AUTOMATON

Team Members:

Andrew Watson, Brandon Parmeter, Blake Parmeter, Josh Townsend, Chris Brice

Faculty Advisor:

Daniel Barber, Institute for Simulation and Training

Faculty Statement: I certify that the vehicle has been significantly modified for this year's competition

---

Daniel Barber

1 Introduction

The Robotics Club at UCF is honored to announce AUTOMATON into the 21st annual Intelligent Ground Vehicle Competition (IGVC). AUTOMATON is the culmination of efforts from a variety of predominantly undergraduate engineers whose efforts have yielded a remarkably competitive platform. With a focus on upgrading capabilities and maintaining reliability the team members were divided into groups which allowed their expertise to be honed in their respective fields. New camera systems, optimized power delivery, and new vision classification algorithms will allow AUTOMATON to extend its faculties to an increasingly arduous competition.

2 Design Process

The Agile method is the process utilized for construction and fabrication of AUTOMATON, and particularly its software. Agile development is centered around an iterative process of team collaboration to improve project clarity and ensure quality of work. This methodology promotes constant releases of software to maintain discussion of project direction. Development occurs in conjunction with requirement refinement thus ensuring minimum delays in progress. Progress is centered on short term goals with the hope of achieving an approach or strategy for solving a more abstract problem. These short term goals are usually released as software updates to AUTOMATON via open source software releases.

Figure 1: Agile Development Cycle

Figure 1 demonstrates the multiple loops involved in the Agile Development strategy. Closer to the center are continuous iterations of development, analogous to the daily software releases of AUTOMATON's code. Further from the center are the more abstract goals. This multi-loop system enables the team to develop in a very dynamic way, reducing risks associated with challenges faced throughout the design process.

3 Mechanical

Team Member	Andrew	Brandon	Blake	Josh	Chris	Total
Mechanical Hours		200				200
Electrical Hours			220	100		320
Software Hours	350			250	80	680

Figure 2: Hours Contributed

To ensure the optimum usage of space, Solidworks 2010 was used to model AUTOMATON prior to manufacture. The use of CAD software facilitated the foresight to create rigid structures under heavy objects such as the batteries. Two-dimensional drawings allowed for ease of passing information to manufacturing personnel. Files for use in three-dimensional printing were generated by the CAD software. The ease of rapid prototyping revolutionized the way unwieldy objects such as the Hokuyo scanning laser and the dual webcam vision system are mounted.

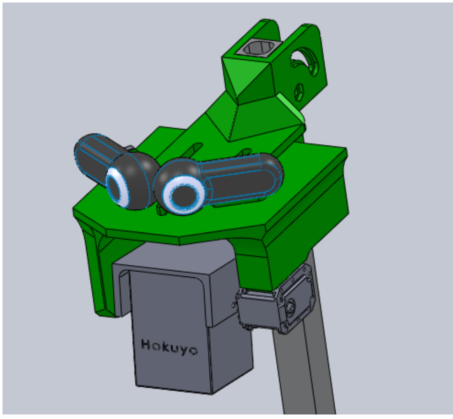

Figure 3: 3D Printed Camera and Tilting Lidar Assembly

3.1 Frame

Our overall frame size is a rectangular prism shape 1 ft. by 2 ft. by 3 ft. It is made mostly out of 1 in. x 1 in. aluminum tubing for weight saving. Four pieces on the bottom of 1 in. x 2 in. tubing provide a wide, flat surface for motor mounting and extra structural support. Also on the bottom is an 'X' pattern to provide extra stability for the two heavy car batteries. On the top of the frame, we incorporated cross braces that are spaced apart to exactly support the payload while allowing easy access to our batteries. Welded on the back of the frame is a sleeve for the mast to slide in which supporting the camera and GPS receiver.

