful to the environment. Complexity is another downside of the generator solution. The generator would also produce noise that would limit the times when ADD could run the vehicle. The generator power option would also have a recurring cost from fuel purchases.

One or multiple batteries is the second possible power option. Batteries provide a good power to weight ratio and can handle current spikes well. Batteries also do not produce significant amounts of harmful emissions directly (the power plant used to charge the batteries may however). Batteries would not have the recurring cost associated with the generator since the batteries can be recharged at the college. A downside to the battery option is that it provides a limited amount of energy. If one battery will not provide the necessary energy required for the competition a second battery must be added. Thus batteries do not have the run time flexibility provided by the generator.

7.2.4.4.3. Decision

After weighing the two options, ADD chose to use a battery system to power the vehicle. The battery system met the team’s design norms, especially about keeping pollution to a minimum. Also the motor controller that ADD decided to use must have a power system that supports regeneration. Regeneration is supported on car batteries - all cars recharge their batteries while the engine is running. A generator system can bypass the regeneration system but this would have increased the complexity of the system and wasted energy.

Several different battery choices were investigated by ADD. Some vendors provide two types of automotive batteries, starter or deep cycle. Deep cycle batteries were ideal for this project because they are designed to be fully discharged before being recharged. Starter batteries, on the other hand, are designed to be using during the ignition of the engine and thereafter recharged to their previous state. ADD found a battery from Optima Batteries that met the criteria specified above. The Optima Battery D34 provides a nominal voltage of 12 volts and a capacity of 55 Amp hours. ADD estimated that the current consumption of all the components of the vehicle to be about 54 amps. Dividing the rating of the battery by the current consumption of the vehicle gave 1 hour of run time. Therefore this battery was determined to be able to provide energy to power the vehicle throughout the whole competition. The
regeneration support of the motor controller also gave ADD a factor of safety and increased the run time of the vehicle.

7.2.4.4.4. Implementation

The original overall design of the vehicle contained one 12 volt battery. After the team decided to power the computer using an inverter, a new 12 volt car battery was needed. Due to load strains from the motors and inverter a third 12 volt battery was needed to power the motor controller. The original 12 volt car battery is rated for 105 Amp hours. This battery is used to power the headlights and the motors. The additional 12 volt marine battery is rated for 55 Amp hours and powers the PCB, the wireless E-stop circuitry, and the inverter. The third battery powers the motor controller. The purpose of the third battery is to keep a constant twelve volts powering the motor controller so that it never shuts off when there are high demands on the other batteries.

7.2.5. Obstacle Avoidance

7.2.5.1. Software

7.2.5.1.1. Criteria

The obstacle avoidance software is in charge of planning and implementing the obstacle avoidance path of the vehicle. The criteria are quite self-explanatory. When the obstacle recognition software locates an obstacle\traffic line the avoidance software must react to this object in an appropriate manner.

7.2.5.1.2. Alternatives

Reactive obstacle avoidance is a possible way of implementing this system. This type of avoidance is usually implemented with proximity sensors, but can be supplemented by the recognition system. When a sensor has detected an obstacle the software would determine the location of the sensor detecting an obstacle and communicate to the navigation software that it must turn the opposite direction of the sensor. The strengths of this method are that avoiding obstacles is reduced to only turn left or turn right decisions. This type of avoidance could then be easily integrated with the control system of the vehicle and would not rely heavily on visual recognition (except for lines and potholes). The IGVC does not look highly on this method, and states that the vehicle should exhibit “intelligent driving behavior.” This type of obstacle avoidance behavior does not seem very intelligent because it does not consider the future course in its obstacle avoidance decisions. However, this method is seriously flawed for additional reasons. Proximity sensors have a tendency to provide false detections. These false detections would
cause problems with this type of scheme. In terms of money, this method also requires at least four proximity sensors and these sensors are too expensive. The design team cannot afford the quality of sensors in the large amounts the vehicle would need.

A possible method is to have two separate control systems. A navigation control system and an obstacle avoidance control system. The navigation control system would be a simple control system concerned with navigating between waypoints, and the obstacle avoidance control system would be concerned with only avoiding obstacles. When an obstacle is detected, the obstacle avoidance control system would interrupt the navigational control system and control the vehicle. Once the vehicle had avoided the obstacles, it would return control to the navigation software. This obstacle avoidance control system would be very difficult to design, but it would keep navigation and obstacle avoidance apart from each other. This would aid in ease of integration down the line, and make them easier to develop separately. This method has its disadvantages because the steering control would have to be implemented twice which implies that there is a better way to do this.

Another method would be to implement a different navigational control system which is also concerned with avoiding obstacles. The obstacle avoidance routines are incorporated into the control of this system, and using the additional obstacle information this control system can steer the vehicle around obstacles. This type of obstacle avoidance is fraught with more weaknesses than strengths. First off, due to the dynamically random nature of the course design of a robust obstacle avoidance and navigation control system would be painful if not futile. Secondly, this type of obstacle avoidance only seems to work with the alternative presented above, so it mainly focuses on reactionary avoidance. The strength is that there is only one control system for the vehicle which simplifies the control.

The final method investigated by the design team was a very simple idea which could work very well. This simple solution eluded the design team for awhile and a lot of effort was placed on some of the other alternatives. This method involves letting the navigation software steer the vehicle from waypoint to waypoint. The obstacle avoidance software runs in the background and when it detects an obstacle it adds or deletes waypoints to make the vehicle avoid it. The navigation control system then continues to navigate between waypoints. The path of the vehicle has changed, but this operation is mostly transparent to navigation. This is because navigation does not care what waypoints it is using it is only concerned with steering the vehicle between the waypoints it has. The advantages of this type of obstacle avoidance are that it keeps the avoidance of obstacles simple, and utilizes another system of the vehicle that will have to be implemented anyway. By its nature it is separate from navigation so it can be developed separately and in parallel. Because of this the obstacle avoidance software can be made more complicated or simplified without affecting the other aspects of vehicle control. The disadvantage is that the deletion of waypoints and addition of virtual waypoints can be a very complicated algorithm.
7.2.5.1.3. Decision

The design team naturally decided on the last option. It can be seen that this option has many benefits over the others. An implementation was needed that could consider future events because the IGVC has been known to place traps for vehicles which do not consider this. This option was one of the only options which could actually consider future events in its avoidance algorithm without a lot of work by the design team. The overall elegance of this approach also gave it much appeal. Because the algorithm can be amazingly complicated, the design team focused on creating a very simple algorithm to delete and add waypoints at first with the goal of making a more complicated algorithm. This original algorithm was designed to avoided obstacles, however it used sharp turns and some jerky behavior.

7.2.5.1.4. Implementation

ADD ended up implementing a simple path decision algorithm to decide the new heading, which was then used to calculate a new waypoint. The basic algorithm of finding a path is that it tries to continue heading straight as far as possible. If it comes to an obstacle it backs up a little and then scans to the right and left to see which way it could go further. It then scans across from current position to that direction, finding where it would first come into contact with an obstacle, and then goes slightly within that obstacle. This allows the vehicle to go through the turn close to the apex of the turn.

7.2.5.1.5. Testing and Integration

Integration of obstacle avoidance was pretty simple since it was done in the same class of the obstacle recognition so everything was already there. The single output of the obstacle avoidance is the new heading which is passed on to navigation that then calculates a waypoint for that heading.

Testing of the obstacle avoidance was done by drawing a course of obstacles on a piece of paper and then moving the camera through the course trying to follow where the software suggests to drive. Also, there was some testing done with the actual vehicle by driving the vehicle in the direction suggested by the software with the joystick.

7.2.6. Operating System

7.2.6.1. Criteria

The timing constraints of the vehicles control system, and the sheer amount of processing that some of the parts of the code would need to function dictated that the design team needed a deterministic operating system. Cost of the operating system and the cost of support was an important part of the criteria. Available development software was another aspect that concerned the design team since several of its members are avid supporters of Visual Studio.
7.2.6.2. Alternatives

Windows or Windows CE are both two possible commercial operating systems which could be made to run in a deterministic fashion. Both of these are readily available and the relatively easy to install. Both versions were available for free download at Calvin College, and support for these products is readily available for those who are willing to pay. The design teams has had a significant amount of experience with the Windows environment, and though ADD was willing to choose a different operating system it would be hard to dethrone this option. This option would also allow the design team to develop with Visual Studio, which some members of the team desired.

RT Linux from FSM labs is a patch to the Linux kernel to give it hard real time capabilities. It was built on top of the Linux kernel so anyone who could compile a Linux kernel should be able to compile the OS. Linux is open source, therefore this option would be completely free and support would be readily available in public forums on the internet. Unfortunately we would have to use an older Linux kernel because the patch would not support newer kernels. Also the design team had cumulatively little experience with the Linux OS and so the migration to this operating system would be a little difficult. Additionally it had a POSIX interface which would speed up the integration effort.

RTAI Linux is a similar operating system to RT Linux, and in fact RTAI Linux is built on top of RT Linux. The lack of a POSIX or even POSIX like interface was its one major drawback.

