University of Missouri-Rolla
Robotics Competition Team

STEREO OPTICON

Design Report
2007 Intelligent Ground Vehicle Competition

1. Description of problem

Stereo Opticon is the second three-wheeled robot from the University of Missouri-Rolla. Stereo Opticon is lighter, more powerful, and more mechanically advanced, due to its full omni-directional drive train, than its predecessor Optical Prime. The robot design is focused on freedom of motion; by enabling rapid changes in direction, and omni-directional movement capability. The code, sensors and electronics combine to implements this motion capability.

2. Mechanical Design

2.1. Mechanical Design Process

The mechanical group followed a very structured design process. Starting with listing product specification gathered from the rules and regulations of the competition, everyone was asked to work together in groups to come up with possible designs that would fit within the product specifications. The team came up with several different design concepts that were submitted to a group of senior members who reviewed them, and a vote was held. The prevailing concept was chosen primarily for its light weight and modular design. Two other important aspects of its design were its compact size and omni-directional drive train.

The mechanical team individuals were each assigned portions of the robot to design. This allowed for maximum coverage of components in the amount of time allowed by the schedule. For more complex areas, several persons were assigned to develop the systems.

Finally, the teams were brought together for assembly. The individual designs, were integrated in an assembly file. Through this process, the team was able to solve many unforeseen problems. This also made it much easier to start construction of the chassis. By having already fitted the parts in a computer model, it was simple to construct the robot from printed diagrams.

2.2. Structural Design

The chassis was designed to be as modular as possible. In previous robots, the team created many unique parts. With Stereo Opticon, the engineers tried to reuse many parts. This way, it was possible to produce replacement parts that could be incorporated into many different parts of the structure. The removable wheel pod for Stereo Opticon for example (Figure 1) is exactly the same on all three corners of the robot

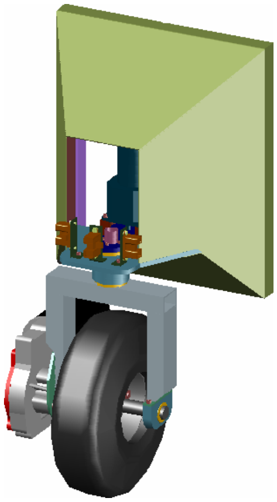

Figure 1: Modular Wheel Pods

The main structure (Figure 2) was also designed to be much lighter than previous designs. By using a shape based on the intersection of hexagons, the designers were able to concentrate and control the various stress points. This design was also able to create a more solid platform for stabilizing the modular wheel pods. This also gave a large number of connection points for various systems and sensors.

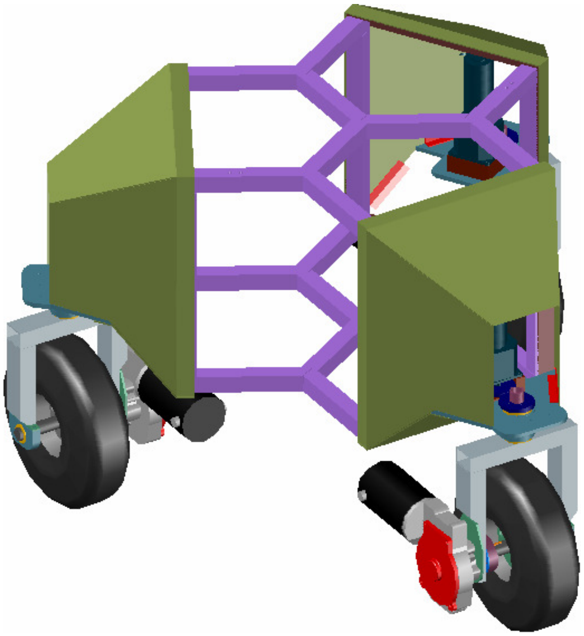

Figure 2: Stereo Opticon Chassis

The three removable parts of the robot are designed to be very light weight for their strength. Sheet metal (1/16th inch aluminum) covers the outside of the wheel pods to provide structural support. Pop-rivets hold the sheet metal together, which results in a very sturdy structure. The wheel and yoke attach to the sheet metal frame on a ¼ inch thick aluminum yoke plate, so the stress is well distributed throughout the sheet metal.

