MISSOURI S&T ROBOTICS COMPETITION TEAM

"Helping Robots Help Themselves"

The Missouri University of Science and Technology Robotics Competition Team

proudly presents:

ALUMINATOR

For entry in the 2010 Intelligent Ground Vehicle Competition

Faculty Advisor Statement:

I hereby certify that design and engineering changes made to this vehicle by the current student members of the team have been significant, including major development on the software, and several hardware upgrades, and that every member has made a significant contribution that would equal or surpass that of a senior design credit.

Dr. Donald Wunsch
Senior Advisor

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1. INTRODUCTION

The Missouri University of Science and Technology (Missouri S&T) Robotics Competition Team is proud to submit "Aluminator" to the 2010 Intelligent Ground Vehicle Competition (IGVC). This will be the fourth year that Aluminator has competed in the IGVC and the sixth year the Missouri S&T Robotics Competition Team has submitted an entry. While originally designed as a reliable and expandable test bed for software, Aluminator has become the most dependable, and primary robot for the team. Aluminator's sturdy and simple frame is ideal for the challenges presented by the IGVC and with its easly expandable architecture, it it the ideal development robot. During this school year we have made several improvements to increase robustness in the electrical, mechanical, and software design. This year's Aluminator shows a large increase in both reliability and intelligence and should be able to navigate almost any course encountered during the 2010 IGVC.

2. DESIGN PROCESS

2.1 TEAM STRUCTURE

The team operates through the Missouri S&T Student Design and Experiential Learning Center (S.D.E.L.C.), which provides logistical support to all ten of the school's student run design teams. It is comprised of roughly 30 members from a variety of different disciplines and a full list can be found in Appendix B. The team is run, by five elected undergraduate officers, who in turn appoint three additional officers to serve year long terms. The team president, vice president, treasurer, public relations officer, and secretary comprise the five elected positions. At the beginning of the school year three division leaders are appointed each whom, oversees and manages one of the team's three divisions: mechanical, electrical, and computing. All of the other team members are a part of one or more of these divisions. This team structure (*Figure 1*) allows for the general members of the team to be able to operate without being distracted by the day-to-day logistics that come with running the team.

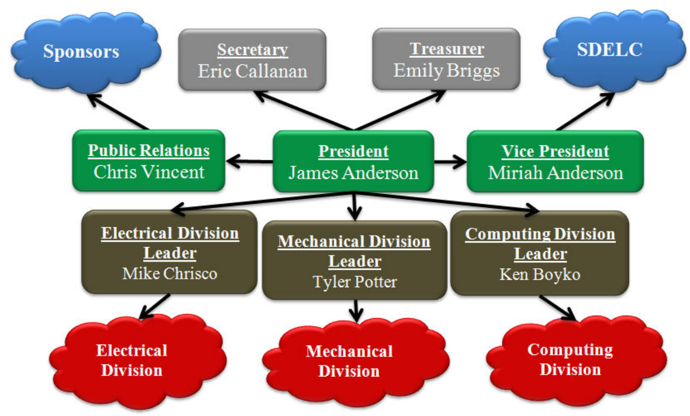


Figure 1: Team Structure

2.2 PLANNING

At the beginning of the 2009-10 school year the officers and advisors of the team looked at all aspects of the upcoming season as well as the events of the previous season. While looking at the team's budget and resources it was decided that the best course would be designing and building a new robot that would be able to utilize much of the hardware the team already owned. Because of Aluminator's admirable performance in previous years it was decided that the new robot should be designed around Aluminator and was thus named Aluminator 2.0. The building of this new robot would give the mechanical and electrical divisions a chance to design and build a robot from the ground up with all the experience they had gained from working on Aluminator. Since the new robot would have a similar architecture, it would also give the computing group the ability to develop software on Aluminator that would run the same on Aluminator 2.0. A full schedule was laid out including ample time for the designing and building of Aluminator 2.0 as well as plenty of testing dates and times for software on both robots. The original Schedule can be found in Appendix A.

2.2 EXECUTION

During a large portion of the 2009-10 school year, the team's efforts were concentrated on designing our new robot Aluminator 2.0, while the computing division worked on developing software on Aluminator. The team had problems throughout the year with Aluminator 2.0 due to delays in the design, fabrication, and the receiving parts. These problems caused the fabrication of Aluminator 2.0 to rapidly fall behind schedule and as the team approached the final months of the school year a decision was made to enter Aluminator and save Aluminator 2.0's debut year for 2011. During the design and fabrication of Aluminator 2.0 many lessons were learned that could be applied back to Aluminator and many improvements were made. The custom camera mounts and new E-stop system were adapted to Aluminator and the shell was given a new finish. During the semester the computing division had been sticking closely to the schedule, developing more robust software and performing regular test on Aluminator. The addition of the new camera mount gave a larger field of view with greater definition, and the new position sensors gave much more accurate results. With the new designs applied to Aluminator it is a better robot than it has ever been before and the team believes that it will make an impressive run in the 2010 IGVC.

