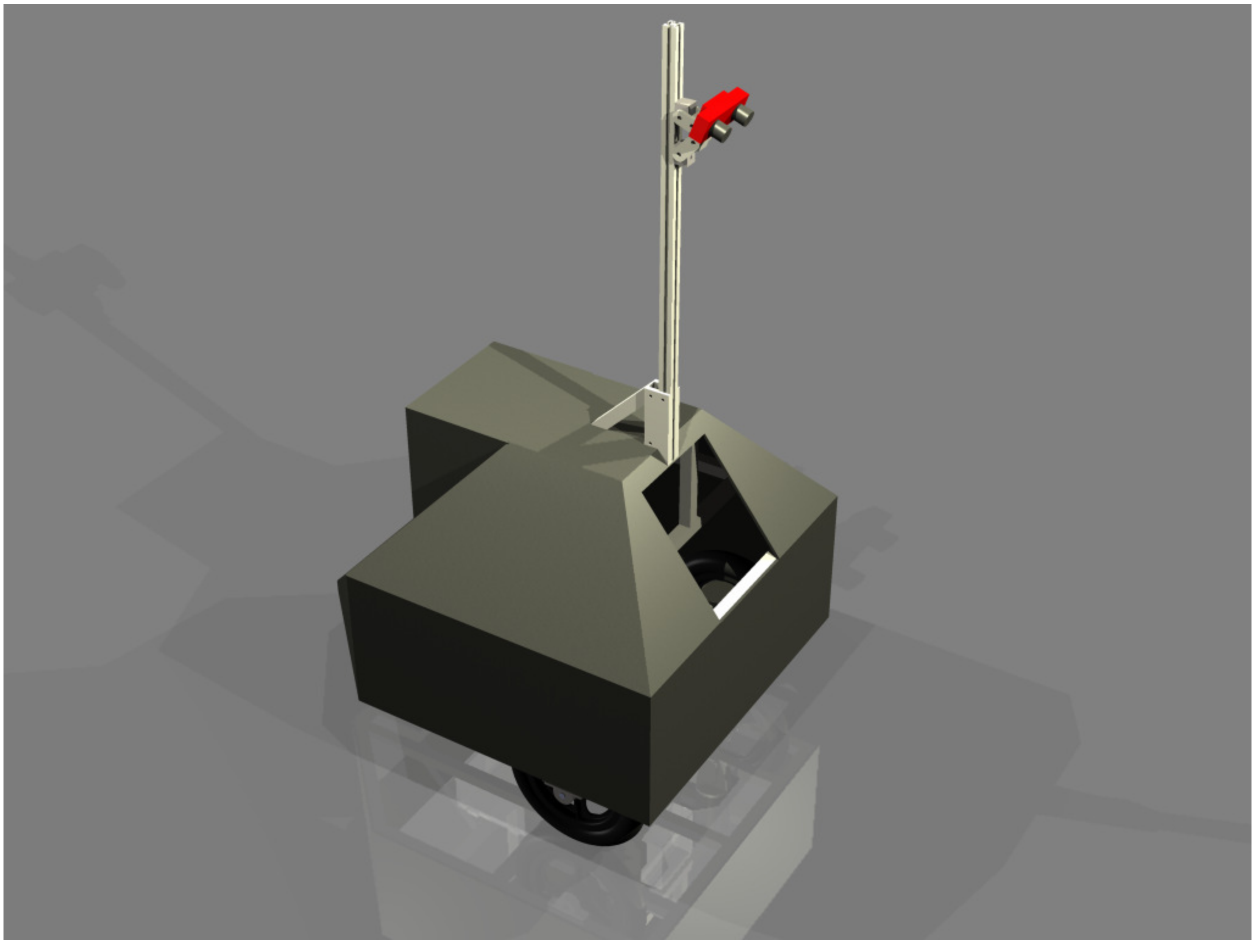
University of Missouri-Rolla
Robotics Competition Team



