LTU Challenger

TEAM MEMBERS:

Andrey Chernolutskiy
Vincent Shih-Nung Chen

Faculty Advisor's Statement:

The work that the LTU Challenger student team performed with regards to design and implementation was significant. It is equivalent to work that is typically awarded credit in Lawrence Technological University Computer Science graduate course.

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Associate Professor, Department of Math and Computer Science, Lawrence Technological University

1. Introduction

Lawrence Technological University proudly presents LTU Challenger, an autonomous robot designed to compete in the 12^{th} Annual Intelligent Ground Vehicle Competition. The key word here is "intelligent", and that's what we've tried to make our robot. With the same hardware available to all the teams, we have focused on the software part to give our robot truly intelligent behavior. LTU Challenger heavily employs fuzzy logic and evolutionary neural network technologies to compete in the Autonomous and Navigation Challenges.

2. Design Process

2.1 Team Organization

Team Member	Man-Hours	Duties	Major
Andrey Chernolutskiy	370	Hardware design, software design and development for the autonomous challenge, project documentation	M.S. in Computer Science
Shih-Nung Chen	390	Hardware design and construction, software design and development for the navigational challenge	M.S. in Computer Science

Table 1

2.2 Design Philosophies

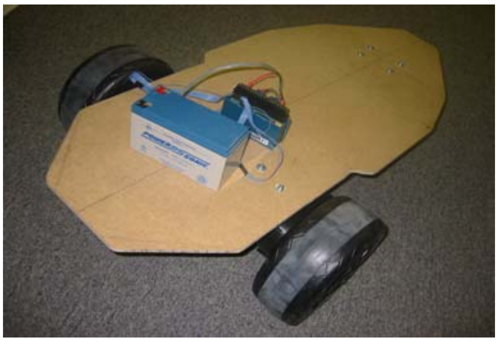
Our goal was to utilize on-board laptop computer as the main control system, which would be interfaced to a microcontroller based control system and serve as a link between the main control module and motor control hardware. In addition, the robot would be able to carry a variety of sensors as need arises. Ideally, it would be reusable in computer science education and would be able to be mass-produced.

2.3 Design Planning Process

To develop the software for the robot, we selected the incremental spiral model. Our first goal was to develop a prototype robot, equipped with a web cam, which could follow a line drawn on a blue tarp. Next, we developed a second prototype, which could follow a course bounded by two dashed white lines. Then, we added obstacles and traps to the course and replaced the web cam with a mini-DV camera. At the same time, we were building a rule base for the fuzzy inference system which would control the robot behavior in the IGVC competition. We also made slight modifications to the robot platform's camera placement and wheels.

3. Hardware Design

3.1 Body



The robot body was designed and built from off-the-shelf components. The majority of the parts were purchased at a local hardware store. The robot is 3 feet long and 2 feet wide in the middle. The main body was constructed from 0.25 inch thick medium density fiber (MDF) board and carries the camera tripod, the battery, the motor controller board and the payload. The upper body was constructed from 0.25 inch thick MDF board and carries the on-board laptop and the GPS unit.

3.2 Drive Train

A front wheel drive was chosen to allow the robot to climb a ramp easily. It is powered by two 12 Volt 7 Amp FisherPrice motor gearboxes with a 111:1 gear ratio. Each motor allows individual speed and direction control, and, as a result, is able to execute a zero-point turn radius which improves maneuverability in tight conditions.

3.4 Motor Control

The motors are controlled using a Vantec CDFR-21 dual-channel driver board. The motor board can handle up to 14 Amps of current per channel which makes it an ideal component for this particular robot. This driver board provides Pulse Width Modulation (PWM) speed and directional control. The board interfaces to the laptop through the parallel port. Commands are sent through the parallel port to the motor driver board, which in turn interprets these commands and generates a PWM signal that is sent to the motors.

We wrote low-level drivers in the Java Native Interface for accessing the parallel port and sending commands to the motor driver board. These drivers present the programmer with a high-level functional interface to the board. The program makes a call to functions such as "*forward()*" or "*reverse()*", and the driver parses these commands and sets the desired bits on the parallel port. This, in turn, forces the motor driver board to send the desired PWM signal out to the motors.