2.3 Accessibility

The structure is not only more solid, but the internal components are highly accessible. The open configuration allows for multiple points of entry. Also, all of the electrical and computer components are mounted on removable boards. The batteries and power distribution components are mounted on a lower drawer and the computer and power supplies are mounted on an upper drawer that both can slide completely out of the robot. All of the micro-controllers are mounted on removable plexiglass sheets. This allows the team to be more flexible with component placement. It also is very helpful in troubleshooting mechanical and computer components.

2.4 Drivetrain

The drive train for each wheel pod is identical. The power to the wheel is provided by a wheel chair motor, supplying the robot with more than enough power to climb ramps without losing speed. They are also estimated to be able to meet and exceed the speed limit provided in the product specifications. The motors are driven using a worm gear and pinion setup, so a braking mechanism is unnecessary

The motor can output 100 in-lbs of torque at a speed that is only 25% less than the motor’s no load speed. This translates through the 9 inch diameter wheels to 22 lbs of thrust on the ground per motor, or 67 total pounds of thrust on the ground. The 15 degree slope would require the 120 lb robot to output 31.1 lbs of thrust on the ground to maintain its velocity while moving up the slope. The robot outputs over double this thrust, so it will have no problems on the slope. The motor turns at a maximum of 200 RPMs under no load. This translates through the 9 inch diameter wheels to a maximum velocity of 5.35 mph. Since the robot's maximum speed is slightly over the course speed limit, this allows the robot a full range of speeds on the course. To meet the IGVC requirements, the speed is limited by the electronics hardware.

Each wheel is turned by a single vertically mounted, internally geared, brushed motor. It has enough power to turn the wheel, no matter the terrain. It acts on the turning yoke through a set of gears that provide a ratio of one-to-one. It takes approximately 3.5 in-lb of torque to turn the wheels on grass when the robot is fully loaded. The motor turns at 50 RPMs when it is under a load of 3.5 in-lbs, so the wheel should be able to make a full turn in 1.2 seconds. With the current driving code it will not need to make turns over 180 degrees, bringing the maximum turn time to 0.6 seconds.

2.5. Safety

Even though the robot is programmed to not hit anything or anyone, there are a few features that keep it from being too dangerous in case of a malfunction. There are no protruding sharp edges, the robot only weighs about 120 pounds, and the drive motors naturally stop if no electrical power is being supplied. The lack of sharp edges is to keep anyone, or anything, from suffering severe lacerations. The weight keeps it from being too heavy, allowing for two people to easily carry it. It also keeps it from crushing someone’s feet, if someone gets in the way. Finally, the naturally locking motors keep the robot from rolling on it's own on slopes or while being transported.

3. Electrical Design

3.1. Design Process

The initial design for Stereo Opticon came from a redesign of the previous UMR robot, Optical Prime. One of the major flaws of this system was the huge bundles of wires that needed to be run to the center of the robot from each wheel pod. After reviewing several options, it was decided that having a small microcontroller on each wheel would solve this. These microcontrollers can process the signals and send any needed information to the central computer via an I^2C bus. The microcontrollers used were chosen because they were simple and reliable, and many team members have experience programming them.

3.2. Design Overview

Electronically, the control system is much like the physical system. There are three satellite processors, one on each wheel pod, that communicate with a fourth processor in the center. The satellite processors handle the low level feedback and control of each pod. The central microcontroller relays messages between the microcontrollers and the main vision processing computer. There are also power conditioning and distribution boards in the center of the robot that distribute power to all electronics onboard.