3. VEHICLE HIGHLIGHTS/INNOVATIONS

Throughout Aluminator's life it has had upgrades on almost all of its parts and as a result has been finely tuned to the needs of this competition. On the surface the 2010 Aluminator may look similar to the 2009 model; however, underneath its Lexan shell there have been major innovations to both hardware and software that will give it the edge in this year's competition.

3.1 MECHANICAL UPGRADES

While most of the frame and drive train have remained the same there have been some major renovations done to Aluminator's camera array (*Figure 2*). During the 2009-10 school year new mounts were designed to support Aluminator's three webcams. The new mounts were arranged in a vertical configuration, giving them one common axis and making the calibration process easier than it has been in previous years. The new cameras have also been outfitted with a small piece of polarized film for outdoor testing. This film will act as sunglasses for the cameras and greatly reduce the glare that comes off of wet grass and obstacles, which has been a serious problem for our color segmentation in the past. These new camera mounts provide a very robust platform for Aluminator's camera array.

Figure 2: Camera Array

3.2 ELECTRICAL UPGRADES

In previous years Aluminator has used a combination of two separate motion control systems. Signals were sent over Ethernet from our main computer to a small drive computer, which would then act as a translator for the robot's two motor controllers. During the beginning of the school year an accidental short was created causing the drive computer to fail. A spare unit was used as a replacement, however during the evaluation of the incident, it was decided that by bypassing the drive computer using serial connections from the main computer, we could make the system more efficient and robust, using less power and decreasing signal time.

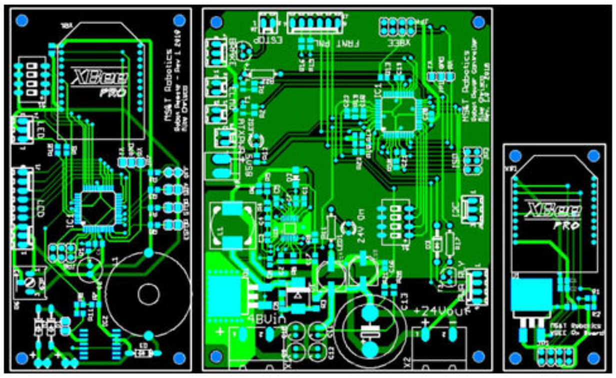


Figure 3: Custom E-Stop Board and Remote

Another serious problem that has plagued our electrical system in the past has been our wireless E-Stop system. Aluminator's previous E-Stop system was built using a relay coupled with a R.C. helicopter controller. This system worked well until last season when it mysteriously died, leading the team to produce a last minute replacement. This year the system's RC board was completely replaced and the remote drive functions are now handled by opening a terminal over Wi-Fi or by linking with the team's Wiimote controller from the Nintendo Wii gaming console. The Wiimote links through Bluetooth protocols and allows for control by a joystick or accelerometer. The Wiimote system has proven to be a reliable way of controlling the robot manually and has proven invaluable for the transportation of Aluminator. To replace the wireless E-Stop system, a new custom P.C.B. board (*Figure 3*) was built. This board is linked with a separate custom controller through a pair of X-Bee wireless transmitters. The system can be run in competition mode and act as a dead man's switch where it will always require a signal, or run in testing mode where it will only require a signal to stop. The wireless E-Stop also has a small display that feeds back information about Aluminator. The motor controllers on Aluminator now also incorporate a watchdog for all programs that will require them to send a continuous signal for the robot to move. The new systems added this year make Aluminator safer and easier to use than ever.

3.4 SOFTWARE UPGRADES

The software functionality of Aluminator has increased significantly since the 2009 IGVC. Developments have been made in every aspect that will give it the edge in this year's competition. The first upgrade comes with the robots new vertical camera array that allows for a very high resolution obstacle map around Aluminator. This enhanced resolution image is comprised of the images taken by Aluminator's three webcams, which are then put through homography transforms and stitched together to give a 180 degree overhead view of the area surrounding Aluminator (*Figure 4*). To speed up this process, all of the transforms have been pre-computed and placed in an array of pointers. Color segmentation is then applied to determine all obstacles. The color segmentation will identify any blobs of colors that could be obstacles and then subtract off colors the team knows are not, such as grass. This high resolution obstacle map is absolutely crucial to all of the robot's guidance applications.

Figure 4: Stitched Homography Transform

Once the obstacle map is computed it can be run through a number of guidance algorithms. This year we have two primary methods, one using ray tracing, and the other using potential fields. In the ray tracing method, polar rays are checked every degree for the 180 degrees surrounding the robot, the data from this is then analyzed to determine the best path and the wheel speeds. The team has increased the speed of the program even more by only performing color segmentation along polar rays until the first obstacle is found. This method gives very fast results and can be combined with several strategies produced in the player-stage simulation program to obtain optimal performance. In the potential field method, the obstacle map is transformed into a series of three-dimensional hills and valleys with targets being given a lower height or dip. This method will cause the robot to be attracted to targets and repelled from obstacles, giving the most efficient path to any target. Depending on the situation, either method can be used through the team's simple Linux S.S.H. terminal menu allowing for adaptations to be applied quickly in the field.