7.2.6.3. Decision

Originally the design team had decided to go with Windows CE for simplicity, but after discussing this option with the team’s advisor and mentors this decision returned to the table. The design team had no experience in this type of operating environment and so much research was needed to come to a conclusion on this decision. After some research, the Linux alternatives proposed above were discovered to be the top two choices for this type of application. Windows was unable to guarantee the response which was needed by the vehicle and the use of Windows was discourage by the teams mentors, therefore a Linux platform was to be chosen. More digging revealed the benefits inherit in POSIX compliant programming and the time savings that it would net the design team so it was an easy decision. RT Linux was the final choice because the POSIX interface would simplify integration and allow the team to install the operating system faster.

7.2.6.4. Implementation

Implementing the OS of the vehicle was not as easy as planned. Initially several members of the design team had trouble compiling the patched kernel. After many hours of work and hacking some of the kernel code ADD finally had a stable install.
7.2.6.5. **Testing and Integration**

Disturbingly, much of the online documentation for RT Linux was either too outdated or blatantly wrong. This compounded the other problems ADD was having with this OS as the coded modules would not compile without strange warnings, and operation did not seem very deterministic. Eventually this was discovered to be a devastating problem. The operating system was effectively starving some of the most important threads of the program, and the vehicle was unable to navigate without oscillations. As a last ditch effort the week before senior design night the design team decided to try to port to our second choice OS. The port was not easy and it has been fraught with many unexpected problems. Most of the problems came from the fact that the team was doing a lot of serial communication with external hardware, and RTAI Linux had its own serial functions. These functions did not provide similar functionality to their POSIX counterparts in any way, and were also incredibly different in their function calls. The lack of a blocking read definitely made the serial interaction with outside hardware all the more interesting. These problems and the odd interface of RTAI caused the design team to have to rewrite significant portions of code in an effort to finish the port. Currently the design team has successfully ported all of the individual threads themselves into RTAI Linux, and has tested them to verify that they are operating correctly in hard real time, but system integration has posed a problem. The program has a couple of unresolved bugs which cause weird things to happen during execution of the program.

7.2.7. **Emergency Stop System**

7.2.7.1. **Printed Circuit Board**

7.2.7.1.1. **Criteria**

The PCB shall handle all of the hardware e-stop functionality required on the car. It shall be less than 8 x 8 inches in size. The PCB shall route all of the connections between the compass, the GPS, the motor controller, and the computer. The PCB shall route the wireless e-stop signal to the appropriate pin on the computer and to the motor controller.

7.2.7.1.2. **Alternatives**

Calvin College has a board making facility that is available for student use. The software that the team is able to use is capable of creating and routing boards up to a maximum size of 3.8 x 6.9 inches. Since no one on the team has any experience in designing the PCB boards it is likely that it will be a timely process.
ADD also has the option of sending out the board. There are several companies such as Advanced Circuits and Photo Express that specialize in board layout and manufacturing. The design team could have sent their schematics to one of these companies and the board would have been sent back within a week. The main problem was that Professor VanderLeest wanted the team to design a major hardware component.

7.2.7.1.3. Decision

After talking to several of their mentors, ADD decided that they would create their PCB at Calvin College. The outside companies were too unreliable. If the board was delayed at the company’s end it would delay the team’s testing considerably. Since all of the components listed in the criteria pass signals through this board it was imperative that the team have the board as quickly as possible.

Add also decided that designing the board themselves gave them more lead way to change future designs. If any new hardware needed to be added or edited the board layout would be in a format that could be used at Calvin’s board making facilities. If the board had to be sent out again then the team would have to post pone testing, redraw the schematic, and resend the board to the company. This process would take more time then the team had.

7.2.7.1.4. Implementation

The primary purpose of the printed circuit board is to provide a safety redundancy in the interface between the computer and the emergency stop mechanisms. The board holds an 84-pin Altera chip, a parallel connector for communication with the computer, a 9-pin serial connector for communication between the computer and the motor controller via the board, one 9-pin serial connector each for the GPS and digital compass to communicate with the computer, a 15-pin serial connector to communicate between the computer and the motor controller via the board, six relays for controlling lights on the car and powering GPS and digital compass, three 12-pin terminal strips for connecting external wires (both signal and power) to the board, and the peripheral circuitry necessary to support all of this.

When a state of emergency stop is signaled from one of the e-stop buttons on the vehicle or the wireless e-stop button, the Altera chip receives the signal and communicates e-stop to the computer, which sends an emergency stop command to the motor controller in turn. After receiving the e-stop signal, the Altera chip waits 662 ms and sends its own e-stop signal to the motor controller. This redundancy ensures that the vehicle will be emergency-stopped electrically even if the computer were to lose power while the vehicle was operating.

The serial connector with which GPS information is communicated to the computer is only connected to one of the terminal strips. This is also true of the digital compass. This is so that most of
the wiring in the vehicle is consolidated onto this single board. Similarly, the 9-pin serial connection from the computer for the motor controller is sent directly to the 15-pin serial connection to the motor controller, with one small addition: The redundant e-stop signal from the Altera chip is added to the 15-pin serial connection on the board.

The Altera chip controls six single-pole double-throw (SPDT) relays on the board. The control circuitry for each relay contains one LED, which indicates when the relay is activated. The LEDs are color-coded in reference to the function of their respective relays. The relay with the red LED is used to control the autonomous operation strobe light, as that light is red. The relay with the blue LED is used to control the obstacle detection strobe light, as that light is blue. The relay with the yellow LED is used to control the headlights, as the headlights are somewhat yellow. The two relays next to each other with green LEDs are used to control power to the GPS and digital compass. The third relay with a green LED is a spare, and was included on the board in case further functionality is desired of the board. In this case, one would have to alter the VHDL in the Altera chip and place a jumper on the board to control this relay.

The fuse is used to provide limited current to the GPS and digital compass. Since each unit is powered with 12 volts and typically draws considerably less than 100 milliamp, a 1 amp fuse is used to protect the board.

7.2.7.1.5. Testing and Integration

Primarily, the PCB testing consisted of continuity checking. When that was completed, the subcircuits were tested by applying power to the proper node. The functionality of both the relay itself and the indicating LED were checked by applying the proper driving voltage to the correct node of the circuit. Finally, the functionality of the Altera chip on the board was checked.

The first problem the design team had with the board was reading a constant voltage of two volts when twelve volts were applied to the power inputs. This problem was quickly fixed. The next problem occurred when a trace lifted off of the board. This problem was fixed and the board was quickly restored to a working status.

7.2.7.2. Programmable Logic Device

7.2.7.2.1. Criteria

The Programmable Logic Device (PLD) used on the PCB shall cost less than $30.00. It shall also be a chip that the team has already had some experience with. It shall have low power functionality and sufficient pins for the control of the various lights and navigation devices. It shall be programmable using equipment available at Calvin College. The device must also be able to operate at 5 volts.
7.2.7.2.2. Alternatives

The number of PLDs available is large. The criteria stated above, however, limit the PLD to Altera devices since they are the only devices that Calvin College currently uses. There are many different Altera chips and families. The MAX7000 family is a 5 volt family with many different speed grades and package types. This family is really the only viable option for the cost and experience criteria.

7.2.7.2.3. Decision

The Altera chip chosen was the EPM7128SLC84-7 part of the MAX7000 series. It is a 5.0 volt EEPROM based chip with 84 pins in a PLCC package of which 68 are usable. The chip has 2,500 usable gates and provides 128 macrocells. The maximum clock speed of the device is 125 MHz. It is included on the Altera University Program 2 board. Calvin College participates in the Altera University Program and has a number of these boards. This allowed for easy programming via the onboard JTAG support and testing.

7.2.7.2.4. Implementation

Very High Speed Integrated Circuit Design Language (VHDL) was used to program the functionality of the chip. This language was well known to the design team and was a natural choice for the chip. Quartus II, software from Altera for compilation and simulation of VHDL code, was used to verify the written code. Some of the chips parameters were also adjusted using this software. For instance, the chip has a low power option that was set. This low power option allows for the macrocells to operate at 50% power while only incurring a nominal timing delay. The Quartus II software was also used to program the chip via the University board’s JTAG interface.

7.2.7.2.5. Testing and Integration

The initial functionality of the chip was tested on the university board using the built-in switches and LEDs. The board has a 25 MHz oscillator which was the only issue that the testing team needed to take into consideration. The E-stop signal speed on the university board was 25 times faster than the speed that it was going to be on our custom made board. After verifying the functionality on the University board the chip was placed on our custom board. ADD made a program that ran the vehicle forward at a slow speed and verified the functionality of the e-stop system.

The chip and board were then fully integrated into the vehicle. The board worked for about a day and then the board experienced some problems. The computer was no longer able to access the GPS or compass. The voltage on the pull-up resistors was tested and was not the correct value. The team then realized that the Altera chip was very warm. This lead the team to determine that the power on the board
was not as it should be. The board was removed from the car and debugged. A new Altera chip was programmed and placed on the board and the board was once again integrated with the car. After resolving these problems the board has performed well and has had no further issues.