# THE ALUMINATOR

Design Report
2007 Intelligent Ground Vehicle Competition

## 1. Description of Problem

The Intelligent Ground Vehicle Competition (IGVC) presents an interesting challenge to university students. Except for physical dimensions and safety, there are few design constraints. The teams must decide for themselves how to detect obstacles and avoid them. The University of Missouri-Rolla (UMR) has designed and constructed a two-wheel drive robot to answer this challenge. In keeping with previous UMR robots, the team has chosen to use stereovision cameras to sense the environment. The design was chosen for its elegance and simplicity: passive vision sensors can sense more of their environment with less power and impact, tank drive is simple to construct and easy to control. This robot is a stable platform that UMR can use to test sensors and algorithms. It is even able to prototype navigation software for more complex robots like UMR's Stereo Opticon.

## 2. Mechanical Design

### *2.1. Mechanical Design Process*

The mechanical team began by formulating the design requirements, which included the following:

- ease of maintenance,
- ease of manufacturing,
- the ability to fit through a standard door,
- the ability to climb a thirty degree incline,
- the ability to temporarily attach different navigation instruments for testing in various configurations.

Two different preliminary CAD models were built, one using Autodesk AutoCAD Mechanical and one using Autodesk Inventor. The final design (Figure 1) was chosen from these two mainly due to the cheaper and faster manufacturing process necessary to complete it, though the final design also lends itself to easier modification. The manufacturing drawings and final assembly were completed within Inventor, allowing the team to spot potential problems and correct them before beginning construction. As a result, very little extra material was ordered and none of it was used to correct design flaws, saving both time and money.

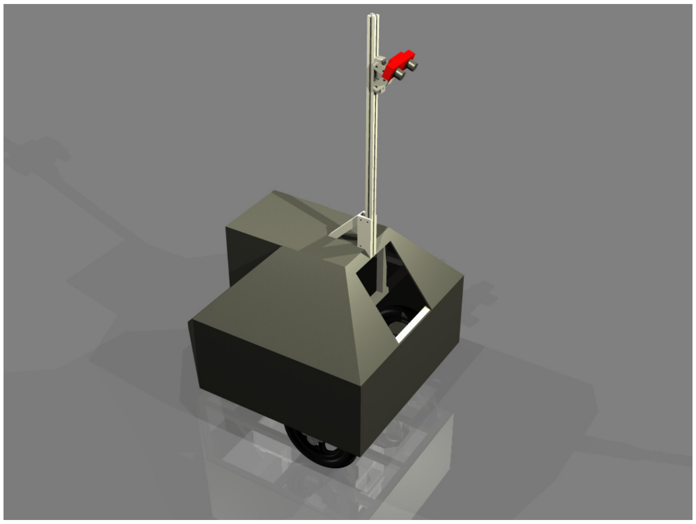


*Figure 1: Aluminator Design Render*

The overall guiding principle the mechanical team followed was simplicity. With the chosen design, very little can go wrong mechanically and if something should fail, the open design and few parts allow for easy fixes meaning increased reliability and durability.

### *2.2. Structural Design*

The frame of the robot (Figure 2) is welded together, providing a stronger joint and saving weight. All of the other components are bolted on. This allows the team to use the robot as a test platform for different computers, vision systems, GPS devices, etc. The box-like aluminum frame is durable, yet very open, allowing for easy access to the electronics and drive system. The fiberglass cover is easy to remove so that internal components can be reached.