While in previous years Aluminator has had position sensors, this will be the first year they will be fully integrated in the code. A large portion of the season has been spent on creating software interfaces for an I.M.U. sensor that was received by the team in the previous year. The sensor was meant for interfacing with a machine running Windows and new drivers had to be written for data to be streamed into Linux. With our new drivers the team has finally been able to get accurate position and to apply that to the navigation challenge. With the improvements that have been made to the team's software, we expect Aluminator to perform well in all aspects of this year's competition.

4. MECHANICAL DESIGN

4.1 FRAME

Aluminator's frame is welded one inch square aluminum tubing (*Figure 5*). The welding of the joints was done by students and gives Aluminator a rigid and reliable base. Aluminator is 28 inches wide by 36 inches long, giving the robot high mobility by allowing it to fit through a standard door frame. This width was designed into the robot to facilitate indoor testing and travel to public relations events. The length was selected for an optimal balance between maneuverability and stability.

Figure 5: Aluminator's Frame

Different weight distributions are possible for Aluminator because the primary factor determining center of gravity is battery position. The robot was balanced left to right, with the batteries were placed on the midline. There were two primary factors governing the battery placement: tipping and weight on the front wheels. To prevent tipping, the batteries should be placed near the center of the robot. To increase maximum torque of the front wheels, the batteries should be placed farther forward. Both of these positions were tested, and tipping was a problem when the robot stopped while moving down a steep slope. The batteries were placed in the middle of the robot, giving the wheels a maximum ground force of approximately 2/3 the weight of the robot.The total weight of the robot is 144 pounds, with 48 pounds of that being the batteries.

Aluminator's shell is comprised of six Lexan panels, which are attached with screws to threaded sockets in the frame. The edges have been covered with aluminum flashing to reduce sharpness and give a cleaner look. Aluminator also incorporates two hinged and latched doors on the sides of the vehicle. These permit access to the internal components without the need for taking off the shell panels. This addition from the previous year has saved large amounts of time and hassle in the maintenance of the robot.

4.2 DRIVE TRAIN

The drive train of Aluminator was designed to be as simple as possible, while being able to perform well in all situations presented in the IGVC. Two fixed drive wheels are in the front of the robot with a caster in back. This allows the robot to make zero-radius turns around its drive axis. The turn radius is not only important for making the tight turns presented in the IGVC, but also for being able to turn and view the area around the robot while in one position. Another important aspect to the wheel setup is that none of the wheels slip during operation with normal motor torque. Not only does this require less power than a tracked or skid steer setup, but it also allows encoders to be used to keep track of position. The drive motors were put in the front to allow the robot to pull the caster through terrain instead of pushing it, which is an important factor in off-road performance.

4.3 CAMERA MOUNTS

This year the team has improved upon Aluminator's vision capabilities, by adding a new camera array (*Figure 3*) to the top of the robot's mast. This addition increased the overall height of the robot from 52 inches to 53 inches. The three webcams are squeezed between two pieces of aluminum. This setup keeps the cameras from moving due to vibrations, which reduces the number of calibrations that need to be made. The sensors are mounted on a mast situated near the rear of the robot giving a wider field of view in the immediate vicinity of the robot. All of the vision sensors are fully adjustable with respect to their vertical distance to the ground, angle on the horizontal axis, and the angle on the vertical axis.

5. ELECTRICAL DESIGN

The robot is powered by two twelve volt batteries (*Figure 6*) wired in series to give 24 volts to Aluminator's systems. The motors are rated for 24 volts, and they consume most of the robot's power, so having them at the same voltage prevented the need for a high amperage voltage adapter.

5.1 ACTUATORS

Aluminator is propelled by two 24V brushed DC motors with built in worm-gear boxes. Each motor is driven by an Elmo 'Drum' motor controller (*Figure 6*). The Drums are rated at 70A continuous, 140A peak at up to 110V. This high amperage is required to create the low-end torque necessary for Aluminator to

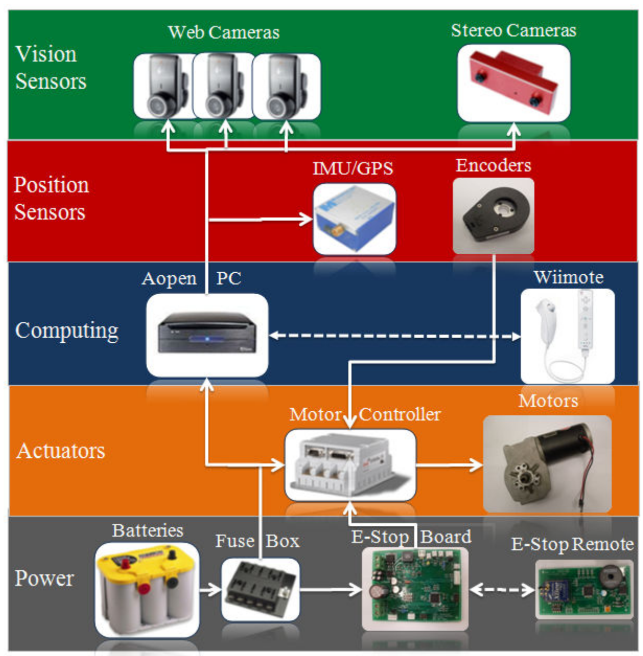


Figure 6: Electrical System

begin moving or to execute a zero-point turn. Each controller also regulates speed automatically using wheel encoder feedback. The controllers interface to Aluminator's on-board computer via two serial ports.