The design uses Phillips 89lpc938 microcontroller as processors and relays on the wheel pods. These microcontrollers take in position information from the potentiometer and velocity information from the optical encoder. It uses this information to generate power commands to send to the steering and drive motors on each wheel. These commands are derived from a commanded position received across the I2C bus from the main computer which are fed into two PID loops.

Because of the close proximity of the electronics in the robot, electromagnetic interference (EMI) is a large problem. The motor control power electronics are an especially bad culprit of this. The team tested many combinations of different motor controllers and EMI reduction techniques to find a final configuration that runs reliably under all conditions.

3.3. Reliability

The battery is calculated to last one hour during heavy use. This is based on running near five miles per hour and having all motors and the computer contributing to the power draw. Since a run on the course will only be approximately 5 minutes, this is sufficient time for the competition and enables extensive testing during development.

3.4. Safety

The team has both wired and wireless e-stop systems. Each of these systems cut power to the drive motors, significantly reducing the risk of failure. Also, the physical e-stop was designed so that the robot will not move unless it is connected properly, reducing the chances of running the robot with a non-functioning e-stop. The robot is not physically capable of exceeding 5.35 miles per hour, so it is very easy to limit the speed of the robot to 5 mph. This is done using the microcontrollers on the wheel pods

4. Computing Design

4.1 Design Overview

Initially, the computing group designed a generic system that could intelligently control either UMR robot. This system had to be able to account for the most complex features that the team could include as well as the simplest. The most challenging portion was to design a system for an omni-directional robot.

The team's solution is to have the robot develop two models of its environment. The first is simply a map of the obstacles detected by the robot's sensors. The second records the uncertainty of each region in the obstacle model. These models are populated by a vision system and accessed by an intelligent control system to drive the robot.

4.2. Perception

Sensory perception is accomplished using a stereovision camera. The camera module uses the difference in images between two cameras to “see” in three dimensions. This data is collected into a height map of the robot's surroundings. If the environment were completely flat then this map could be used to find all of the obstacles in the area. To allow the robot to navigate in uneven terrain, a derivative of the height map is taken to make a slope map. Areas with very large slopes are defined as obstacles, whereas areas with smaller slopes are assumed to be minor terrain changes. A filtering algorithm is applied to ignore regions of the terrain with low slope. White lines are passed through the filter and are given a high traversal cost (Figure 3). This filtering results in the elimination of unimportant regions in the camera’s view.

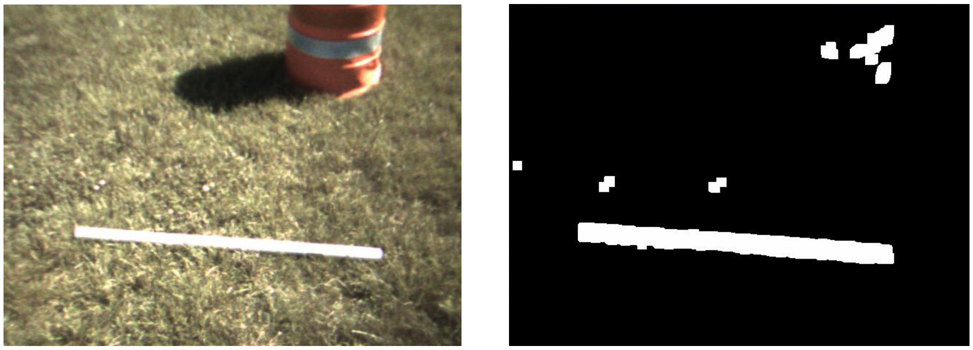

Figure 3: Video Capture and White Filter

Also, ground-plane estimation is employed to calculate the robot's tilt by averaging the overall slope in the camera's view. The resulting ground plane is used to transform the camera's three-dimensional coordinates into a new frame of reference relative to the ground. This affectively eliminates the effect of robot tilt on visual perception and prevents obstacle height miscalculations.