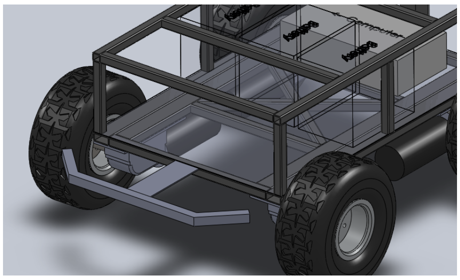
Figure 4: Frame and Bumper Assembly

The team's calculations indicated that the four power chair motors used are powerful enough for the specifications of the course. The only modifications made to them were adding the encoders with a fixture plate in place of the brake. The fixture plate design allowed for four different mounting positions of the encoders that enabled us to run the wires easily for a clean look. To mount the motors to the frame, a fixture plate was fabricated that provided a flat surface for the motors to mount over the welds. For easy steering, the motors are located center on the frame in an exact square pattern measured from the apex of the center of the tires. The hubs used were made for the motor spindles, held in place by a key way. No two piece wheels were available that fit the hubs, so an interface plate was designed and manufactured. This made the two compatible while allowing extra clearance room between the tires and the frame.

3.2 Drive System

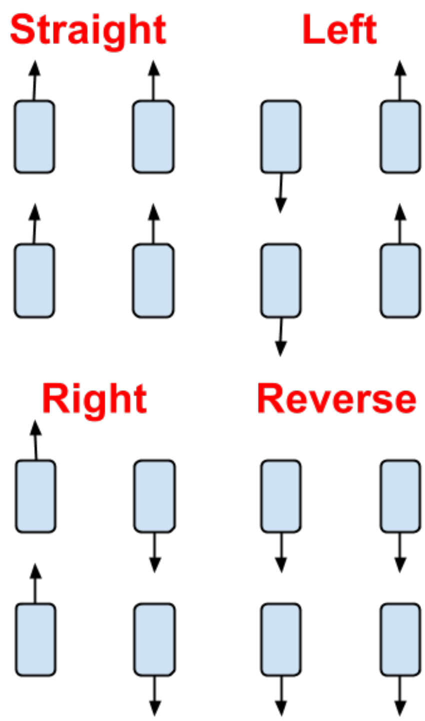

Figure 5: Skid Steering System

AUTOMATON's drive system includes four power chair motors mounted in a differential skid steering configuration. The power chair motors provide plenty of torque and speed to allow precise maneuvering through the course. Brakes were removed from the wheelchair motors to allow fitment of the quadrature encoders. They are used to monitor the speed of each individual motor to close a feedback loop. An aluminum plate was implemented to provide a flat surface for the motors to mount to. An in house fabricated adapting plate holds the wheel hubs to the stock motor hubs. To circumvent adding a heavy suspension system, inflatable tube tires were chosen to absorb vibrations due to the course's terrain.

4 Electrical

The electrical system in AUTOMATON meant to be as strait forward as possible, predominantly using off-the-shelf parts to minimize cost and reduce human error during construction. This simple philosophy proved to be very effective in making a solid platform which works consistently and effectively.