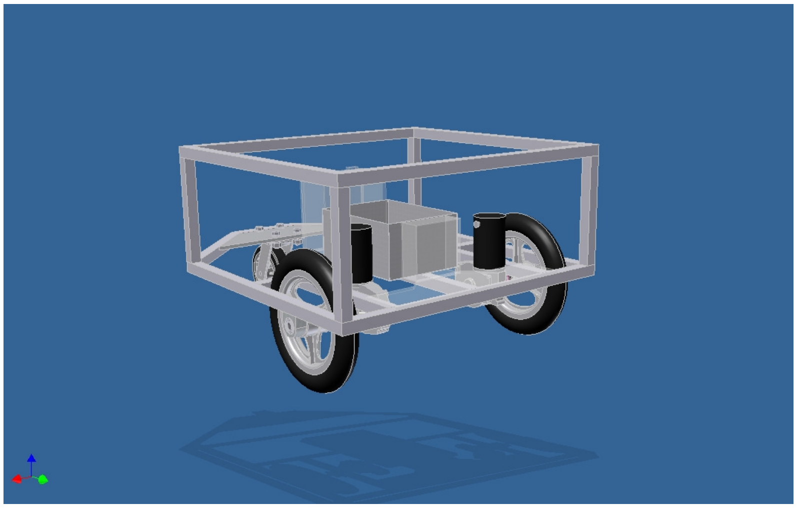


*Figure 2: Aluminator Frame Design*

Another feature of the robot is the mast. It is a section of 80-20 square aluminum extrusion with slots along its length that allows a sensor to be mounted at any height very easily. With the 80-20 system, multiple instruments can be mounted quickly and adjusted to the optimal height and angle. Currently, this mast is used for the stereovision camera but it can easily be adapted other sensors, including LIDAR or ultrasonic ranging sensors.

### *2.3. Drivetrain*

Aluminator is UMR's first tank-drive design. This facilitates excellent maneuverability with low control complexity. The robot can rotate three hundred sixty degrees in place, as well as make easy sweeping turns. Each wheel is driven by a wheelchair motor so the robot can easily drive over any terrain on the course, including ramps. Tests have confirmed that it can climb 30 degree ramps, but the design is slightly top-heavy. A hard stop while angled down could cause the robot to tip. This has never happened in testing, so it is unlikely to happen in competition as the course only includes 15 degree slopes. This unfortunate drawback is a result of a design tradeoff to make The Aluminator more maneuverable.

## 3. Electrical Design

### *3.1. Design Overview*

Past UMR robots have been held back by their complex, custom built electronics. The Aluminator was designed to use as many off-the-shelf components as possible to increase its reliability. The robot has three main components: a dual channel drive motor controller, a radio controller, and a computer. This simple system allows the electronics group engineers to focus on tuning the motor controller and designing power electronics.

### *3.2. Motor Controller*

The design centers around the motor controllers and the computer. The motor controller chosen was a commercial, off-the-shelf AX3500 from Roboteq. This allowed simple control and feedback on two motors with both an RC remote control and a serial interface from a computer. The AX3500 motor controller was chosen because it can handle many needed functions without computer intervention. With a small amount of external circuitry (Figure 3), it can switch between RC control and serial computer control via a switch on the remote. It also performs proportional-integral-derivative feedback on the encoder signal sent from the wheels to keep the wheels at the commanded velocity. The integrated encoder functionality also allows the computer to do simple position estimation from the wheel encoder data.

There is a custom electronics board that allows switching between RC control of the robot and serial control from the onboard computer. This board also distributes power to the other subsystems on the robot.