5.2 SENSORS

Aluminator employs two types of vision sensors, and five types of position sensors.

Figure 7: Camera Mast

- ### VISION SENSORS

Aluminator employs an array three Logitech QuickCam Pro webcams (*Figure 7*). These web cams are capable of 2.0 Megapixel resolution, but for increased speed, VGA (640 * 480) rgb-color mode is used. The cameras connect to Aluminator's computer via a USB 2.0 interface, and in conjunction with OpenCV 2.0, operate at approximately 14 FPS.

Aluminator also employs a Videre Design STOC (Stereo On a Chip) stereo camera (*Figure 7*). This camera performs real-time image correlation using an on-board FPGA, and runs at 30 FPS. The stereo camera connects to Aluminator's computer via a fire wire (1394a) interface.

- ### POSITION SENSORS

Aluminator utilizes a Microbotics MIDG-II INS/GPS (*Figure 3*) as it's primary position / pose sensor. This device includes a WAAS compliant GPS, 3-axis accelerometer, 3-axis rate gyro, and a 3-axis magnetometer. The device is capable of integrating positional information through an on-board Kalman filter, and sending revised position / pose information via serial interface at 50 hertz.

Additional positional information can be derived from the motor controllers which maintain a running position based the wheel encoders. This derived positional information is relatively accurate at short time scales, but tends to drift due to wheel slippage. The combination of the GPS for long-term absolute accuracy, accelerometers for intermediate accuracy, and the wheel encoders for short-term accuracy is used to determine the most probable position at any point in time.

5.3 COMPUTING

All vision processing is done on Aluminator's onboard computer. Aluminator contains a small Aopen media P.C. (*Figure 6*) with a Core 2 Duo 1.6 Gigahertz processor. This computer provides ample processing power for a relatively small amount of battery power and is essential for the running of software. The computer is linked to a wireless router through which any other computer can use S.S.H. to make changes. Since it runs Ubuntu Linux this allows for code to be edited and compiled directly on the robot, as well as for changes to be made to the team's Bazaar revision control server. By using a prebuilt computer with open source software the team is able to keep cost and power low while still maintaining a high productivity.

6. SOFTWARE STRATEGY

The high-level functions are grouped into five primary modules that are described below (Figure 8). These modules help to organize the code, making it easier to edit or even replace whole modules without the user being required to comprehend the program as a whole.

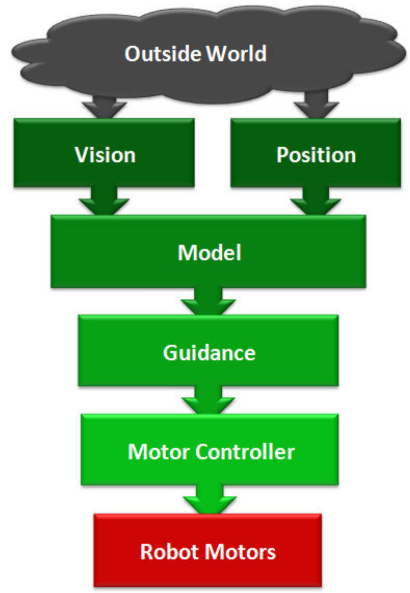


Figure 8: Software Architecture

- ***VISION***

Responsible for detecting lane line and obstacle features in the outside world using optical imaging cameras. Basic obstacles are classified by using stereo perception, color segmentation, and spatial filtering. Obstacle feature recognition is performed using advanced image processing techniques such as Hough filtering and curvilinear trend analysis.

- ***POSITION***

Responsible for determining relative and absolute position and orientation of the robot using a multitude of sensors including GPS, 3-axis Accelerometer, 3-axis Gyro, 3-axis magnetometer, and wheel encoders.

- ***MODEL***

Responsible for integrating vision and position information to enable building a map of the local environment. Also generates synthetic ray casts for use with some of the guidance algorithms based on lidar-like range finder sensors.

- ***GUIDANCE***

Responsible for determining the optimal path through the local environment and issuing commands to the Motor Controller Modules to move the robot.

- ***MOTOR CONTROLLER:***

Responsible for converting high-level movement commands generated in the Guidance module to low-level commands used by the motor controller hardware.

All of the team's software is written in C++, using object-oriented design. OpenCV is used extensively to support vision functions. The classes supporting a module are located in its module directory. Other directories are utilized for common information (configuration and calibration files), diagnostics (images / video sequences taken during testing), and advanced techniques under development. The entire software suite is managed by Bazaar revision control software. All team members are given access to and trained how to utilize the Bazaar system to facilitate coordinated parallel development. The flexibility of this software architecture and repository system has allowed for the team to test numerous strategies and over time come to the software solution that is being used today.