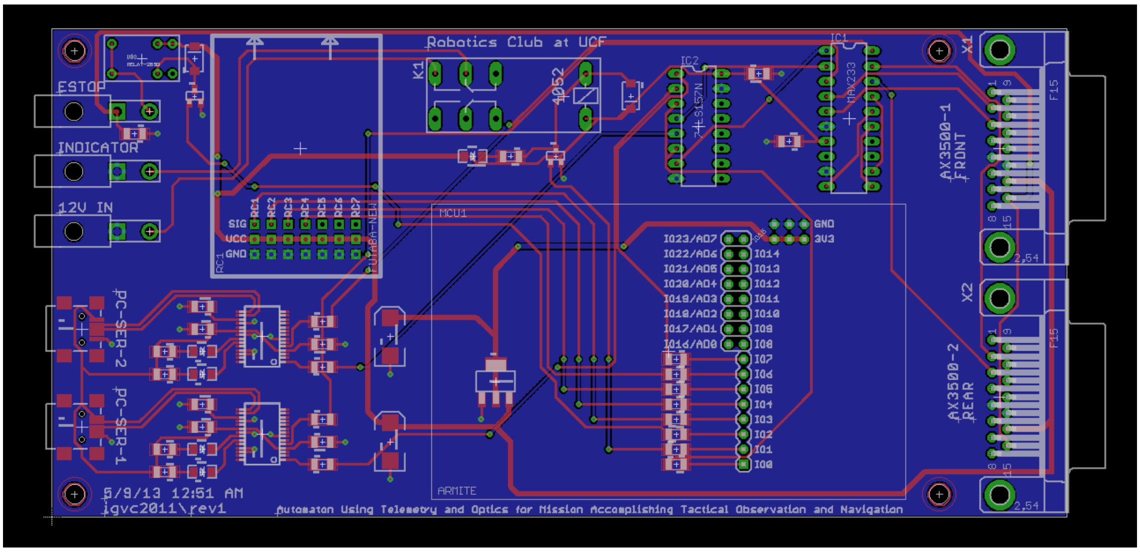

Figure 6: Microcontroller and RC Circuit Board

4.1 Motor Controllers and RC

Two Roboteq AX3500 motor controllers are employed to actuate the robot's motors. Each controller can output 60A per channel, with one motor connected to each channel. This allows the robot to have the capability to actuate each motor independently of the others. Commands to the controller are sent over RS232 serial. RC and PC control are toggled using an ARMmite processor on a customer circuit board, enabling AUTOMOTON to be driven Without the onboard PC being turned on.

4.2 Power System

Three 12 Volt 55 Amp-hour lead-acid marine batteries are used to power the platform. Assuming maximum efficiency of the motors, a 1-mile operational range is achieved. With all the sensors enabled and the computer on, a draw of 5 Amps was recorded, allowing for a maximum run time of 11 hours.The robustness of this battery technology allowed for the implementation of the four high-torque motors and the power-hungry computer. Battery chargers are also built into the vehicle, allowing for a convenient shore power setup.

4.3 Computer

AUTOMATON is equipped with a Quad-Core Hyper-threaded Intel Sandybridge i7 processor. The computer also has 8 GB of DDR3 RAM. In addition, it has support for connecting to devices which use 1394 FireWire, USB 2.0 and 3.0. RS232 communication is achieved using USB to Serial connectors external to the computer. It has a 300 Watt power supply in order to give it significant room for the machine's 95W processor.

4.4 Safety

Safety is a primary concern of the team, and thus precautions are in place in the event of system failure. There are two main methods of disabling the vehicle: wireless ESTOP and hard ESTOP. The wireless ESTOP can be activated by the RC controller, which bypasses the computer system and forces the robot to stop all actuation. The hard ESTOP is activated by a button about 4 feet from the base of the vehicle. This function completely disables the robot's motion, requiring both a reset of the ESTOP button and for the motor system to be power cycled. Additionally, the system is tied actively to the ESTOP button in such a way that if the line connecting the button were disabled, the system would go into ESTOP mode requiring a power cycle and reconnection of the button.

4.5 Sensors

Figure 7: Sensor Mast

AUTOMATON takes advantage of several different sensors to understand its own kinematics and surroundings. Kinematics are resolved using a 3-axis digital compass, the Coral AHRS, along with 4 quadrature encoders (one for each wheel), and a differential GPS to interpret its motion. The encoders, which run at 180 ticks per revolution before the gear box, deliver sub-millimeter accuracy in the rotation of each of the individual wheels enabling high precision closed-loop operation. The Differential GPS on board provides sub-meter accuracy, with tests indicating 2 to 8 decimeters.

Sensor List

- Hokuyo UTM-30LX scanning laser
  - Two dimensional scanning laser
- MicroStrain 3DM-GX1 compass accelerometer
  - Compact compass and accelerometer, 0.5°accuracy
- 2 x Logitech Webcam Pro 9000 camera
  - Commercial off the shelf webcam
  - Selected for superior image stability and color quality
- CSI Wireless MD Minimax GPS unit
  - Global Positioning unit with sub meter accuracy

5 Software

The JAUS challenge has stringent requirements for adherence to the SAE JAUS standard. The service-based architecture defines reusable capabilities of autonomous vehicles broken down to the most abstract levels. The architecture heavily influenced design of AUTOMATONs software and implementation in order to comply with the standard. Continuing the success of previous iterations the software base utilizes two separate programs for vehicle operation.