7.2.7.3. **Wireless Emergency Stop System**

7.2.7.3.1. **Criteria**

The wireless E-Stop system must have a minimum range of 50 feet. It must use radio frequency to transmit the emergency stop signal. It must have some system to allow for changing channels or decreasing the interference caused by other wireless systems. The wireless system may be encrypted to prevent malicious people from activating the e-stop system. The system should also allow for multiple transmitters and should run off of a 12 volt unregulated or 5 volt regulated power source. The system must also have multiple buttons to allow for emergency stop as well as resume.

7.2.7.3.2. **Alternatives**

One wireless E-stop system is the Rolling Code 4-channel UHF Remote Control. This system is a kit that the team must build themselves. This system meets all of the criteria. The only drawback with this system is that the team needs to build it from the kit.

The secondary E-stop system is the E400/R400. This system exceeds the criteria set above. The power voltage is 12 volts and the transmitter draws 500 milliamps per hour, which is causes the power dissipation in this system to be higher than the first E-stop system.

The third system was the Rolling Code 10- channel UHF Remote Control. The only difference between this system and the first system described is that it has ten channels instead of four.

7.2.7.3.3. **Decision**

The decision was fairly simple. ADD had a total of three choices to decide between. The E400/R400 choice was more expensive and drew more power then the other two systems. It had a lot of features that went beyond the criteria, which would have been nice, but unnecessary. The ten channel UHF remote control was not necessary either because the team only needed four channels. Using a process of elimination, the Rolling Code 4-channel UHF Remote Control was the only choice left. It met all of the requirements and only cost the team $40. With this system the team has the capability of purchasing extra transmitters at $15 a piece.
7.2.7.3.4. Implementation

The wireless E-stop system was connected to a twelve volt battery. A ground wire was connected to the common input of one channel. On that same channel a wire connected the normally open pin to the PCB E-stop input and to the common input of the second channel. Another wire connected the second channel normally open pin to the motor controller e-stop pin. This setup ensured that when the wireless e-stop button was pressed the correct pin on the board was set low. If for some reason the board did not correctly send the command to the computer or the computer did not correctly implement E-stop the user had the ability to hit the second channel button and bypass the PCB board. This would send the ground signal straight to the motor controller for a quick stop of the motors.

7.2.7.3.5. Testing and Integration

The wireless e-stop circuit was tested in much the same way as the team-made PCB. After the wireless e-stop kit was assembled, it was continuity-checked, and then both states (normally open/normally closed) of each of the four relays (one per channel) was checked for proper functionality while in each of the two jumper states. Each channel can be in either latched mode or momentary mode, which is determined by the placement of a jumper on the board. Since each channel has its own jumper, some channels can be in latched mode while others are in momentary mode. In latched mode, when the button for the given channel on the remote is pressed, the relay is activated. The relay is not deactivated until the button for that channel is pressed again. In momentary mode, the relay is activated as long as the button is pressed, but as soon as the button is released, the relay is deactivated again. Each relay was found to function properly while in each of the four possible states.

7.3. Overall System Testing

7.3.1. Vehicle Drift

When running straight forward, without being given any turning commands, the vehicle “drifts” to the right. This is because, even though the motors are the same model, they are not perfectly identical. It turns out that the motor on the left side of the vehicle (from the vehicle’s standpoint, facing forward) is slightly stronger than the motor on the right side of the vehicle. Thus, when the motor controller is given commands to apply equal power to each motor, the left wheel travels farther than the right wheel, so the vehicle turns slightly to the right. To correct this, the error, dependent on motor power, needed to be determined. The team did this by commanding the vehicle to travel three meters forward, at a given motor power. The team then read the encoder counts (number of clock ticks produced by the encoder over a given distance) for each encoder. This was done for every five percent of motor power, from five to sixty. This information was entered into an Excel spreadsheet, and the ratio between the left and right
encoder counts was determined and graphed (see below in Figure 4). These ratios were used to form a look-up table, which is used to increase the power of the command sent to the right motor, so that, while the left and right motors now receive different commands, their performance will be the same.

![Figure 4 - Encoder Count Ratio vs. Percent Motor Power](image)

7.3.2. PID

The two PID controllers on the vehicle are both implemented entirely in software. One PID controller is for translational (forward) movements and the second PID controller is for angular (turning) movements. Since the car itself is a very complex model only approximate PID values were obtained using mathematical models. After asking the Control System Professor at Calvin College and the teams mentors at Smiths Aerospace the team determined that the only method of determining adequate PID values was to guess-and-check.

The first PID controller tuned was for translation speed control. The goal of the tuning process was to control the vehicle’s acceleration speed. The team was attempting to have the vehicle accelerate to the desired speed without overshooting and then continuously traveling at a relatively constant speed. With poor values used, the vehicle would accelerate, then decelerate, then accelerate again, then decelerate again, etc., until the vehicle was stopped. After tuning the PID values to nearly optimal
conditions the vehicle would get up to speed, with little to no overshoot, in approximately half of a second where it remain very close to the correct speed for the remainder of the drive.

The second PID that needed to be tuned was the angular controller. The goal of tuning this PID was to have the vehicle be able to turn to a desired heading without overshooting this heading and then staying relatively close to the desired heading. This controller was tuned several times. The team’s first attempts at tuning this PID controller were very successful. The team created a difficult path for the vehicle to maneuver inside of a building. This path consisted of numerous turns and narrow spaces for the car to fit. The car was successfully able to maneuver around this path with no human intervention.

Once the vehicle’s body was constructed and the vehicle moved outside the same PID values were tried, but it was clear they needed to be changed. The vehicle continued to oscillate continuously around the desired heading. The team was able to determine several reasons that the same PID values were not working as they had inside. The first reason was because the body of the vehicle added additional weight to the rear. The proportional term needed to be increased to compensate for the additional weight. The second and main problem that the angular PID faced was thread starvation. During the inside test of the vehicle the navigation software was the only software running. When the obstacle detection and avoidance software was incorporated into the code the navigation software was not able to update as reliably. During the inside test the navigation software updated at approximately 20 Hz, as opposed to the sporadic 5 to 15 Hz update speed outside. This caused the PID control to have increased oscillation. Due to this last problem the team needed to change operating systems to RTAI Linux before continuing to test the angular PID controller.

8. Conclusion

In conclusion, ADD has accomplished many tasks during the last nine months. They have designed and built a working vehicle, which very closely resembles a truck, with a team of four electrical engineers and one computer science major. The amount of work accomplished on this project was enormous for a time span of nine months. Many of the software sections of the design have been tested to be working by themselves; including navigation, the waypoint queue, and the obstacle recognition. When integrating these various classes and functions together they do not work as well together. However, the team still has one month before the competition. This means that if the team can get the various functions and classes to work well together ADD can still enter the IGVC as previously planned.

9. Recommendations

The mechanical design of the car was adequate for this team of electrical engineers. There were several mechanical aspects that could be updated that would significantly help the project as a whole.
Even though the left shaft has not broken in a significant amount of time, the team feels as if it will eventually break again. A true solution to the shaft problem is to redesign how the motors are mounted to the frame and determine a better wheel mounting system that does not put so much stress on the shaft itself. These fixes would allow the team to continually test the vehicle without having to worry about the shaft slipping inside of the tires.

The team’s rear caster wheels could have been changed also. These wheels were relatively cheap in price and also in quality. The ball bearings on the inside of caster were loose and the wheels were actually slanted inwards during the vehicles travel causing unwanted drift and other various side effects.

The body of the car is rigid and sturdy, but the frame could be adapted so that it is easier to take the side panels off. Currently the car looks good and it is water resistant, however, if a team member needs to access a component inside of the car it will be very difficult since the side panels can not be removed without damaging the water resistant sealing.

One other possible improvement is to have real roll bar lights attached to the roll bar. The design team was going to implement these, but the problem was that the team ran out of time and could not order the lights to come quickly enough. They would bring more aesthetic value to the vehicle.

The software and algorithms of the vehicle code be improved in many areas to numerous to mention here, but some possible improvements to the system are to implement multiple cameras or the resolution of some of the longstanding bugs in the code. From an algorithm stand point, the current obstacle avoidance algorithm needs to be improved.

Some possible hardware improvements for the vehicle are also pretty numerous, but the team will list a few. Additional sensors can be added to the vehicles which do not require the use of visual recognition techniques to see the obstacles. The computer platform of the vehicle could be embedded to decrease its footprint, and increase specialization. A very nice hardware inclusion would be a microcontroller with multiple serial ports which could be programmed to act as a go-between between the CPU and the devices connected to the serial ports. This would eliminate a lot of the software which is dedicated to serial port interaction (three modules in all), and would save CPU time for the other processes.