6.1 SIGNAL PROCESSING

- ### COLOR SEGMENTATION

For color segmentation, a training set is built by manually sampling all colors deemed to be "obstacles". These colors are mapped to a reduced resolution "RGB" cube to serve as a color signature. Colors accidentally collected as obstacles may be manually removed by mousing over areas that are not obstacles (grass, for example).

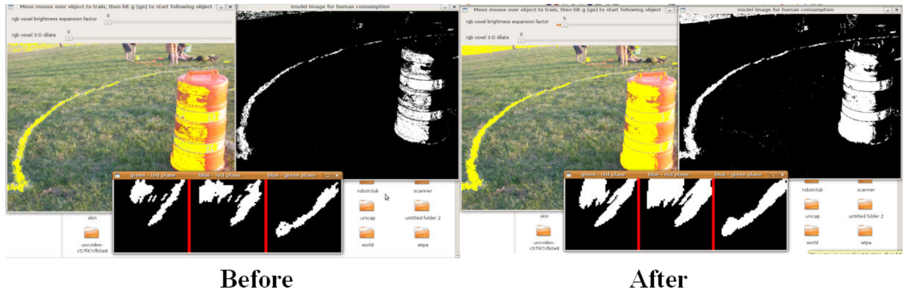


Figure 9: RGB Stretching Noise Removal

To enable Aluminator to correctly classify colors under changing light conditions, each color signature in the RBG cube can be stretched in the "zero vector" direction. This operation keeps the essential nature of the color signature (ratio of red-to-green-to-blue), but allows slightly darker or lighter versions of that signature to qualify as the same color.

A similar adjustment is provided which gently expands the RGB range of each color signature in all (RGB) directions(*Figure 9*). While this operation is less selective, it will essentially fills in small holes in the color signature. By stretching colors in the zero-vector direction to improve obstacle detection under a variety of lighting conditions.

- ### STEREO IMAGE PROCESSING

The stereo camera generates a point-cloud of (x,y,z) points (Figure 10) for all image points passing a correlation reliability filter. To separate the real-object voxels from mis-correlated noise, the point-cloud is rotated and rectified to fit the same ground plane used by the web camera array. A statistical analysis of this overlay provides additional information on which stereo voxels represent real-world objects.

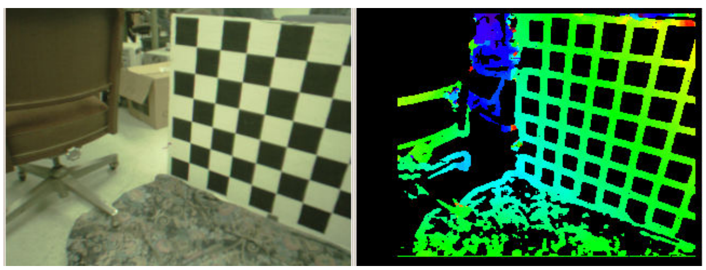


Figure 10: Stereo Camera Disparity Map

In addition, the positions of obstacles such as suspended plank saw-horses, as detected with the stereo camera, are mapped to a more accurate position than the same feature as observed by the web cams. This is due to the projective nature of the perspective rectification performed for the web cams. For objects touching the ground plane, the web cams will map their positions correctly; however, for obstacles that float above the ground plane (like planks on a saw-horse), the position of the obstacle will appear to be further away than it actually is. This situation is corrected by using the stereo-camera version of the same obstacle to correctly reposition it in the model space.

- **GPS / POSITION SIGNAL CONDITIONING**

The on-board MIDG-II microcontoller is capable of resolving differences in position as reported individually by its' internal GPS and accelerometers. This requires careful calibration to work properly. An internal Kalman filter determines the most probably position by taking into account the inherent time-scale and accuracy characteristics of both the GPS and accelerometers.

6.2 GUIDANCE

Aluminator employs two different guidance algorithms which are selectable depending on the type of situation.

- **RAY-CAST METHOD**

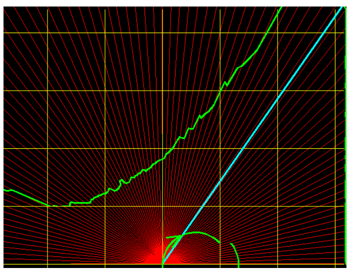


Figure 11: Ray-Cast Debugging Display

A ray-cast-based algorithm is utilized in situations where guidance methods developed under the player-stage simulation environment closely mimic the real world.

The image (*Figure 11*) to the left illustrates the ray-cast algorithm. The red lines (every degree) are the ray casts. The green line represents the obstacle detected (a white lane line on grass). The blue line represents the chosen direction and is the longest path available, that provides sufficient clearance for the width of the robot. The curved green arrow at the bottom center represents the path of the robot if this vector were pursued for 3 seconds. The yellow lines represent a 1-meter grid overlay for reference.