5.1 Structure

The two main programs "Baseline" and "Ground" are run on AUTOMATON to complete all course challenges. The Baseline program is responsible for integration of all hardware and sensors (I/O devices). Using JAUS as an abstraction Baseline is a standalone program allowing for any JAUS compliant program to subscribe to data streams and to request vehicle control. The ground program utilizes JAUS messages to maintain control of the vehicle through the Baseline program. This program contains all AI and intelligence including vision processing, path planning, and obstacle avoidance. The JAUS library utilized is JAUS++ which is available on sourceforge.net. The JAUS++ library was selected for its proven compliance with the SAE standard at previous AUVSI competitions and strong documentation.

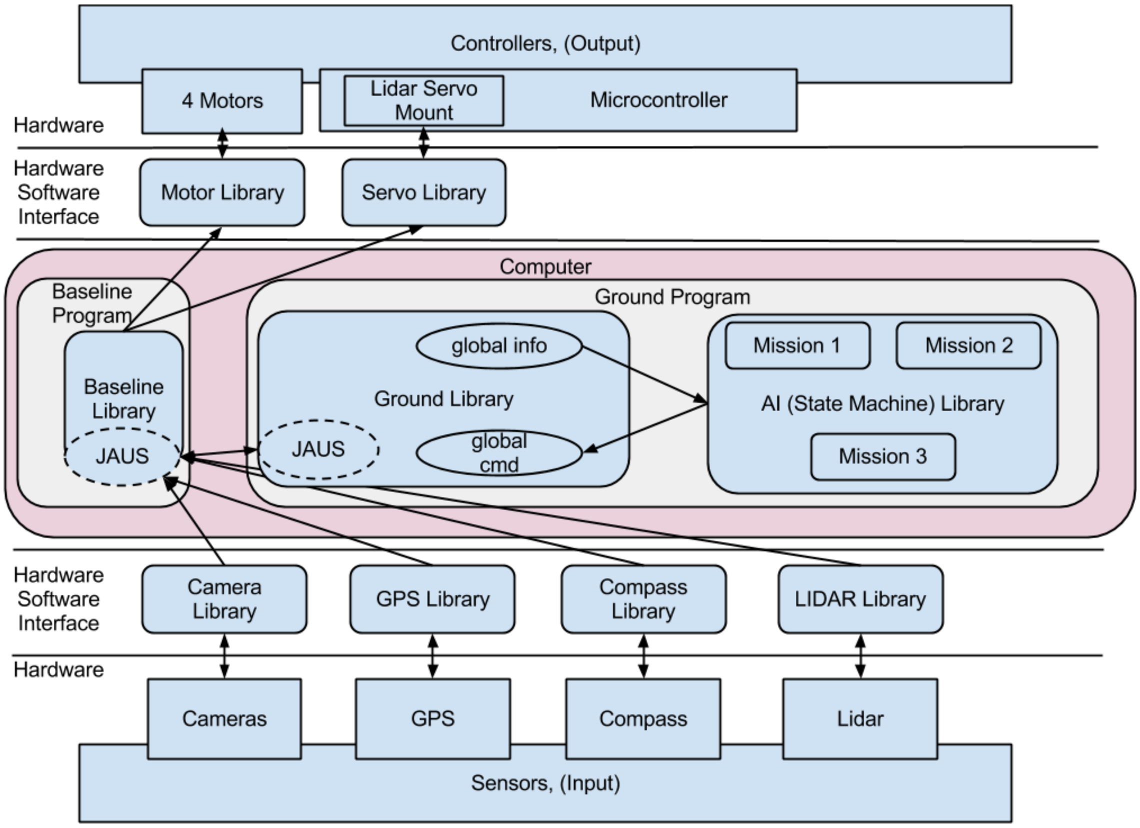

Figure 8: Software Overview

The programs are currently using version 2.0 of the open source JAUS++ library available on sourceforge.net to provide JAUS compatibility.