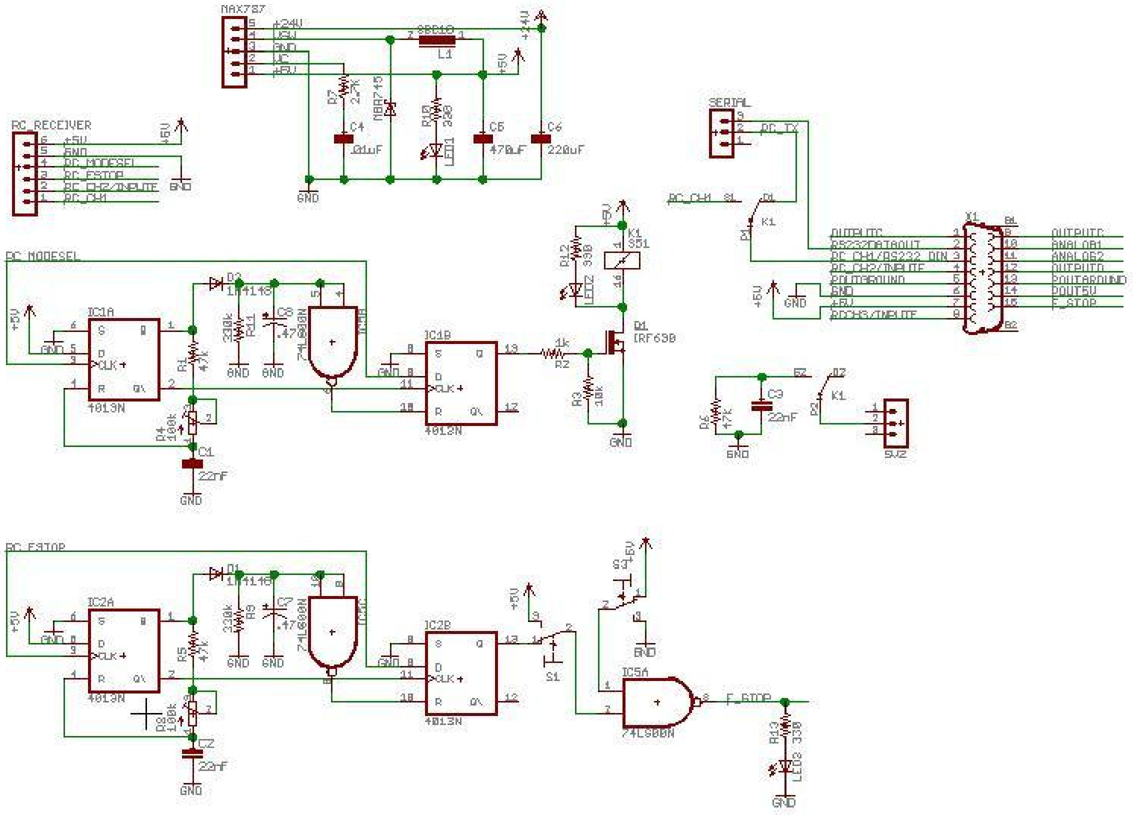


Figure 3: RC/Computer Interface

### 3.3 Computer

The computer is a mini-ITX form factor with a Pentium-M processor powered by a 12V DC power supply. This gave both low power consumption and high computing power. Instead of a hard drive, the computer has a 2 GB compact flash card. This card contains the operating system and intelligent control software. The computer receives images from the stereovision cameras using an IEEE1394 Firewire card.

### 3.3. Reliability

Each of the major system components are off-the-shelf devices, and are very reliable, easy to interface and simple to maintain.  As commercial products, the system components have been tested extensively, resulting in high reliability.  Additionally, the system as a whole is simple, contributing to the robot's reliability. The battery life estimated to be more than 2 hours with heavy use of the drive motors, and 3 to 4 hours under light motor load (during testing).

### *3.4. Safety*

Safety is ensured by three levels of control. At a hardware level, the motor controllers limit the top speed to five miles per hour. The physical e-stop is implemented at the hardware level through the motor controller for reliability. The second level is a remote e-stop through the RC remote. This is decoded on the electronics board and an e-stop signal is sent to the motor controller. The third level is high level software control that will only attempt to traverse terrain that is deemed safe by the perception system.

## 4. Computing Design/integration

### *4.1. Design Overview*

The Aluminator was designed to be a test platform for many types of software and hardware. Once it was complete, the software engineers were able to start testing perception, navigation and control algorithms. The computing group communicated very closely with the electrical group in order to make the high level software architecture compatible with the low level drivers. All of this design work was done in the fall semester and revised over the winter, once the robot was complete. At this point, the software engineers changed from architects into programmers. The group had some code written during the design process, but nothing quite ready to run on the robot. A control system was quickly prototyped and integrated with the low level drivers. The perception system was being created in parallel so that everything could be integrated with the model towards the end of the spring semester. This gave the team a little over a month to test the systems on the physical robot. Once initial testing was complete, the programming team split the code into two forks, one for Aluminator and one for Stereo Opticon. Aluminator's system was tuned to take more risks in order to run the course faster. This meant that it took the first path available instead of looking for the safest way around. This risky behavior was still designed to be safe; the robot will stop before hitting any obstacle that it can sense. Since it could theoretically allow the robot to be trapped, it was intended for an "easy" IGVC course. If the robot does not perform well in its first run then the parameters can be changed such that the system is more careful and can more easily navigate switchbacks. The design allows for a dynamic relationship between speed and caution.