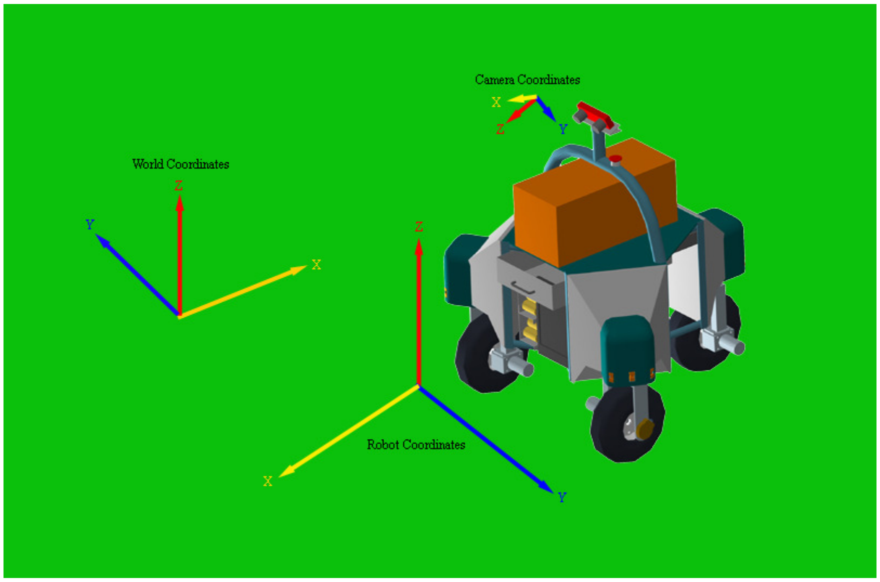

Figure 4: Coordinate Systems

4.3. Environment Models

The output of the slope and line filters are fed into the cost map (Figure 5). Every object not filtered in the vision system is placed into the cost map with a traversal cost proportional to its height. The cost for unknown areas is initialized to 50% so that the robot does not assume that undetected areas are cost-free. When boundary lines are detected they are given a 100% cost (lethal) so that the robot stays on the course. This cost map allows the higher-level navigation algorithms to avoid obstacles that have been detected by the vision system.

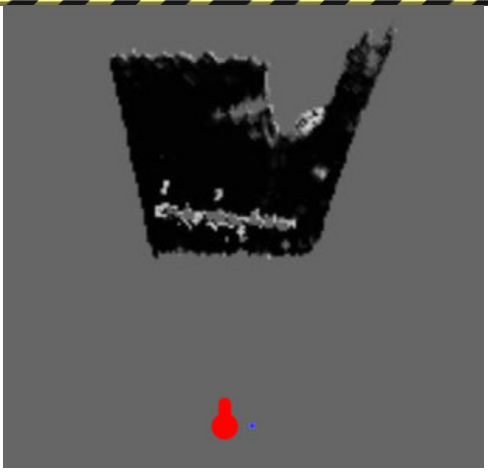

Figure 5: Cost Map

The certainty model gives the robot a confidence value for each location in the cost map. This value is calculated using a heuristic built from the variance in cost over the number of updates received for that region. This heuristic causes inconsistent data to disappear quickly and reinforces consistent data. By adjusting this heuristic, it is possible to make the robot exhibit varying degrees of caution. The model is initialized to 0% certainty everywhere so that the robot is encouraged to look around before moving rather than making false assumptions about the world. The certainty model, coupled with the obstacle model, allows the robot to speed through simple terrain and trudge slowly through unexplored, hazardous regions.

4.4. Navigation

The intelligent control system starts with a movement tree. The tree is composed of every possible move that the robot can make within its physical limitations, divided into discrete, simple steps. This tree starts at the immediate next move and projects numerous moves into the future. An A* search is used to find the best path through this tree. The search uses data from the cost and certainty maps to evaluate a cost heuristic for each edge it visits. The cost heuristic is weighted towards the current direction of travel to give the robot virtual inertia, preventing oscillations in the immediate path. The heuristic is also weighted with distance and heading calculations, so that the robot takes the shortest path to its target position. The search finds the optimal path and produces the robot's drive vector.