5.2 Baseline Program

Abstraction of sensors and all hardware into JAUS services are the primary goals of the Baseline program. This program also provides crucial support for the JAUS Challenge via the following implemented services: Velocity State Sensor, Local Pose Sensor, List Manager, and Local Waypoint List Driver. Additional JAUS services are also implemented to ensure support for open and closed-loop control. Primitive Driver service allows JAUS components to acquire low level open-loop drive control of AUTOMATON. The Velocity State Driver utilizes subscriptions to the Primitive Driver, Local State, and Velocity State Sensors to provide closed-loop velocity and rotation rate control. Baseline allows developers to leverage vehicle capabilities in order to design applications for autonomous control via a well defined standard.

5.3 Ground Program

A stable platform with robust capabilities is at the focus of design of AUTOMATON and all programmed intelligence therein. With Baseline as a host the Ground program builds autonomy into the system with the use of object detection, path planning, and finite state machine logic to accomplish tasks provided by the competition. The separation of the AI allows developers to quickly analyze system and algorithmic performance of the system as well as provide separate interfaces to the different subsystems. The Ground program provides useful debugging tools by supplying an interface for sensor data playback logged during practice runs. Logging is useful for debugging all intelligence systems from vision classification to state machine logic.

5.4 Computer Vision

All aspects of the IGVC course depend on the ability of vehicles to detect objects and markers in a dynamic environment. AUTOMATON accomplishes this via a robust detection system which leverages onboard vision processing from a dual webcam vision system. The platform applies vision algorithms for locating boundary lines of the course and providing supplemental cues to the AI of possible obstacles and other regions of interest. Vision algorithms are responsible for classifying, estimating, and detecting angles of lane boundaries. Other tasks include recognizing and filtering out potential obstacles in the path of the vehicle. OpenCV is a computer vision library utilized for all vision processing as it is powerful, well supported, and features many useful tools for accomplishing both lane line and obstacle detection.

5.4.1 Lane Line Detection

Figure 9: Raw Image

The most fundamental asset of navigation in AUTOMATON's AI is the ability to estimate position relative to lane lines discovered in vision processing. Software research discovered existing approaches to the problem and were used in conjunction with algorithms from previous IGVC events. The solution applied to AUTOMATON requires an application of a white filter to the image upon removal of any obstacles seen. Bright areas of interest are identified and the image is then passed through a Gaussian blur to smooth areas of noise. Edge detection outlines contrasting areas of the remaining image and a

Canny edge detector outlines the edges of the white lines on the grass. To perfect and improve reliability of lane line detection blob detection is used to remove any edges smaller than predetermined levels so as to remove random noise caused by uneven terrain or brown patches of grass.

After all filters have been applied the image consist of white outlines on a black background outlining the lines. To compute a line the team utilized a RANSAC (RANdom SAmple Consensus) algorithm. Tests of the RANSAC against Hough line transforms proved more consistent in line fitness and had an added benefit of returning a single line rather than many. The algorithm is run twice to detect both lines.

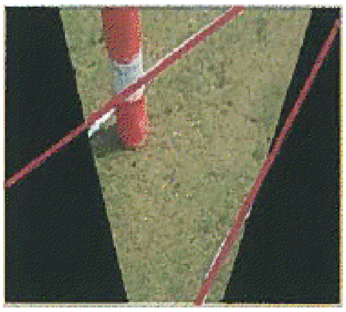

Figure 10: Post Processing

5.4.2 Obstacle Detection

Vision processing is used in conjunction with laser readings to detect obstacles. Algorithms running blob and color classification are run on captured images from the panoramic vision system. Images capture in the RGB color space are converted to HLS (Hue Lightness Saturation) for more reliable color classification as hue becomes the favored channel.