### *4.2. Sensing/Obstacle Detection*

Perception of obstacles is accomplished with a stereovision camera. The camera is able to detect distance by triangulating the differences from the two camera images. The program then transforms these three dimensional camera coordinates into robot-centric coordinates (See Figure 4). Now that the environment data is mapped onto a standard coordinate system, the software can calculate the slope of the surrounding area by taking the first derivative of the height. Objects with a steep slope are assumed to be obstacles, while slight slopes are assumed to be ramps or small changes in terrain. This filters out all non obstacles so that the environment model only knows about true obstructions. A simple color filter is used to detect white and yellow objects. These are assumed to be boundary lines (or other important obstacles) and are passed through regardless of their slope.

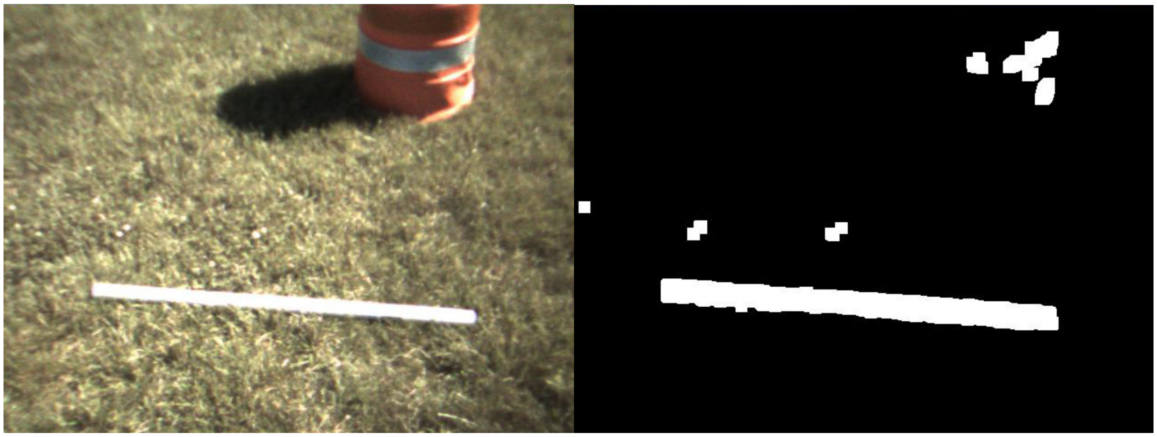


Figure 4 *: Video Capture (left) and White Filter (right).*

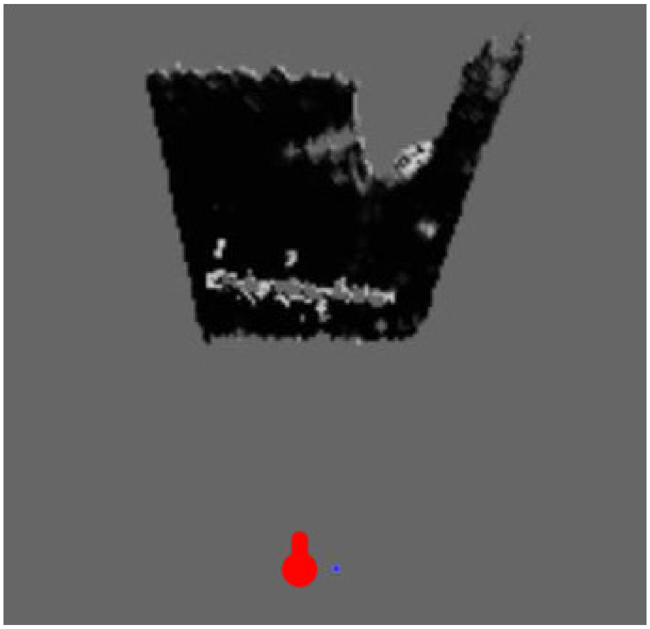


*Figure 5: Cost Map resulting from Figure 4. The robot is in red, facing the top of the image. Brighter areas represent higher cost.*