The algorithm is designed to work with robots which can travel and look in separate directions. A gradient descent search is applied to the certainty map starting at the robot's current position to determine the point of lowest certainty in the path ahead. This “look vector” is calculated less often than the drive vector since it is not absolutely necessary for the path planning. However, it will give the robot a seemingly intelligent curiosity about its unexplored surroundings and optimize sensory perception by focusing on new data.

For the navigation challenge, the robot chooses its next destination by picking the next nearest waypoint from the list. For the autonomous challenge, the robot must pick a point that is far away and will allow the robot to continue the circular course. This is accomplished by finding a point on the lane marker in the distance. This allows the robot to continue in the forward direction and ensures that the robot will not be confused when it is told to make a circle.

5. Team info

5.1. Organization

Since the UMR Robotics Team decided to enter two robots in the 2007 IGVC it was necessary to break the team into two engineering groups: one for Stereo Opticon and one for the Aluminator. Each of these groups was then split into three specialized groups: mechanical, electrical and computing. Each of the robot groups is managed by a chief engineer responsible for signing off on the design, creating an action plan, and managing the three specialized group leaders. The specialized group leaders were in charge of designing and fabricating all parts, components and software for the robot.

The team as an entirety is managed by a board of officers. These officers included a president, vice president, treasurer, secretary and public relations (PR) officer. The president’s job is to make sure that every task involving the robot, ranging from installing motors to attending financial meetings is completed. The vice president’s job is to assist the president in his duties, head up fundraising, and work closely with the chief engineers. The job of the treasurer is to approve all purchase requests from specialized group leaders and chief engineers and then purchase the approved items. The treasurer must also keep track of all incoming and outgoing money. The secretary takes minutes at all meetings, keeps records of the team, and maintains contact information for all team members. Finally, the PR officer is in charge of brochures and newsletters, as well as heading presentations of the robots to potential donors, UMR students and faculty, and the public. Unfortunately, several months into the semester the PR officer left the team. The work that was left behind was split up over the remaining officers.