5.4.3 Perspective Correction

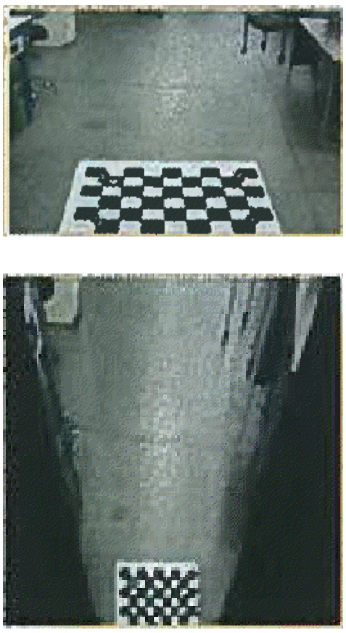

Figure 11: Homography

AUTOMATON's single camera is mounted about 6 feet above ground and aimed at a downward angle to see the ground directly in front of the vehicle. In a 2D image captured from the camera, objects and lines close to the vehicle appear large or far apart, while objects and lines further from the vehicle appear small or close together. This is the illusion of perspective, and because of this illusion an accurate mapping of line angles, lengths and locations cannot be done without some transformation of the 2D image.

Correcting perspective requires an offline calibration phase in which a rectangular object of known size is placed on the ground plane in front of the vehicle. The corners are picked out, and a matrix is generated that transform relative pixel coordinates of the corners to the actual known relative corner positions. This matrix can then be applied to the entire image to correct each pixel for perspective distortion. This has the primary benefit of correcting angles that would be incorrect due to perspective, such as the illusion of parallel lines converging in the distance.

The secondary benefit of this correction is that pixels can also be mapped to an arbitrary unit of distance; in AUTOMATON's case each pixel is mapped to 1 centimeter. This mapping only applies to features on the ground(such as lane lines), and can be fairly accurate depending on the quality of image and calibration.

5.5 Real-Time Configuration

Most important variables that tweak AUTOMATON's behavior have been added to XML files which are easily human readable and modifiable. These files contain information about the robots JAUS configuration, hardware devices, vehicle dimensions, mission, and so on. For situations that require input or training, such as vision processing or Proportional Integral Derivative (PID) controller tweaking, AUTOMATON can load changes in real-time so that effects can be observed immediately.

5.6 Logging and Playback

Recording data for analysis is an important part of improving performance of this vehicle. Through XML, logging of all sensors, including video and LIDAR can be turned on at any specified rate. Recording runs through courses will be valuable data for not only the current team but for future UCF teams that wish to attend this competition. Because of the flexibility and modular nature of AUTOMATON's software systems, logged data can be replayed through AUTOMATON's AI, this allows for a powerful way to understand the dynamics of AUTOMATON's decision making, as the system knows no difference between being fed logged data or real-time data.

5.7 Real-Time Mapping

The Cartographer mapping library has been used before in previous competitions, but not to the same extent as AUTOMATON. This year sees the addition of more efficient map storage and retrieval, improved path planning and navigation and for the first time cooperation with the vision processing subsystem. Lane lines found through vision are merged with LIDAR data to create a detailed and cohesive map of the environment around AUTOMATON.

6 Mapping

All of the maps are constructed in a framework called Cartographer. This framework is very flexible, allowing the system to build vector or raster based maps depending on what is deemed best for a given situation. Abstracting the type of underlying map, developers can implement different types of path planning algorithms for obstacle avoidance and navigation. This specific feature supports prototyping many different algorithms to determine what works best for the challenges presented. The map used is a 2 or 3 dimensional, top down view of the world. Map information is stored in a Quadtree structure to take advantage of spatial locality of objects in order to minimize search space for path searching algorithm.

6.1 Navigation Challenge

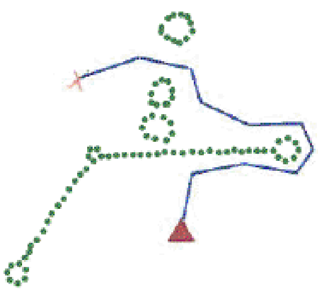

Figure 12: Best-First Algorithm

For the navigation challenge a similar system to the autonomous challenge is employed, with the exception being that there are no lines added to the map. Additionally, maps maintain a longer persistence in this challenge, due to the higher tendency of traps which could be encountered repeatedly. Although this creates some problems with map data conflicting when something has been viewed at different times, showing up in different locations, these anomalies are accounted for through combining objects discovered with similar parameters, applying a time-to-live for objects within the map, and continuous reassessrnent of the environment. Navigation is done using a best-first traversal algorithm, where goal points are set in a list given before run time. This algorithm was chosen because it is one of the fastest approaches to search. However, unlike Dijkstra's algorithm and A*, which take O(n) amount of memory, best-first uses memory O(n^2). The system can tolerate this memory usage because it has 8 GB of on-board RAM, and therefore memory was traded in favor of speed.