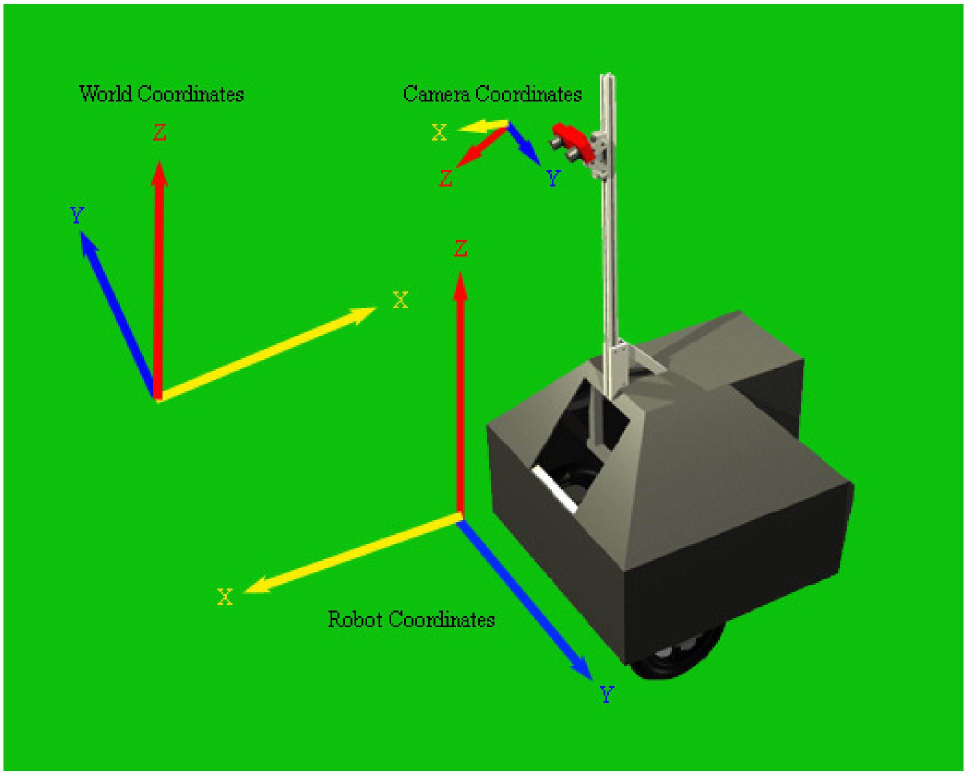


*Figure 6: Coordinate Systems*

### 4.3. Path Planning

Obstacles detected by the vision module are passed to an environment model. This model keeps track of all obstacles, including lines, in absolute world coordinates. It queries the pose system for the robot's current location and uses this to place obstacles in the world frame (See Figure 4). Now the robot has a list of all obstacles in two dimensions but it still needs to have a destination. For the Navigation Challenge the next waypoint is the destination. For the Autonomous Challenge the robot looks for the furthest boundary line and uses that as a destination. This ensures that the robot will be able to follow the lanes without turning around or being confused by a circular course. A search algorithm is necessary to determine the best path around all of the obstacles. The team chose to use an A* Search to accomplish this. If all of the obstacles can be seen, the robot will easily be able to traverse complex obstacle courses, including switchbacks and traps. Since this robot is programmed to be a risk taker, it is possible that it will become trapped by previously unseen objects, but it is always possible for the robot to backtrack until it sees a new path. The entire system, including vision and control, runs about 12 times a second. This is significantly faster than the robot can physically respond.