- **POTENTIAL FIELD METHOD**

A Potential Field algorithm is utilized where more complex types of obstacles are to be expected. After web cam images are rectified, combined, and color-segmented, a binary model is generated (*Figure 12*).

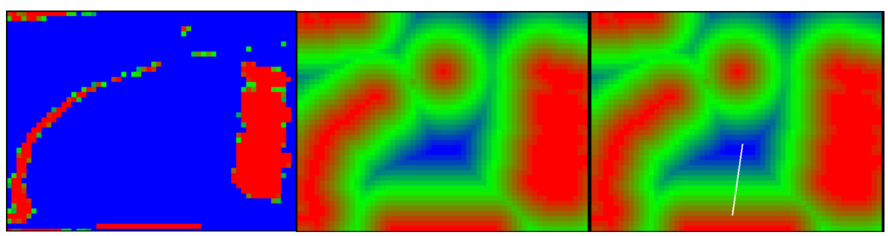


Figure 12: Potential Feild Model

When using the potential field method, obstacles are represented as hills, and way points are represented as depressions. A "robot repulser" hill is dynamically built behind the robot to encourage the robot to move in generally a forward direction. A simple gravity model is employ to propel the robot through the potential field. Local minimums are avoided by thresholding the surface, adjusting the strength of the repulser hill, and optionally, tilting the entire potential surface to favor flow toward the target position.

A reduced-resolution Field Strength is determined using a statistical surface derived from the relative density of pixels classified as "obstructions". A Potential Field is then built from the Field Strength surface, resulting in a topographic surface of the local obstruction environment.

The robot is located just above the center bottom in this potential field image. To provide Aluminator with an incentive to generally move forward (in robot-centric space), a "repulser" bar object is added to the bottom of the potential field. Next, a search is made of the immediate local area to determine a target position to move to. This location will always be "downhill" from where the robot is currently positioned within this potential field.

Previously, the combination of forward speeds and rotation rates necessary to travel to every reduced resolution potential field cell has been calculated and stored in a look-up table. Once the target potential field cell is identified, the forward and rotational velocities are derived from this look-up table (*Figure 13*), and passed on as motor commands to the motor controller module. Careful calibration and tuning of the curvilinear trend analysis parameters is required to achieve reliable results with this method.

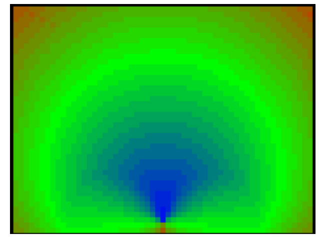


Figure 13: Motor Velocity Map

7. SYSTEM INTEGRATION PLAN

The control software for Aluminator was developed by several student members of the team – all working on different modules and levels. Early in the design process, emphasis was placed on higher-level module functional descriptions and interface specifications. After desired functionality and interfaces were designed, sub-teams were free to start coding up the internals of each module.

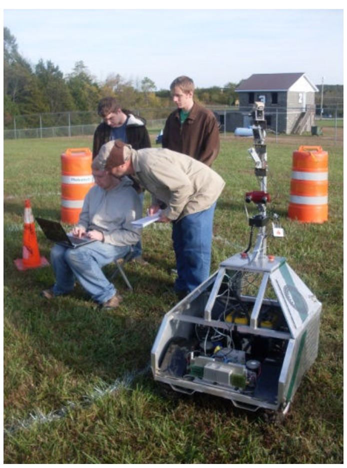


Figure 14: Field Testing

Testing was accomplished at both the module level, using test drivers, and at the system level using lab and hall-way operational tests. Once acceptable behaviors were reliably demonstrated in the lab environment, outdoor operational tests were conducted on a local field designed to replicate the IGVC course.

Since several team members participated in past IGVC events, the team was able to re-create all of the challenging features typically found at the IGVC event, including solid and dashed white painted lines, various densities of grass / dirt, shadows, sun glare, ramps, cones of various types and colors, snow fencing, plank saw-horses, switchbacks, center islands, dead-ends, traps, potholes, and sand pits.

During spring semester, the team scheduled numerous outdoor tests – each focused on a particular set of issues. After each test, the testing sub-team reviewed the results, took notes, and made plans to address any deficient performance observed.

8. PERFORMANCE EXPECTATIONS

The whole team feels very confident in the 2010 version of Aluminator and its superiority to previous versions. The robustness of its algorithms have been proven time and again in simulation. The new Elmo Drum motor controllers are much more reliable and powerful than the past Roboteq model. The team's predictions along with the demonstrated values can be found in *Table 1* bellow. The team has taken steps to ensure that spare parts for every component on the robot will be available at the 2010 IGVC. In short; the Missouri S&T Robotics Team is expecting Aluminator to have the university's best outing ever in the IGVC and finish among the top ten in the field.