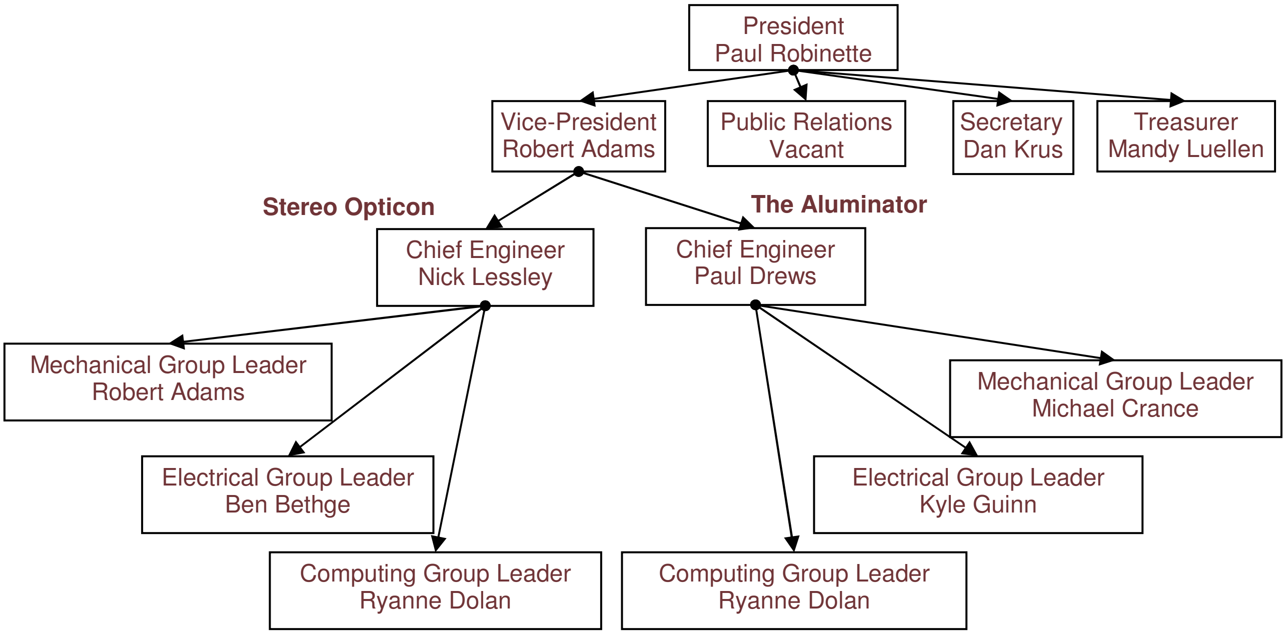

Figure 6: Organizational Chart

5.2. Expense

A significant portion of the expense was during the 2006 competition cycle. At this time, the cameras were purchased, the chassis was fabricated and most of the electronics were complete. In 2007, the team purchased a new computer for the robot. Gears and motor controllers had to be replaced as the previous ones were found to be problematic. Plexiglass was added to make the robot more aesthetically pleasing.

Item	**Cost**
Mechanical	
Drive Motors	$450
Steering Motors	$200
Aluminum	$400
Gears and Fasteners	$400
Wheels	$50
Plexiglass	$50
Total	*$1,550*
Electrical	
Computer	$800
Camera	$1,400
Wheel Encoders	$75
Batteries	$150
Wiring	$50
GPS	$200
Drive Motor Controllers	$600
Steering Motor Controllers	$200
Misc Electronics	$150
Total	*$3,625*
Grand Total	***$5,175***

Table 1. Itemized Expenses

5.3. Schedule

Throughout the year we encountered numerous mechanical, electrical and computing set backs. Fortunately, we realized from our previous experiences to budget time for unexpected problems, which allowed us to work through the problems and stay on schedule for competition. (Figure 7)

At the beginning of this school year, Stereo Opticon was nearly mechanically complete. It was finished by early December. In late February, when testing began, some of the gears were found to be slipping on their motor shafts. At this point, the mechanical group went to work to fix this slipping error as well as several smaller errors. These unexpected problems set back some of the software testing.

Electrically, Stereo Opticon was a blank slate at the beginning of the year. The electrical engineers started wiring and completed according to schedule with few setbacks. The primary setback was during initial testing, when the motor controllers were experiencing high electro-magnetic interference (EMI). This was an ongoing problem that is solved at this point.

Before Stereo Opticon was running, the computer scientists began writing low-level code for the motor controllers. As the robot came closer to rolling, programmers began writing code for omni-directional drive and path finding. The computer scientists had a setback in their plans because of the mechanical problems that resulted at the beginning of testing. This delayed when they could start testing on a running robot.