### 4.5. Pose Estimation

The current position of the robot is calculated using both GPS and wheel encoders. In previous years, the team has used the Garmin GPS-18. This device was inexpensive and included differential support but it was not very accurate (1 to 3 meters of error). The team considered purchasing a more accurate GPS but these were prohibitively expensive. Instead, the team contacted a Computer Science senior design project group and asked them to develop a solution that averages the results from three GPS receivers to find a better estimate of location than just one GPS. The robot also uses feedback from optical wheel encoders to determine how far it has traveled and which direction it is facing. For most of the course, the robot can rely on wheel encoder data to plot its current position. Occasionally, it will use the GPS data to correct for drift due to wheel slippage. During the Navigation Challenge the robot must rely much more on the GPS data. So far, the GPS averaging has produced a slightly more accurate estimate for the robot's position than just one GPS. The group is still working on implementing a Kalman filter to improve accuracy.

### *4.6. Safety*

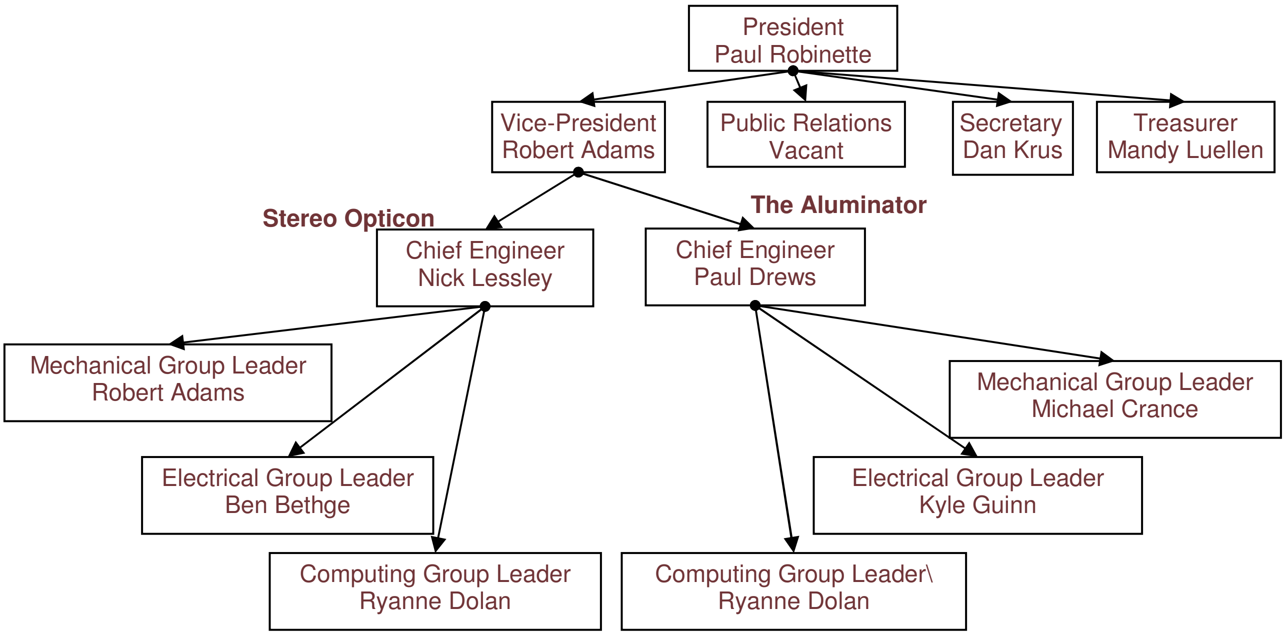
The entire software system was designed to be safe from the start. The robot will tend to avoid all objects with a large slope, so it will even avoid humans if someone happens to walk in front of it. The robot could hit an object if that object moved in front of the robot in between software updates. Since the software updates 12 times a second that would be unlikely.

## 5. Team info

### *5.1. Organization*

The Aluminator team was divided into a two level hierarchy: team members reported to group leaders who reported to a chief engineer who was responsible for the project as a whole. The group leaders were responsible for the three specialist groups: mechanical, electrical and computing. Each group leader was responsible for about five engineers. This kept the groups small enough to be manageable for one student leader but big enough to be productive.