6.2 Autonomous Challenge

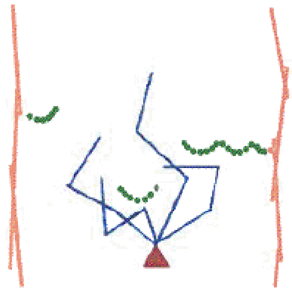
Figure 13: Beam Search Algorithm

For the autonomous challenge, there are two types of objects added to the map. The first are points, generated from the LIDAR, represent elements of a point cloud in the environment. These points come together to form barrels and other obstacles. The other type is the lines, which are treated like Walls in the map's representation. The computer vision system projects the lane lines it finds into the ground coordinate space and then added to the map as a line segment (or Wall segment). All obstacle avoidance is then carried out to navigate around these dots and lines. Lane lines are given a unique ID within the map, for determination of lane direction and center.

For path generation, a beam search algorithm was chosen. This type of algorithm attempts to find a set of connected beams which will reach the desired goal without hitting any obstacles. A depth of 3 beams slightly wider than the vehicle are chosen to give tolerance to the size of the vehicle and also because it gave a sufficient search space for the robot to a path in most instances. A single path is chosen using a fitness function which Weighs paths on their length and proximity to the goal. Using the results of the algorithm, a velocity and heading are generated for closed-loop drive control.

Higher and lower speeds can be tolerated dynamically by adjusting the beam length and depth. For instance, if the robot travels at a faster speed, the length of the beams can be extended and the maximum angle which the beams are allowed to bend is reduced so that the robot can anticipate motion in advance and does not need to make as drastic of turns. Vehicle speeds are selected based on how cluttered the surrounding environment is, with high speeds chosen in 10W density areas, and low speeds when object density is high.

7 Innovative Features

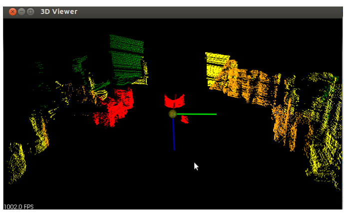
Figure 14: 3D Laser Scan

AUTOMATON employs a plethora of innovative features that will set the vehicle above the playing field in the 2013 IGVC competition. A wireless network bridge is implemented to establish a reliable data link to the vehicle.

This bridge allows for a solid stream of up to 54Mbps to a mobile cart at a distance of up to several miles! containing a computer and an uninterruptible power supply.

In previous submissions a scanning laser was employed, this sensor has since been improved. This improvement consisted of a implementation of a servo motor to change the pitch of the laser. This allowed for the sensor to be placed higher on AUTOMATON in a more protected area. It also allowed for scanning on multiple planes so that a Point cloud of the vehicle's environment could be formed.

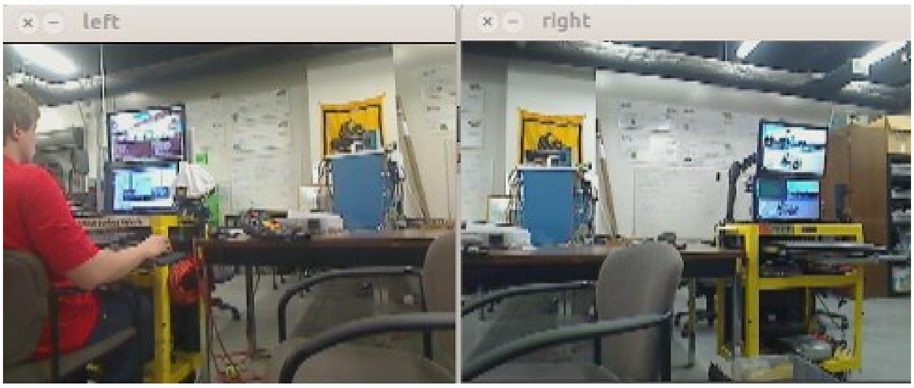

Figure 15: Camera Streams

This year the vision system was improved by implementing an array of two webcams. The webcams provided a vibrant colors pallet when compared to other video sources. The cameras were offset from each other to provide a wider field of view than a single camera. The two video streams are put together using a stitching algorithm and then sent to the computer vision system for processing. Another