Characteristic	Design Goal	Demonstrated in Field Test
Max Speed	5 MPH (2.237 M/s)	3.2 M/s (limited to 2.2 M/s in motor controller firmware)
Ramp Climbing Ability	15 degrees	22 degrees
Reaction time - processing rate (sense-think-act loop)	4 hertz	7 hertz
Battery Life	1 hour	1.6 hours
Distance at which obstacles are detected	• Web Cameras : o 4 M forward o 3 M side – looking o 5 M Diagonal • Stereo Camera: o 10 M forward o 60 degree FOV	• Web Cameras : o 4.5 M o 3.2 M o 5.52 M • Stereo Camera: o 12 M o 65 degrees
Accuracy of arrival at way points	2 M	1.5 M

Table 1: Performance Comparison Table

8.1 COMPLEX OBSTACLES

The following special situations are detected and handled by the control software. Specific detection / handling methods are described below:

- ### SWITCHBACKS

When a switchback situation is encountered, Aluminator will seek a path of least resistance. When no such path is obvious within 190 degrees of the front view, Aluminator will turn 180 degrees and examine the rear environment for a potential exit path. The limited obstacle model memory will discourage Aluminator from repeatedly taking the same path again.

- ### CENTER ISLANDS

Aluminator will tend to drive toward an area equi-distant from all obstacles – be they lane lines or barrels. This forces the robot to choose the widest path available, thus avoiding barrels in the center of a wide lane.

- ### DEAD ENDS

Aluminator retains a short-range memory of objects visited in the past few dozen cycles. If a dead-end is encountered, Aluminator will rotate 180 degrees (as in the switchback case above) to look for a more promising path.

- ### TRAPS

Aluminator employs a method similar to that used in detecting and navigating out of dead-ends.

- ### POTHOLES

Aluminator can be trained to avoid the color of sand and/or white circles. The stereo camera is capable of detecting slight depressions in the ground plane, even if not revealed by a unique color signature.

- ### DASHED LANE LINES

Aluminator employs Hough transforms and curvilinear trend analysis to connect partial white lane lines. This technique helps to avoid the situation where the robot "escapes" through an opening in the white lane line.

9. Safety

Aluminator is equipped with three emergency stops: one hard and two soft. The hard stop actually consists of two different push buttons located on the top rear of the robot. These are normally closed (meaning any break in the circuit will automatically trigger the stops, even if it's simply a wiring fault) stops, that are connected directly to Aluminator's motor controllers. Aluminator may also be stopped by a switch on our wireless E-Stop remote or through the use of the drive controls from a wireless laptop.

By controlling Aluminator with the Wiimote controller from the Wii gaming console the team now has more control over the robot than ever. The team can link the Wiimote and drive manually to testing areas and then the remote can be placed in standby mode to allow for autonomous testing. Aluminator's speed has been limited in the hardware to just under five miles per hour and the fuses installed on the motors ensure that they receive no more than forty amps. The robot is also programmed to stop upon the loss of a Wiimote or Wireless E-Stop connection or in the event of a crashed program. All programs are required to include a kick_the_dog function in their main loop that will reset a watchdog timer to prevent runaway situations.

10. Cost in Dollars/Hours

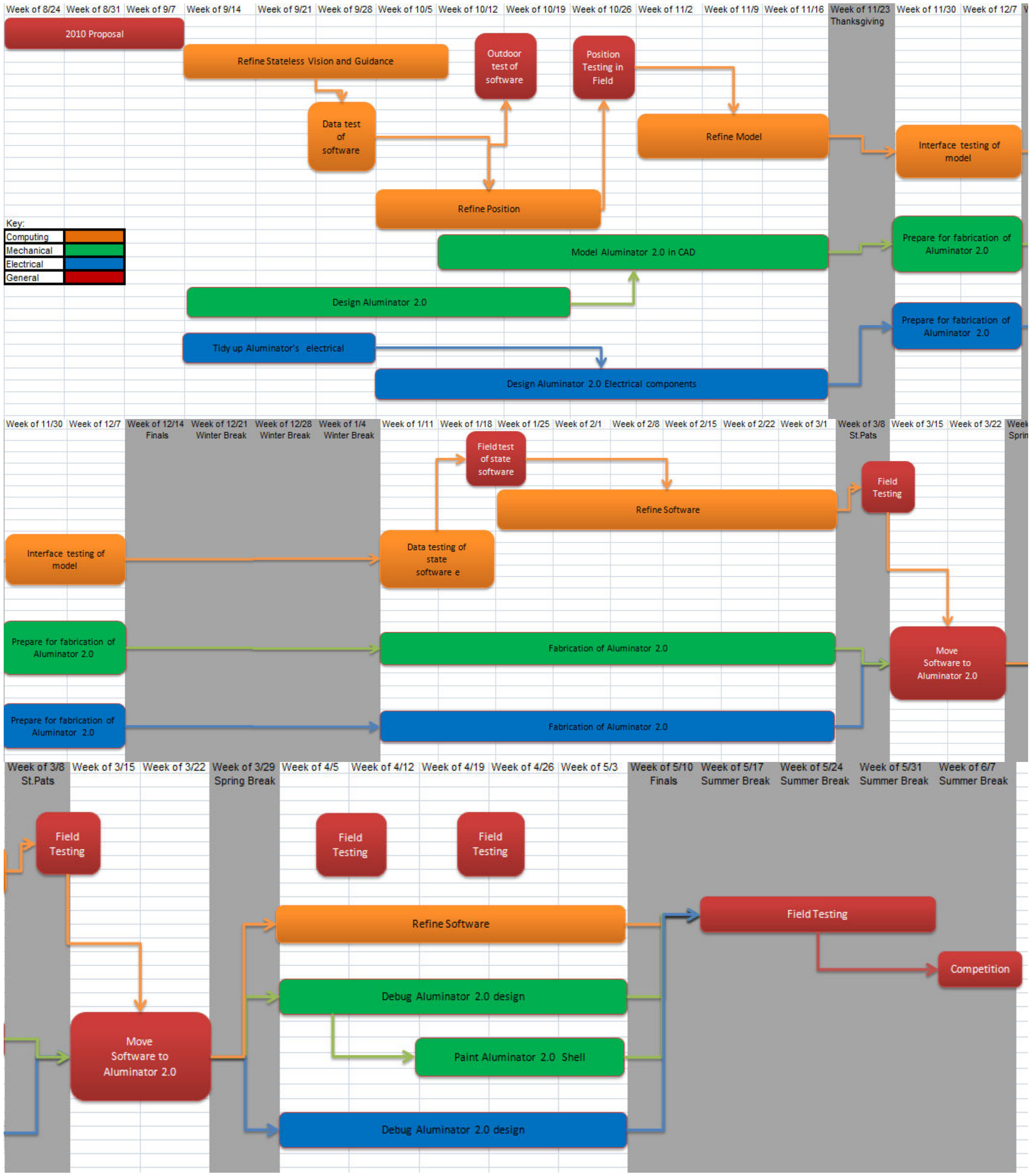
Aluminator has been in development for three years now. The total dollars costs for Aluminator in those years is shown below in *Table2*.