10. Acknowledgements

Automated Designated Driver would like to thank the following people and companies:

- John Washburn, Frank Saggio, and Jerry Jakeway, all of Smiths Aerospace, for the time and thought they put into mentoring the members of this team;
- Smiths Aerospace, for furnishing the funding necessary to finance this project;
- Tim Theriault, also of Smiths Aerospace, for serving as the team’s industrial consultant;
• Professor Steven VanderLeest, for serving as the team’s faculty advisor;
• Bob Dekraker, for ordering the team’s parts;
• Dave Ryskamp, for teaching the team to MIG weld, and for teaching the team how to operate the equipment in the metal shop;
• Chuck Holwerda, for teaching the team to make a printed circuit board;
• Newark, for sending the team two 1 MHz clock oscillators for free;
• SAE, for giving the team four 24 threads/in. specialty bolts without charge;
• Andy Wallner, for donating headlights and giving the team ideas.
• Brohm’s Online Sales, for selling a power inverter to the team at cost;
• Formula K, for giving the team a go-kart frame;
• Professor Robert Medema, for arranging for the team to receive two free lights from SoundOff Signal;
• SoundOff Signal, for giving two free lights to the team, no questions asked;
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Enable Obstacle Avoidance and Path Planning

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Finalize

04/09/05 05/07/05
04/14/05 05/07/05
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Project: Timeline
Date: Sat 4/23/05

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Project: Timeline
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Appendix B.  Project Requirements

A. Course Requirements
   a. The team shall work efficiently as a team
   b. The design team shall learn about the engineering profession in the real world
   c. The design team shall learn more about the difference between engineering and engineering from a reformed perspective
   d. It is a goal of the design team to receive a good grade in the course
   e. The design team shall finish all necessary paperwork for the course in a timely manner

B. Final Design Requirements
   a. Physical Requirements
      i. Weight
         1. The basic assembled vehicle shall weigh less than 220 lbs
         2. The vehicle as a whole shall weigh less the 250 lbs. including the vehicle payload, cameras, and computer system
      ii. Size
         1. The length of the vehicle shall not be less than five feet
         2. The length of the vehicle shall not exceed seven feet
         3. The width shall not exceed four feet
         4. The height (not including antennas) shall not exceed six feet*
      iii. Performance
         1. The vehicle shall be unmanned
         2. The vehicle shall require no external inputs for operation
         3. The vehicle shall require no external power for operation
         4. The vehicle shall use no wireless output devices
         5. The vehicle shall be propelled by direct mechanical to ground contact*
         6. The vehicle shall carry a 20 pound payload mounted on top of the vehicle with dimensions 18”x8”x8”*
         7. The vehicle shall be able to travel at a speed of at least 7.5 mph on a level plane
         8. The vehicle shall be able to drive up and down inclines with a 15% gradient while maintaining vehicle speed
9. The vehicle shall travel at no more than 5 mph during competition*

iv. Stability
1. The vehicle shall be able to survive the rigors of competition intact
2. On-Board equipment shall be protected to minimize damage, vibration, and shock during competition
3. The vehicle shall be designed to facilitate potential repairs and replacements made by the design team

v. Environmental
1. The vehicle shall be able to operate from 32-100 F
2. The vehicle shall operate in the following weather conditions: fair, light to medium rainfall, and overcast
3. The vehicle shall not be able to operate in weather or daytime conditions which impair its ability to view the course ahead of it
4. The vehicle shall operate on grass and pavement

b. Power Requirements
   i. Main battery power shall be supplied by a deep discharge high capacity battery
   ii. It shall be rechargeable
   iii. DC battery power shall be used for propulsion
   iv. Computer power shall be derived from the propulsion battery
   v. All other voltages shall be derived from the propulsion battery, or provided by commercial batteries (9v, AA, AAA)
   vi. The combined battery weight of the vehicle shall not exceed 85 lbs
   vii. The vehicle shall have enough power for a minimum of 30 minutes of autonomous travel

c. Hardware Requirements
   i. Motor Controller
      1. It shall provide a speed controlled control system
      2. The motor controller shall be able to supply the motors with operating voltage and current of 24 volts and 0-40 amps
      3. The motor controller shall have means in place to prevent motor damage
      4. The motor controller shall be able to survive current spikes up to 80 amps.
ii. Emergency Signal Converter
   1. The emergency signal converter shall accept a stop command from the computer
   2. The emergency signal converter shall accept input from the remote control
   3. The emergency signal converter shall accept input from the push button
   4. The emergency signal converter shall signal emergency stop to the computer through the encoder serial converter and directly to the computer through a serial connection
   5. The emergency signal converter shall signal start/resume operation to the computer
   6. The emergency signal converter shall activate and deactivate the braking mechanism of the vehicle
d. Functional Requirements
   i. The vehicle shall be able to navigate using a set of GPS waypoints
   ii. The vehicle shall be able to avoid the obstacles of the IGVC as it navigates
e. Interface Requirements
   i. Remote Control
      1. The vehicle shall accept remote commands from a remote control
      2. The remote control shall be a push button control which utilizes a simple encryption scheme
      3. These commands shall be limited to start and emergency stop
      4. The range of the remote control shall be at least 50 feet*
   ii. Push Button
      1. The vehicle shall have an onboard emergency stop button*
      2. The emergency stop button shall be a red 1”-3” diameter push button
      3. The emergency stop button shall be located at the center rear of vehicle two to four feet above the ground*
f. Safety Requirements
   i. Vehicle
      1. The vehicle itself shall not pose a safety hazard (i.e. sharp edges)
   ii. External Emergency Stop
1. The vehicle shall stop within six feet after receiving the emergency stop signal*
2. Emergency stop shall be implemented with a high level of redundancy
3. If emergency stop is signaled from any subsystem, all subsystems shall implement their emergency protocols
4. The vehicle shall resume operation after the emergency stop button has been depressed and the start button on the remote control has been pressed

g. Economic Requirements
   i. The vehicle shall cost less than $5000
   ii. The vehicle shall cost the design team less than $4000

h. Time Requirements
   i. The preliminary prototype shall be completed by May 7th
   ii. The final prototype shall be completed by June 11th

i. Deliverable Requirements
   i. The design team shall include a basic users manual in the final design report
Appendix C. Navigation Block Diagram

Key

Motor Controller

GPS

GPS Sentence Parser

Lie Detector

Course Plotter

Digital Compass

Dead Reckoning

Filtering

Motor Control System (PID)

Emergency Stop

Navigation Points

Current Path/Position

Desired Path/Position

Serial to Computer

Serial from Computer

Data Flow

External Object

Hardware

Software

Data Object

Analog

Digital

Object

Software

Data Object

Analog

Digital

Object

External Object
Appendix D. Obstacle Detection Block Diagram

Key:
- External Object
- Hardware
- Software
- Data Object
- Analog
- Digital
- Data Flow

Diagram:
- 2-D Obstacle Map
- Combine
- Obstacle Position Triangulation
- Line Position Triangulation
- Obstacle Filtering
- Line Filtering
- Computer
- USB
- Camera

Flow:
- 2-D Obstacle Map to Combine
- Combine to Obstacle Position Triangulation
- Obstacle Position Triangulation to Obstacle Filtering
- Obstacle Filtering to Line Filtering
- Line Filtering to Computer
- Computer to USB
- USB to Camera
- Camera to USB
- USB to Computer
- Computer to Combine
- Combine to 2-D Obstacle Map
Appendix E. Motor Control Block Diagram

Encoder 1 → Motor Controller → Motor 1 → Computer
Encoder 2 → Motor Controller → Motor 2

Key:
- External Object
- Hardware
- Mechanical
- Analog
- Digital
- Motor
Appendix F.  Emergency Stop Block Diagram

Emergency Radio

Emergency Pushbutton

Hardware

Printed Circuit Board (PCB)

Motor Controller

Computer

Key

- External Object
- Hardware
- Software
- Data Object
- Analog
- Digital
- Data Flow
Appendix G. Obstacle Avoidance Block Diagram

Key
- External Object
- Hardware
- Software
- Data Object
- Analog
- Digital
- Data Flow

Emergency Stop

Critical Path

Emergency Detection

Conflict Detection

Navigation Points

2-D Obstacle Map

Current Path/Position

Navigation Points

Emergency Stop

Serial to/from Computer
Appendix H. PCB Schematic
Appendix I. PCB Schematic

Cimin College Senior Design
Team 3 2004-2005
Automated Designated Driver
Atera Design: Paul Bakker
PCB Layout/Assembly: Brian Bournia
Moral Support: Matt Huson, Dan Reussker, Nate Studer
Appendix J.  E-stop VHDL code

Date: May, 2005
Project: ESTOP

FILE ESTOP.vhd

LIBRARY IEEE;
LIBRARY work;
USE IEEE.std_logic_1164.all;
USE work.adder.all;
USE work.all;

ENTITY ESTOP IS
PORT:
  clock : in std_logic;  -- use 1 MHz oscillator
  estop_buttons_n : in std_logic; -- low to activate
  resume_n : in std_logic; -- low to activate
  shutdown_n : in std_logic; -- low to activate
  GPI : in std_logic_vector(7 downto 0); -- general purpose input
  gps_relay : out std_logic; -- control power to GPS
  comms_relay : out std_logic; -- control power to communicate
  autoslight_relay : out std_logic; -- control power to autonomous light
  obslight_relay : out std_logic; -- control power to obstacle light
  resume_comp : out std_logic; -- resume signal sent to computer
  shutdown_comp : out std_logic; -- shutdown signal sent to computer
  estop_comp_n : out std_logic; -- estop signal sent to computer
  estop_nc_n : out std_logic; -- estop signal sent to motor controller
END ESTOP;
architecture estopl of ESTOP is