The team as a whole was split between the two robots, Stereo Opticon and the Aluminator. Each chief engineer reported to the vice president who then reported to the president. The public relations officer was responsible for the team’s external image. The secretary was responsible for maintaining all of the teams written and membership records. The treasurer was responsible for purchasing supplies and managing team funds.



### *5.2. Expense*

The Aluminator was designed to be inexpensive to allow for quick fabrication. Previous projects have been held back due to slow fundraising income. Since the aluminum, plexiglass, axles, motors and wheels were chosen to be inexpensive, the materials could be purchased early in the year and the chassis could be fabricated quickly. Electrical components took longer since they cost more, but by the time the mechanical group had finished most of the fabrication the team had enough funding to purchase everything.

*Table 1: Itemized Expense*

| **Item** | **Expense** |
|---|---|
| *Mechanical* | |
| Aluminum | $200 |
| Motors | $300 |
| Axles | $75 |
| Plexiglass | $40 |
| Wheels | $50 |
| Nuts and Bolts, etc | $20 |
| Fiberglass | $500 |
| *Total* | *$1,185* |
| *Electrical* | |
| Computer | $800 |
| Motor Controller | $400 |
| Remote Control | $200 |
| Camera | $1,400 |
| Wheel Encoders | $50 |
| GPS | $600 |
| Batteries | $150 |
| Wiring | $30 |
| Misc Components | $100 |
| *Total* | *$3,730* |
| ***Grand Total*** | ***$4,915*** |

### *5.3. Schedule*

Design for The Aluminator began early in the Fall semester. Drawings were quickly rendered and a final design was chosen by October. At this point, funding had not yet been acquired for all of the necessary parts so the fabrication could not begin. Instead, the team designed specific parts so that construction could begin as soon as funding was acquired. By November most of the materials were purchased and the chassis began to take shape. By the beginning of the first semester the robot was ready to be programmed.

The first step in the programming process was to make a working motor controller driver. This took most of January and February. While this was being programmed, other members of the computing group started to work on designing the high level control system. Work began on implementing this system during the month of March and continued throughout the rest of the semester. Control tests were performed on the robot starting in March. Vision tests started during

April. The system was integrated in May and testing will be ongoing until the competition in June.

## 6. Conclusions

The Aluminator is UMR’s most stable entry to date for the IGVC. The software is robust and efficient. The electrical system was mostly assembled from off-the-shelf components to increase reliability. The mechanical structure is stable and maneuverable. All of these points combine to make one robot that is capable of being competitive in the 2007 Intelligent Ground Vehicle Competition.

## Appendix A: Team member list

| First Name | Last Name | Department | Class |
|---|---|---|---|
| Michael | Crance | Mechanical and Aerospace Engineering | Freshman |
| Ryanne | Dolan | Computer Science and Computer Engineering | Senior |
| Paul | Drews | Computer and Electrical Engineering | Junior |
| Ron | Erickson | Computer Engineering | Freshman |
| Kyle | Guinn | Electrical Engineering | Senior |
| Aaron | Jackson | Computer Science | Senior |
| Foti | Kacani | Electrical Engineering | Junior |
| James | Kendall | Electrical Engineering | Freshman |
| Daniel | Krus | Mechanical Engineering | Masters Student |
| Cory | Marchant | Mechanical and Aerospace Engineering | Freshman |
| Ryan | Meuth | Computer Engineering | Masters Student |
| Stephen | Mues | Mechanical Engineering | Freshman |
| Bryson | Nixon | Freshman Engineering | Freshman |
| Paul | Robinette | Computer Engineering and Physics | Senior |
| Stuart | Salvador | Mechanical Engineering | Senior |
| Lee | Seckinger | Freshman Engineering | Freshman |
| JR | Slane | Computer Science | Senior |
| Jeremy | Smedley | Mechanical Engineering | Junior |
| Chris | Vincent | Mechanical Engineering | Freshman |
| David | Wehner | Electrical Engineering | Freshman |