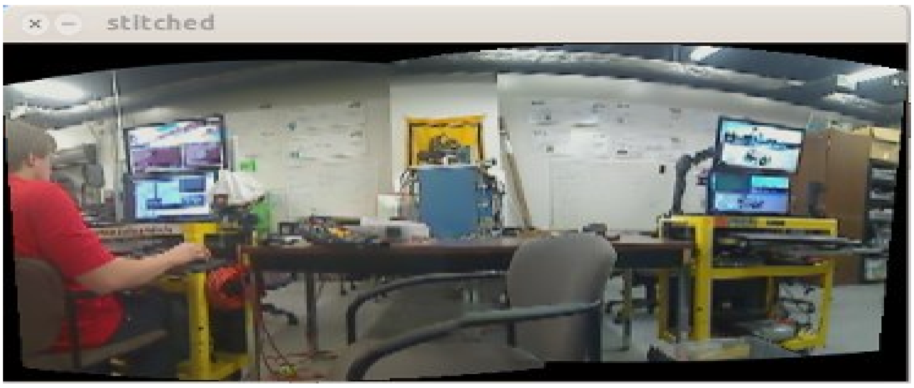

Figure 16: Final Panorama

feature implemented in the 2013 submission is a video streaming server. The server allows for multicast connections to clients vastly improving network efficiency. Although only implemented for a single video source, this system allows for a wider array of video input devices to be seamlessly integrated. Future video streams may include a two dimensional representation of the environmental point cloud or an infrared camera system.

8 Vehicle Performance & Analysis

8.1 Performance

AUTOMATON has been designed to meet or exceed the requirements of this competition now and years to come. It is rugged and robust, built to be weather resistant and terrain dominating.

Metric	**Analysis**
Speed	7.6 miles per hour
Battery Life	2-3 hours (approximately)
Total Stored Power	2 kWh
Max Tested Incline	50°
Reaction Time	.07 seconds (approximately)
Object Visible Range	30 meters
Trap, Dead End Compensation	Global map stored so alternate routes can be found
Waypoint Accuracy	20-80 centimeter

8.2 Budget

Although several of these parts were inherited from previous projects at the lab, their cost has been included in order to better describe the price to duplicate the work.

Item	**Unit Cost**	**Quantity**	**Total Cost**
Computer	$900.00	1	$900.00
Aluminum (box and sheet)for Frame	$350.00	-	$350.00
Welding Work	$100.00	-	$100.00
Wheelchair Motors with Gearbox	$299.99	4	$1,199.96
Mini-MAX DGPS	$2,000.00	1	$2,000.00
180 PPR Quadrature Optical Encoders	$50.00	4	$200.00
Wheels, Inner tubes, Hubs	$78.04	4	$312.16
Hokuyo LIDAR	$5,000.00	1	$5,000.00
Dynamixel RX-24F	$140.00	1	$140.00
Coral AHRS Digital Compass and IMU	$1,245.00	1	$1,245.00
Logitech Webcam Pro 9000	$90.00	1	$180.00
Roboteq AX3500	$400.00	2	$800.00
Ubiquiti Wireless System	$250.00	2	$500.00
Miscellaneous Electronics	$700.00	-	$700.00
Miscellaneous Mechanical	$350.00	-	$350.00
Total			$13,977.12

9 Conclusion

AUTOMATON, The University of Central Florida's entry to the 2013 International Ground Vehicle Competition is a rugged platform for robotics education. The integration of hardware and software has yielded a vehicle that is robust enough to navigate the most challenging obstacles in the most extreme environments that AUVSI has to offer.