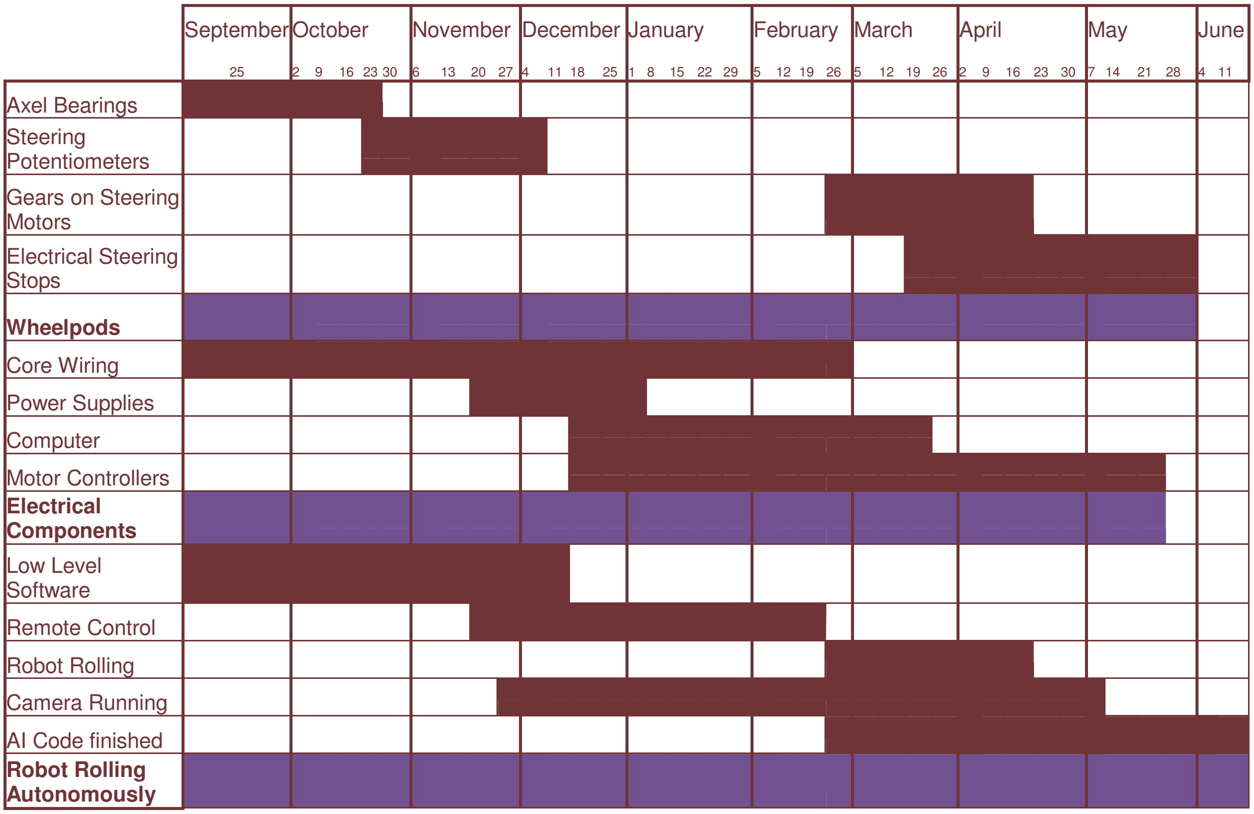

Figure 7: Gantt Chart

6. Conclusions

Stereo Opticon is a compact, light weight, very powerful, omni-directional robot. Its large freedom of motion will give it advantages over the more traditional robot. With the ability to look and drive in different directions implement into the code, Stereo Opticon will be able to handle complex maneuvers that are impossible for most robots. Also, the modular electrical control design with multiple computers allows the system to process data from all of the motors and their control sensors as well as the large amounts of data that come from the stereo-vision camera at fast rates. The stereo-vision camera is not only a very powerful sensor because of the large amount of data it can perceive, but it is also cost effective and a passive sensor which is often important for military uses. With Stereo Opticon's Mechanical, Electrical, and Computer power and versatility, it will be a highly competitive robot in the 2007 IGVC Competition.

Appendix A: Team member list

First Name	Last Name	Department	Class
Robert	Adams	Mechanical Engineering	Sophomore
Ben	Bethge	Physics	Senior
Ryanne	Dolan	Computer Engineering and Computer Science	Senior
Paul	Drews	Computer and Electrical Engineering	Junior
Alan	Harris	Mechanical Engineering	Junior
Aaron	Jackson	Computer Science	Senior
Nick	Lessley	Mechanical Engineering	Junior
Matt	Marsh	Computer Science	Junior
Joe	Mazzola	Computer Engineering	Junior
Ryan	Meuth	Computer Engineering	Masters Student
Stephen	Mues	Mechanical Engineering	Freshman
Paul	Robinette	Computer Engineering and Physics	Senior
David	Wehner	Electrical Engineering	Freshman