-- Adder found in previous library
component adder
  port(
    data  : IN STD_LOGIC_VECTOR (23 DOWNTO 0);
    clock : IN STD_LOGIC;
    anr   : IN STD_LOGIC;
    clon  : IN STD_LOGIC;
  result : OUT STD_LOGIC_VECTOR (23 DOWNTO 0)
  );
end component;

-- Type declared to keep track of the reduced clock value
type clock_reduce is (full, half, fourth, eighth, sixteen);
signal state : clock_reduce;

signal count : std_logic_vector(23 downto 0);
signal count_temp : std_logic_vector(23 downto 0);
signal addone : std_logic;
signal clear_add : std_logic;
signal estop : std_logic;

begin
  add: adder port map(count, clock, clear_add, addone, count_temp);

process(clock)
begin
  -- GPI commands from computer to activate certain devices
  variable autolight_on : std_logic_vector(7 downto 0) := x"01";
  variable obslight_on  : std_logic_vector(7 downto 0) := x"02";
  variable gp_on  : std_logic_vector(7 downto 0) := x"03";
  variable compass_on : std_logic_vector(7 downto 0) := x"04";
  variable autolight_off : std_logic_vector(7 downto 0) := x"F1";
  variable obslight_off : std_logic_vector(7 downto 0) := x"F2";
  variable gp_off : std_logic_vector(7 downto 0) := x"F3";
  variable compass_off : std_logic_vector(7 downto 0) := x"F4";

  -- delay value was calculated to give about 1 second delay
variable startup : std_logic := '0';
variable delay : std_logic_vector(23 downto 0) := x"01FFFFFF";

begin
  if clock'EVENT and clock = '1' then
    -- state machine is to reduce clock to 1/16 original value
    case state is
    when full =>
      state <= half;
      addone <= '0';
    when half =>
      state <= fourth;
    when fourth =>
      state <= eighth;
    when eighth =>
      state <= sixteenth;
    when full =>
      state <= full;
    end case;

    -- After clock has been reduced to 1/16 of its original value
    if(estop_buttons_n = '0' or estop = '1') then
      estop_comp_n <= '0'; -- send estop to computer immediately
      estop <= '1';
      addone <= '1';
      count <= count_temp;
    end if;

    if(count = delay or count > delay) then
      estop_mc_n <= '0'; -- delay estop to motor controller
      count <= x"000001";
    end if;

    -- Resume functionality
    if(resume_n = '0') then
      resume_comp <= '1';
      count <= x"000001";
    end if;

  end if;
end if;

-- When estop has been sent to computer
if(estop_buttons_n = '1' and resume_n = '0') then
  estop <= '0';
estop_comp_n <= '1';
estop_mc_n <= '1';
end if;

else
    resume_comp <= '0';
clear_add <= '0';
end if;

--Shutdown functionality
if(shutdown_n = '0') then
    shutdown_comp <= '1';
else
    shutdown_comp <= '0';
end if;

--Autonomous light functionality
if(GPI = autolight_on and estop = '0') then
    autolightrelay <= '1';
end if;
if(GPI = autolight_off or estop = '1') then
    autolightrelay <= '0';
end if;

--Obstacle light functionality
if(GPI = obslight_on and estop = '0') then
    obslightrelay <= '1';
end if;
if(GPI = obslight_off or estop = '1') then
    obslightrelay <= '0';
end if;

--GPS functionality
if(GPI = gps_on) then
    gpsrelay <= '1';
end if;
if(GPI = gps_off) then
    gpsrelay <= '0';
end if;

--Compass functionality
if(GPI = compass_on) then
    compasrelay <= '1';
end if;
if(GPI = compass_off) then
    compasrelay <= '0';
end if;
end case;
end if;
Date: May, 2005

161 end process;
162 end estop1;
163
Appendix K.  E-stop VHDL simulation
## Appendix L. Bill of Materials

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Total = $4,113.90
Appendix M. User’s Guide

CAUTION!! BEFORE MOVING THE CAR MAKE SURE WIRELESS E-STOP IS IN HAND AND SOMEONE IS BY THE PHYSICAL EMERGENCY STOP BUTTONS!!!!! NEVER OPERATE ALONE!!

Instructions

1. Under Hood – on switch panel
   a. Turn on the Inverter (top left switch)
   b. Turn on the Compass/GPS (bottom left switch)
   c. Turn on the PCB Board (mounted switch by motor controller)
   d. Turn on the Computer (top right button)

2. Be sure that there are no LED’s lit on the wireless E-stop board (right side of car)

3. Press Resume on Remote Control (top Button)

4. Under Hood turn on motor controller

5. Close Hood

6. Once computer is booted up
   a. Autonomous Travel
      i. Open VLpoint2.txt
      ii. Add or subtract any GPS coordinates
      iii. Save and close
      iv. Run the program
   b. Joystick Travel
      i. Run the program

7. GUI
a. Both travel uses
   i. Status display first shows the current point that the vehicle is at
   ii. Future displays the GPS point that you are traveling to
   iii. The next section shows
      1. How far into the Waypoint Queue the vehicle is
      2. The total run time of the vehicle
      3. The velocity of the vehicle
      4. The highest Velocity of the vehicle
b. Joystick Travel
   i. If you want to drive with the joystick be sure the joystick is selected
   ii. If you want to have the camera’s view display on the screen keep obstacle
      recognition checked
   iii. Sliders control the filtering of camera
c. Autonomous Travel
   i. Be sure that all devices that are checked are actually present (GPS and Compass)
   ii. The upper GPS point can be used as a starting location if GPS is not present
   iii. The WPQ option allows you to edit VLPoint2.txt from the GUI.
   iv. Headlights allows you to turn on and off the headlights
d. After Travel Decisions
   i. When you are ready for the vehicle to either begin moving or you are ready to
      begin driving the vehicle with the joystick
      1. CAUTION!! BEFORE PROCEEDING MAKE SURE WIRELESS E-
         STOP IS IN HAND AND SOMEONE IS BY THE PHYSICAL
         EMERGENCY STOP BUTTONS!!!!! NEVER OPERATE
         ALONE!!!
   2. Press the Execute button
e. Once the car stops or E-stop is pressed
   i. To reset the wireless e-stop
      1. turn off E-stop (hit button again)
      2. Press Resume (top button on remote)
   ii. To reset physical e-stop
      1. release button or buttons that are pressed
      2. Press Resume (top button on remote)
   iii. Travel or Quit
      1. To continue traveling press execute again
      2. To quit operating and close the GUI press quit

8. Emergency Stop
a. If the vehicle represents erratic or unpredictable behavior and the run needs to be
   terminated before it reaches completion there are two ways to terminate the run
   i. Physical Emergency stop buttons on the back of the car. One on each side
   ii. Wireless Emergency stop button through computer( the button that is off by
      itself)
   iii. Wireless Emergency stop button straight to Motor controller. For this feature to
        work the emergency stop button in ii needs to be pushed and then the bottom left
        button also needs to be pushed. This causes the motor controller to
        instantaneously stop the car. (This form of E-stop is not recommended.)
Appendix N. IGVC Rules

Official Competition Details, Rules and Format

The 13th Annual Intelligent Ground Vehicle Competition (IGVC)

In memory of Paul Lescoe

June 11th-13th, 2005
Grand Traverse Resort and Spa
Grand Traverse, Michigan

Held in conjunction with the 5th Annual Intelligent Vehicle Systems Symposium & Exhibition. Student Teams are Invited to Display Their Vehicles at the Exhibition

Student Teams are Invited to Display Their Vehicles at The Association for Unmanned Vehicle Systems International’s Unmanned Systems North America 2005 Symposium & Exhibition Held at Baltimore Convention Center (Baltimore, Maryland) on June 28-30, 2005

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   I.3. NAVIGATION CHALLENGE COMPETITION
   I.4. PUBLICATION AND RECOGNITION

II. AUTONOMOUS CHALLENGE COMPETITION
   II.1. OBJECTIVE
   II.2. VEHICLE CONTROL
   II.3. VEHICLE SAFETY
   II.4. VEHICLE CONFIGURATION
   II.5. OBSTACLE COURSE
I. AWARDS AND RECOGNITION

(All vehicles must qualify for the Autonomous Challenge to be eligible for the Standard and Grand Award Money)

Short of the Money Barrel in the Autonomous Challenge, or short of 5 waypoints (and more than 2) in the navigation challenge, the performance points are 50% of the amount listed. A Grand Award, totaling $10,000, given to the team that does the best overall, in all three competitions. The Grand Award amount will replace all the individual Standard Award earned for that team. The team must have passed the money barrel and the minimum number of waypoints to be eligible for the Grand Award. For each competition, points will be awarded to each team, placing first, second, or third. Below is a breakdown of the points:

<table>
<thead>
<tr>
<th></th>
<th>First</th>
<th>Second</th>
<th>Third</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autonomous Challenge</td>
<td>15 points</td>
<td>10 points</td>
<td>8 points</td>
</tr>
<tr>
<td>Navigation Challenge</td>
<td>10 points</td>
<td>8 points</td>
<td>6 points</td>
</tr>
<tr>
<td>Design Competition</td>
<td>10 points</td>
<td>8 points</td>
<td>6 points</td>
</tr>
</tbody>
</table>
### I.1 AUTONOMOUS CHALLENGE COMPETITION

**Autonomous Competition Standard Awards**

<table>
<thead>
<tr>
<th>Place</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>1ST</td>
<td>$2,000</td>
</tr>
<tr>
<td>2ND</td>
<td>$1,500</td>
</tr>
<tr>
<td>3RD</td>
<td>$1,000</td>
</tr>
<tr>
<td>4TH</td>
<td>$750</td>
</tr>
<tr>
<td>5TH</td>
<td>$500</td>
</tr>
<tr>
<td>6TH</td>
<td>$250</td>
</tr>
</tbody>
</table>

**Nominal Award Money**

(Short of money barrel OR vehicle did not qualify)

<table>
<thead>
<tr>
<th>Place</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>1ST</td>
<td>$750</td>
</tr>
<tr>
<td>2ND</td>
<td>$500</td>
</tr>
<tr>
<td>3RD</td>
<td>$250</td>
</tr>
<tr>
<td>4TH</td>
<td>$0</td>
</tr>
<tr>
<td>5TH</td>
<td>$0</td>
</tr>
<tr>
<td>6TH</td>
<td>$0</td>
</tr>
</tbody>
</table>

### I.2 VEHICLE DESIGN COMPETITION

**Design Competition Standard Awards**

<table>
<thead>
<tr>
<th>Place</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>1ST</td>
<td>$1,500</td>
</tr>
<tr>
<td>2ND</td>
<td>$1,000</td>
</tr>
<tr>
<td>3RD</td>
<td>$500</td>
</tr>
</tbody>
</table>

**Nominal Award Money**

(Vehicle did not qualify)

<table>
<thead>
<tr>
<th>Place</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>1ST</td>
<td>$500</td>
</tr>
<tr>
<td>2ND</td>
<td>$400</td>
</tr>
<tr>
<td>3RD</td>
<td>$300</td>
</tr>
</tbody>
</table>

### I.3 NAVIGATION CHALLENGE COMPETITION

**Navigation Competition Standard Awards**

<table>
<thead>
<tr>
<th>Place</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>1ST</td>
<td>$1,500</td>
</tr>
<tr>
<td>2ND</td>
<td>$1,000</td>
</tr>
<tr>
<td>3RD</td>
<td>$500</td>
</tr>
</tbody>
</table>

**Nominal Award Money**

(Reached between 2 and 5 waypoints OR vehicle did not qualify)

<table>
<thead>
<tr>
<th>Place</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>1ST</td>
<td>$500</td>
</tr>
<tr>
<td>2ND</td>
<td>$400</td>
</tr>
<tr>
<td>3RD</td>
<td>$300</td>
</tr>
</tbody>
</table>
I.4 PUBLICATION AND RECOGNITION

International recognition of all participating teams through AUVSI and SAE publications.

Special recognition for the vehicles will be held at the AUVSI 2005 Symposium and Exhibits at the Baltimore Convention Center summer of 2005.

All teams are invited to display the winning vehicles in the AUVSI exhibit hall.

Videotapes & CDs of the competition event will be distributed to sponsors, media and the public.

II AUTONOMOUS CHALLENGE COMPETITION

All team vehicle entries must be designed for the Autonomous Challenge. All teams must qualify to receive Grand Award Money in all events.

II.1. OBJECTIVE

A fully autonomous unmanned ground robotic vehicle must negotiate around an outdoor obstacle course under a prescribed time while staying within the 5 mph speed limit, and avoiding the obstacles on the track.

Judges will rank the entries that complete the course based on shortest adjusted time taken. In the event that a vehicle does not finish the course, the judges will rank the entry based on longest adjusted distance traveled. Adjusted time and distance are the net scores given by judges after taking penalties, incurred from obstacle collisions, pothole hits, and boundary crossings, into consideration.

II.2. VEHICLE CONTROL

Vehicles must be unmanned and autonomous. They must compete based on their ability to perceive the course environment and avoid obstacles. Vehicles cannot be remotely controlled by a human operator during competition. All computational power, sensing and control equipment must be carried on board the vehicle.

II.3. VEHICLE SAFETY

- **Speed:** For safety, a maximum vehicle speed of five miles per hour (5 mph) will be enforced. All vehicles must be governed not to exceed this maximum speed. No changes to maximum speed control software and hardware are allowed after qualification.

- **E-Stop:** Each vehicle must be equipped with both a manual and a wireless (RF) remote emergency stop (E-Stop) capability. The wireless E-Stop must be effective for a minimum of 50 feet. The manual E-Stop must be easy to identify and activate safely, even if the vehicle is moving. Activating the E-Stop must bring the vehicle to a quick and complete stop (stopping distance not to exceed six feet on inclines up to 15%). Vehicles that are judged to be unsafe will not be allowed to compete.

II.4. VEHICLE CONFIGURATION
The competition is designed for a small semi-rugged outdoor vehicle (all terrain vehicle, golf cart, lawn tractor, etc.). Vehicle chassis can be fabricated from scratch or commercially bought. Entries must conform to the following specifications:

- **Mechanical E-stop location**: Center rear of vehicle at least two feet from ground, not to exceed four feet above ground. The E-stop button will be a push to stop, red in color and a minimum of one inch in diameter.

- **Length**: Minimum length three feet, maximum length nine feet.

- **Width**: Not to exceed five feet.

- **Height**: Not to exceed 6 feet (excluding emergency stop antenna).

- **Propulsion**: Vehicles must be propelled by direct mechanical to ground contact such as wheels, tracks, pods, etc. No air or hovercraft vehicles are eligible. Vehicle power can only be supplied by combustible fuel (gasoline, diesel, propane, etc.) or electric power. combustible fuel powered vehicles will not be run inside of tents or buildings.

- **Payload**: Each vehicle will be required to carry a 20-pound payload. The shape and size is approximately that of an 18" x 8" x 8" cinder block. Refer to section II.12 Payload.

### II.5. OBSTACLE COURSE

The course will be laid out on grass, pavement, simulated pavement, or any combination, over an area of approximately 60 to 120 yards long, by 40 to 60 yards wide. The course boundaries will be designated by continuous or dashed white and/or yellow lane markers (lines) approximately three inches wide, painted on the ground. Track width will be approximately ten feet wide with a turning radius not less than five feet. Alternating side-to-side dashes will be 15-20 feet long, with 10-15 feet separation.

Expect natural or artificial inclines with gradients not to exceed 15%, a sand pit (sand depth 2 - 3 inches) and randomly placed obstacles along the course. The course will become more difficult to navigate autonomously as vehicle progresses. The sand pit may be simulated with a light beige canvas tarp covering the entire width of the track for ten feet.

Obstacles on the course will consist of 5-gallon white pails as well as full-size orange and white construction drums, cones, pedestals and barricades that are used on roadways and highways. The placement of the obstacles may be randomized from left, right, and center placements prior to every run. Potholes will be two feet in diameter and two inches in depth and placed on the course. Simulated potholes are two feet diameter white circles, and may also be used on the course (Course width will be adjusted here to insure minimum passage width).

There will be a minimum of six feet clearance, minimum passage width, between the line and the obstacles, i.e. if the obstacle is in the middle of the course then on either side of the obstacle will be six feet of driving space. Or if the obstacle is closer to one side of the lane then the other side of the obstacle must have at least six feet of driving space for the vehicles.

Also in the event will be passable barricades as shown in the figure below. A few series of pails/drums will simulate obstacles that may result in a trap if a wrong turn is chosen by the vehicle.
II.6. TEAM ENTRIES

Teams may be comprised of undergraduate and graduate students, and must be supervised by at least one faculty advisor. Interdisciplinary teams are encouraged (EE, ME, CS, etc.). Students must staff each team. Only the student component of each team will be eligible for the awards. Faculty supervisor will certify that all team members are bonafide students on application form. Business/Non-Engineering students are encouraged to join teams to promote marketing, sponsorships, and other program management functions.

Team sponsors are encouraged. Sponsors’ participation will be limited to hardware donation and/or funding support. Sponsors’ logos may be placed on the vehicle and may be displayed inside of the team maintenance area. Teams should encourage sponsor attendance at the IGVC. Schools are encouraged to have more than one entry. Each entry must be based on a different chassis and navigation system and must be documented by a separate application form, submitted in accordance with all deadlines. Each application form must be TYPED and accompanied with a $200.00 non-refundable registration fee made payable to Oakland University. This fee includes up to five AUVSI student memberships.

Intention to compete must be received no later than April 1, 2005, by mailing your application form to:

Renee Lane
C/O Dr. Ka C. Cheok
102G SEB
SECS-ESE Dept.
Oakland University
Rochester, MI 48309-4478

If you have any questions, please contact Bernie Theisen by telephone at (586) 574-8680, fax: (248) 370-4633 or e-mail: theisenb@tacom.army.mil.