Component	Cost to Team	Retail Value
Frame	$200	$200
Motors	$300	$300
Shell	$250	$250
Wheels	$140	$140
Misc. Hardware	$100	$100
Misc. Electrical	$200	$200
Elmo Motor Controllers	$4,000	$4,000
Encoders	$170	$170
Batteries	$0	$336
Videre Stereo Camera	$1,450	$1,450
Computer	$500	$500
Blue-tooth Control	$0	$65
Web Cameras	$200	$200
Microbotics INS/GPS	$0	$5,710
Wireless Router	$60	$60
Totals	***$7,570***	***$13,681***

Table 2: Cost Analysis

The construction and programming for Aluminator has also required a large amount of man hours. On the whole, the team has spent an average of forty one hours a week preparing Aluminator for this competition. Over the past 3 years, this amounts to a conservative estimate one thousand five hundred man hours.

APPENDIX A: 2010 SCHEDULE



APPENDIX B. MEMBERSHIP LIST

First Name	Last Name	Standing	Major
Anderson	James	Junior	Computer Eng
Anderson	Miriah	Sophomore	Mechanical Eng
Bessent	Christopher	Junior	Computer Eng
Boyko	Ken	BS	Undeclared
Briggs	Emily	Junior	Mechanical Eng
Burge	Alex	Senior	Comp Sci/Computer Eng
Callanan	Eric	Junior	Mechanical Eng
Chrisco	Micheal	Junior	Electrical Eng
Chulick	Pete	Senior	Computer Eng
Fanger	Corey	Sophomore	Mechanical Eng/ Electrical Eng
Fitspatrick	Frank IV	Freshman	Mechaical Eng
Hall	Aaron	Junior	Computer Eng/ Electrical Eng
Heinlein	Daniel	Graduate	Mechanical Eng
Herrington	Shawn	Freshman	Mechanical Eng
Hoff	James	Junior	Mechanical Eng
Honse	Adam	Sophomore	Computer Eng
Howe	Kevin	Senior	Comp Sci
Isitt	Josh	Senior	Comp Sci/Computer Eng
James	Nathan	Gradute	MBA
Johnson	Jeremy	Freshman	Mechanical Eng
Marlowe	James	Freshman	Comp Sci/Computer Eng
McClendon	Eric	Freshman	Comp Sci
McQuay	Sean	Sophomore	Electrical Eng
Painter	Christopher	Freshman	Mechanical Eng
Patel	Neil	Sophomore	Computer Eng
Peterson	John Daniel	Freshman	Electrical Eng
Potter	Tyler	Senior	Mechanical Eng
Pryor	John	Sophomore	Undeclared
Sabatini	Antonio	Junior	Computer Eng
Steurer	Joseph	Sophomore	Comp Sci
Taylor	Arundel	Senior	Mechanical Eng
Turnbull	Jason	Senior	Mechanical Eng
Uhlman	David	Junior	Mechanical Eng
Vincent	Christopher	Senior	Mechanical Eng
Wisely	Michael	Junior	Comp Sci/ Computer Eng