II.7. SAFETY CHECK AND QUALIFYING TEST

All vehicles will be inspected to ensure conformity to the vehicle type specifications (size, weight, propulsion). A safety check will be conducted to test the functionality of the vehicle manual and wireless E-stop, and verify that the top speed of the vehicle is below 5 mph. Qualifying test will be conducted to check the ability to follow and operate inside course lane markers and avoid obstacles. Judges and/or
officials will disqualify vehicles that fail to meet these requirements. Teams may fine tune their vehicles and resubmit for qualification and/or safety tests. No changes to maximum speed control software and hardware will be allowed after qualification.

All entries will be required to pass a qualifying certification prior to competition. Judges/officials will determine compliance with all rules. In the event of any conflict, the judges’ decision will be final. Fuel storage or running of internal combustion engines are not permitted in the team maintenance area (tent/building).

II.8. AUTONOMOUS CHALLENGE COMPETITION PROCEDURES

- The competition will take place in the event of light rain or drizzle but not in heavy rain.
- Each team will have the opportunity to run in all three (3) heats.
- Judges/officials will assign a designated on-deck time and competing time for each attempt to each team. Only members from the competing and on-deck teams are permitted on the course during competition.
- At the designated on-deck time, the competing team will be asked to prepare their vehicle for an attempt. On-deck teams start in the order they arrive in the starting area unless they give way to another team.
- An attempt will be declared valid when a designated judge gives the start signal at the designated competing time. An attempt will continue until one of the following occurs:
  - The vehicle finishes the course.
  - The vehicle was E-Stopped by a judge’s call.
  - The team E-Stops the vehicle.
  - The vehicle has not started after two minutes after moving to the start line or at the judges discretion.
- Up to a total of 9 attempts in 3 heats will be allowed, rotated in lottery order.
- Time for each heat will be strictly observed.
- Tactile sensors will not be allowed.
- Actual potholes two feet in diameter and two inches deep or simulated potholes will be marked on the grass as a two feet diameter white circle.
- For video and audience purposes, competing vehicles should mount a blinking light or strobe that indicates the vehicle has sensed an obstacle or pothole.
- Each vehicle must navigate the course by remaining inside the course boundaries and navigating around course obstacles. For the following Traffic Violations, the appropriate ticket will be issued and deducted from the overall distance or time score. Tickets are as follows:

II.9 TRAFFIC VIOLATION LAWS

<table>
<thead>
<tr>
<th>Traffic Violations</th>
<th>5-Point Ticket</th>
<th>E-Stop</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Leave the Course/Scene</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2 Crash/Obstacle Displacement</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>3 Careless Driving</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>4 Sideswipe/Obstacle Touch</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>5 Student's Choice E-Stop</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>6 Judge’s Choice E-Stop</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>7 Potholes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
• **Leave the scene (course):** A mechanical footing is defined as a wheel, track or pod. The overall distance will be measured from the starting line to the furthest point where the final remaining footing crossed the boundary outside edge.

• **Crash:** The overall distance will be measured from the starting line to the collision point with the obstacle.

• **Careless Driving:** Crossing the boundary while at least one mechanical footing remains in bounds.

• **E-Stop:** The overall distance will be measured from the starting line to the front of the vehicle or where the final/furthest remaining footing or side of vehicle if stopped, crossed the boundary outside edge.

• **Obstacle Displacement:** Defined as displacing permanently the obstacle from its original position. Rocking/Tilting an obstacle with no permanent displacement is not considered obstacle displacement. Rocking/Tilting is a 5-point ticket.

• **Actual and Simulated Potholes:** Hitting or crossing potholes prior to the money barrel will result in 5 point ticket for each pothole hit or crossed.

• **Blocking Traffic:** Vehicles stopping on course for over one minute will be stopped and measured.

### II.10 HOW COMPETITION WILL BE JUDGED

- A team of judges and officials will determine compliance with all rules.
- Designated competition judges will determine the official times, distances and ticket deductions of each entry.
- At the end of the competition, those vehicles crossing the finish line will be scored on the time taken to complete the course minus any ticket deductions. (1 Second per Point)
- The team with the adjusted shortest time will be declared the winner.
- In the event that no vehicle completes the course, the score will be based on the distance traveled by the vehicle minus the ticket deductions. The team with the adjusted longest distance will be declared the winner. (1 Foot per Point)
- For grand award money consideration, entry must exhibit sufficient degree of autonomous mobility by passing the money barrel. The money barrel location is determined by the judges during the final/actual course layout. If a tie is declared between entries, the prize money will be split between them. ALL POTHOLES MUST BE MISSED TO BE ELIGIBLE FOR GRAND AWARD MONEY.

### II.11 GROUNDS FOR DISQUALIFICATION

- Judges will disqualify any vehicle which appears to be a safety hazard or violate the safety requirements during the competition.
- Intentional interference with another competitor's vehicle and/or data link will result in disqualification of the offending contestant's entry.
- Damaging the course or deliberate movement of the obstacles or running over the obstacles may result in disqualification.
- Actions designed to damage or destroy an opponent's vehicle are not in the spirit of the competition and will result in disqualification of the offending contestant's entry.

### II.12 PAYLOAD

| 8 | Blocking Traffic | Yes | Yes | Yes |

| | | | | |
1. The payload must be mounted on the top of the vehicle as shown in the figure below.

2. The payload specifications are as follows.

   - **Length**: 18 inches
   - **Width**: 8 inches
   - **Height**: 8 inches
   - **Weight**: 20 pounds

3. The payload will contain a video camera; the camera will send streaming audio and video back to the IGVC committee during the Competition. It will be displayed in the Team Tent. The camera MUST be facing forward!

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### III. VEHICLE DESIGN COMPETITION

#### III.1 OBJECTIVE

Participation in the design competition is a mandatory part of the Intelligent Ground Vehicle Competition. Participation in the two performance challenges is optional. However, failure to fully qualify for the Autonomous Challenge will result in only nominal prize awards in the Design Competition and the Navigation Challenge.

Although the ability of the vehicles to negotiate the competition course is the ultimate measure of product quality, the officials are also interested in the design process that engineering teams follow to produce their vehicles. Design judging will be by a panel of expert judges and will be conducted separate from and without regard to vehicle performance on the test course. Judging will be based on a written report, an oral presentation, and examination of the vehicle.

#### III.2 WRITTEN REPORT

The report should not exceed 15 letter-sized pages, including graphic material, and line spacing must be at least 1.5, with at least an 11 point font (12 is preferred). Each vehicle must have a complete report of its own (a report cannot cover more than one vehicle). Four hard copies of the report must be mailed so as to arrive by May 27, 2005, addressed to the Organizer of the Design Judging:
Papers arriving after that date will lose 10 points in scoring for each business day late. Teams are encouraged to submit reports even several weeks early to avoid the last minute rush of preparing vehicles for the competition, and there will be no penalty for last minute changes in the vehicle from the design reported. Participants are required to submit an electronic copy of the report along with the hard copies, in order that the reports may be published on the competition’s web site. An electronic copy must be emailed to theisenb@tacom.army.mil. Failure to email the file will result in a 20 point penalty. For more information contact Bernie Theisen at <theisenb@tacom.army.mil> or call at (586) 574-8680.

The paper should present the conceptual design of the vehicle and its components. Especially important to highlight are any unique innovative aspects of the design and the intelligence aspects of the vehicle. Also included must be descriptions of:

- Electronics design planning process
- Electrical system signal processing
- Actuators plan for path following
- Software strategy (both solid & dashed lines)
- Sensors plan for control decisions
- Computers means of system integration
- Means of obstacle detection/avoidance systems must be specifically described. Also, if it is planned to compete in the Navigation Challenge, the system used for this event should be detailed.

Components acquired ready-made must be identified, but their internal components need not be described in detail. The steps followed during the design process should be described along with any use of Computer-Aided Design. How considerations of safety, reliability, and durability were addressed in the design process should be specifically described, as well as problems encountered in the design process and how they were overcome.

The analysis leading to the predicted performance of the vehicle should be documented, specifically:

- Speed
- Ramp climbing ability
- Reaction times
- Battery life
- Distance at which obstacles are detected
- How the vehicle deals with dead ends, traps, and potholes
- Accuracy of arrival at navigation waypoints
- Comparison of these predictions with actual trial data is desirable.

Although cost itself is not a factor in judging (these are considered research vehicles), the report should include a cost estimate (not counting student labor) for the final product if it were to be duplicated. A breakdown of the cost by component is helpful.

The team organization and the names of all members of the design team, with academic department and class, should be included along with an estimate of the project's total number of person-hours expended.

Vehicles that have been entered in IGVC in earlier years and have not had significant changes in design are ineligible in either the design or performance events. Vehicles that have been changed significantly in design (hardware or software) from an earlier year are eligible, but will require a completely new design report (15 pages or less) treating both the old and new features, thus describing the complete vehicle as if it were all new.
All reports, both for new vehicles and for earlier vehicles with design changes, must include a statement signed by the faculty advisor certifying that the engineering design in the vehicle (original or changes) by the current student team has been significant and equivalent to what might be awarded credit in a senior design course.

Judges will score the written reports as follows:

<table>
<thead>
<tr>
<th><strong>Maximum Points</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Conduct of the design process and team organization (including decision-making &amp; software development)</td>
<td>50</td>
</tr>
<tr>
<td>2. Completeness of the documentation</td>
<td>50</td>
</tr>
<tr>
<td>3. Quality of documentation (English, grammar, and style)</td>
<td>50</td>
</tr>
<tr>
<td>4. Effective innovation represented in the design</td>
<td>50</td>
</tr>
<tr>
<td>5. Description of electronic design*</td>
<td>100</td>
</tr>
<tr>
<td>6. Description of software strategy*</td>
<td>100</td>
</tr>
<tr>
<td>7. Description of systems integration*</td>
<td>100</td>
</tr>
<tr>
<td>*Descriptions to include: lane following, obstacle detection/avoidance, and, if applicable, waypoint navigation (GPS or other)</td>
<td></td>
</tr>
<tr>
<td>8. Efficient use of power and materials</td>
<td>100</td>
</tr>
<tr>
<td>9. Attention given to safety, reliability, and durability</td>
<td>100</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>600</strong></td>
</tr>
</tbody>
</table>

**III.3 ORAL PRESENTATION**

The technical talk should relate the highlights of the written report described above and include any updates of the design since the written report. Audio or video tape presentations of the text are not allowed, but graphic aids may be presented by video tape, slide projection, computer projection, overhead transparencies, or easel charts. The presentation must be made by one or more student members of the team to the judges and other interested members of the audience and should last not more than 10 minutes. A penalty of 5 points will be assessed for each minute or fraction thereof over 11 minutes. After the presentation, judges only may ask questions for up to 5 minutes. The audience should be considered as a senior management group of generally knowledgeable engineers upon whom the project is dependent for funding and the team is dependent for their employment. Scoring will be as follows:

<table>
<thead>
<tr>
<th><strong>Maximum Points</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Logical organization of the talk</td>
<td>25</td>
</tr>
<tr>
<td>2. Effective use of graphic aids</td>
<td>25</td>
</tr>
<tr>
<td>3. Articulation</td>
<td>20</td>
</tr>
<tr>
<td>4. Demonstrated simulation of vehicle control in performance events</td>
<td>10</td>
</tr>
<tr>
<td>5. Response to questions</td>
<td>10</td>
</tr>
<tr>
<td>6. Salesmanship</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Effective use of graphic aids includes not blocking the view of the screen by the presenter and simple enough graphics that are large enough to read (block diagrams rather than detailed circuit diagrams). Articulation refers to the clarity and loudness of speaking. Response to questions means short answers.
that address only the question. Salesmanship refers to the enthusiasm and pride exhibited (why this vehicle is the best).
Participants are responsible for providing their own visual aids and related equipment (the vehicle itself may be displayed). A computer-connected projector, and VHS VCR player will be made available. Computer-connected projectors may also be supplied by the participants.

**III.4 EXAMINATION OF THE VEHICLE**

The vehicle will be examined by the judges either at the time and location of the oral presentation or at some other convenient time and location during the competition. Software is not included in this judging. Judging will be as follows:

<table>
<thead>
<tr>
<th></th>
<th>Maximum Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Packaging neatness, efficient use of space</td>
<td>20</td>
</tr>
<tr>
<td>2. Serviceability</td>
<td>20</td>
</tr>
<tr>
<td>3. Ruggedness</td>
<td>20</td>
</tr>
<tr>
<td>4. Safety</td>
<td>20</td>
</tr>
<tr>
<td>5. Degree of original content in the vehicle</td>
<td>10</td>
</tr>
<tr>
<td>6. Style (overall appearance)</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>

**III.5 FINAL SCORING**

The number of points awarded by the individual judges will be averaged for each of the 21 judging areas above, and these results will be offered to each participating team for their edification. The total of the average scores over all 20 areas (max 800) will be used to determine the prize winners.

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**IV. NAVIGATION CHALLENGE**

**IV.1 OBJECTIVE**

Navigation is a practice that is thousands of years old. It is used on land by hikers and soldiers, on the sea by sailors, and in the air by pilots. Procedures have continuously improved from line-of-sight to moss on trees to dead reckoning to celestial observation to use of the Global Positioning System (GPS). The challenge in this event is for a vehicle to autonomously travel from a starting point to a number of target destinations (waypoints or landmarks) and return to home base, given only a map showing the coordinates of those targets. Coordinates of the targets will be given in latitude and longitude as well as in meters on an x-y grid.

**IV.2 QUALIFICATION**

All participant vehicles in the Navigation Challenge must be fully qualified for safety, control, and configuration by the Autonomous Challenge judges prior to competing and must carry the 20-pound payload during competition. In addition, those vehicles failing to fully qualify for Autonomous Challenge performance (lane following and obstacle avoidance) will be eligible only for nominal cash awards.
IV.3 ON-BOARD SENSORS

It is expected that most contestants will use Differential GPS, but non-differential GPS is allowed as well as dead reckoning with compasses, gyros, and wheel odometers. Vision systems and/or sonar and laser rangefinders may be used for obstacle detection. There are a number of handheld GPS systems that connect to laptop computers available on the market for under $200. Garmin, SkyMap/GPS, and Magellan are some; Earthmate even has one for Macintosh. These may not be convenient to integrate in vehicle control programs. However, differential GPS units are available from CSI Wireless, Trimble, Thales, Magellan, Garmin, NovAtel, and Starlink (and possibly others). Differential correction signals are available in the Northwest Michigan area from the U.S. Coast Guard (broadcast sites at Cheboygan, MI and Sturgeon Bay, WI). WAAS or any of the commercial suppliers of corrections are also allowed.

IV.4 THE COURSE

The map below shows a typical course for the Navigation Challenge. This map is a practice map for use by teams during development. Coordinates on this map are in meters measured from the origin. The map used for actual competition, with different target locations, will be given to the contestants when they arrive at the competition site on June 11, 2005 and the coordinates will be given in latitude and longitude, as well as in meters on an x-y grid.

The competition course will be run on a grassy field approximately 50 by 60 meters (0.8 acres), and the total travel distance on the course will be on the order of 180 meters depending on the route chosen for the vehicles. The exact target locations will be marked on the grass for use by the judges, but there will be no standup markers to indicate those positions. Construction barrels and certain other obstacles will be located on the course in such positions that they must be circumvented to reach the waypoints. No team participant is allowed on the course before the team’s first trial run, and only one team member (with the e-stop) is allowed on the course during a run.
IV.5 RUN PROCEDURE AND SCORING

It is intended that each team will have an opportunity for three tries on the course, the trial with the best performance being used for scoring. Starting times will be first-come-first-served, except that teams up for their first trial will have priority over those wanting a second or third trial, and teams up for a second trial will have priority over those wanting a third trial.

Vehicles will park in the starting box and have 5 minutes for final adjustments before starting. Vehicles may seek the waypoints in any order, and the vehicle actually reaching the most waypoints in the allotted six minute run time will be the winner. If two or more vehicles reach the same number of waypoints, the vehicle doing so in the least time will be declared the leader. If two or more vehicles reach the same number of waypoints while stopped by the six-minute rule, they will be declared tied and will share any awards.
If a vehicle fails to come within two meters of a target, it will not be judged to have reached that target. In order to qualify for standard prize money a vehicle must reach at least five targets; for the nominal award money, two targets.

IV.6 RUN TERMINATION

All runs will be terminated by an E-stop (by students or the judges) signaled by a judge’s whistle either:

- When the vehicle arrives back at the starting point or enters the starting box any time after first leaving it.
- If the vehicle entirely leaves the perimeter of the field indicated in the map.
- If the vehicle strikes a construction barrel.
- If six minutes have elapsed since the start of the run (180 meters in seven minutes is 1.1 miles per hour).

In all cases the judges' call will be final.

V. INDEMNIFICATION AND INSURANCE

Teams will be required to sign an application form prior to April 1, 2005. Along with the application form, there will be a Waivers of Claims that will need to be signed by each individual who will be participating at the competition.

Additionally, the Team’s sponsoring institution will also be required to supply AUVSI with a Certificate of Insurance at the time the Application Form is submitted. The certificate is to show commercial general liability coverage in an amount not less than $1 million.

NOTE: The IGVC Committee and Officials will try to adhere to the above official competition details, rules and format as much as possible. However, it reserves the right to change or modify the competition where deemed necessary for preserving fairness of the competition. Modifications, if any, will be announced prior to the competition as early as possible.

<table>
<thead>
<tr>
<th>Name</th>
<th>Years as Editor</th>
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<tbody>
<tr>
<td>Bernard Theisen</td>
<td>2004-2005</td>
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<tr>
<td>Dan Maslach</td>
<td>2003-2004</td>
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<tr>
<td>Bernard Theisen</td>
<td>2001-2003</td>
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<td>G. Edzko Smid</td>
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<td>Candy McLellan and G. Edzko Smid</td>
<td>1996-1997</td>
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