4. Electrical Systems

4.1 Vision Sensors

Our primary method for obstacle and lane detection was to use a JVC GR-D93 mini-DV camcorder with an automatic shutter and a 0.5x wide angle lens. We reviewed several models and chose this camera for its IEEE1394 interface and above average performance in bright lighting conditions. Previous IGVC teams from Lawrence Tech successfully competed with simple web cams, and we believe upgrading to a DV camcorder will eliminate the need for other sensors.

4.2 Power System

The main power source for the robot is a 12 Volt 7 Amp sealed lead acid battery. The laptop, the GPS unit, and the camera have their own rechargeable batteries separate from the main robot electrical system. This design isolates and protects the laptop and GPS from the unlikely event of a dangerous electrical surge in the robot power system. A 30-amp fuse protects the entire robot electrical system and Vantec motor board from overcurrents. For safety reasons and as part of the IGVC qualification requirements, manual and remote electronic emergency stop switches are wired in series to the battery connection. Thus, both switches must be closed to power the main system power bus. Any one of these switches can be opened to cut off all electrical power and stop the robot in the event of a dangerous loss of control. The remote e-stop consists of an automotive keyless entry remote switch unit with a range of 50 feet and a relay in series with the battery connection to the main power bus.

4.3 GPS Navigation

At the center of any successful GPS navigation is the GPS unit itself. The LTU Challenger uses the Garmin eTrex GPS unit. It is designed to provide precise GPS positioning using correction data obtained from the Wide Area Augmentation System (WAAS). The Garmin eTrex GPS unit will provide position accuracy to less than three meters when receiving WAAS corrections. The positional information is communicated over a serial port to the robot's onboard laptop.

We used a pre-computed shortest path algorithm to determine the order in which the waypoints are visited. As obstacles are encountered and detected by camcorder, the robot will modify its course to avoid obstacles while continuing toward the next waypoint.

4.4 Computational Hardware

The onboard computer used for all vehicle control, sensor interfacing, and communications is a laptop computer that uses a Pentium III 600 MHz processor running the Windows 2000 operating system. The laptop has two USB ports, a single IEEE1394 port, a parallel port for connecting the motor driver board, and a serial port for connecting to GPS unit.

4.5 System Integration

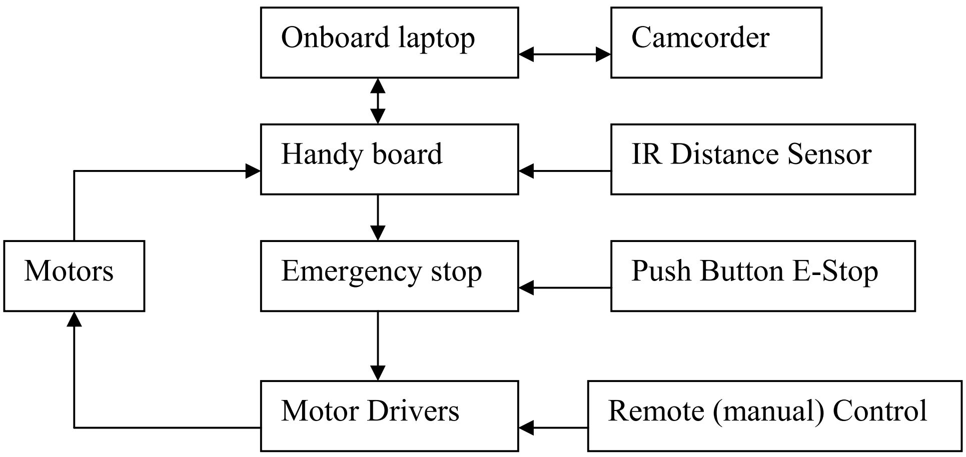


Figure 1

5. Software Design

LTU software consists of several key components. Vision processing is used as a primary sensory input for line and obstacle detection. Images are pre-processed by an evolutionary neural network. Decision processing uses a fuzzy inference system to determine the rules for following the lines and avoiding obstacles. A motor processing unit sends commands to the motors and controls the motion of the robot.

5.1 Software Architecture

The figures below show the key elements involved in the processing for the Autonomous and Navigation Challenge.

Autonomous Challenge - High-Level Architecture

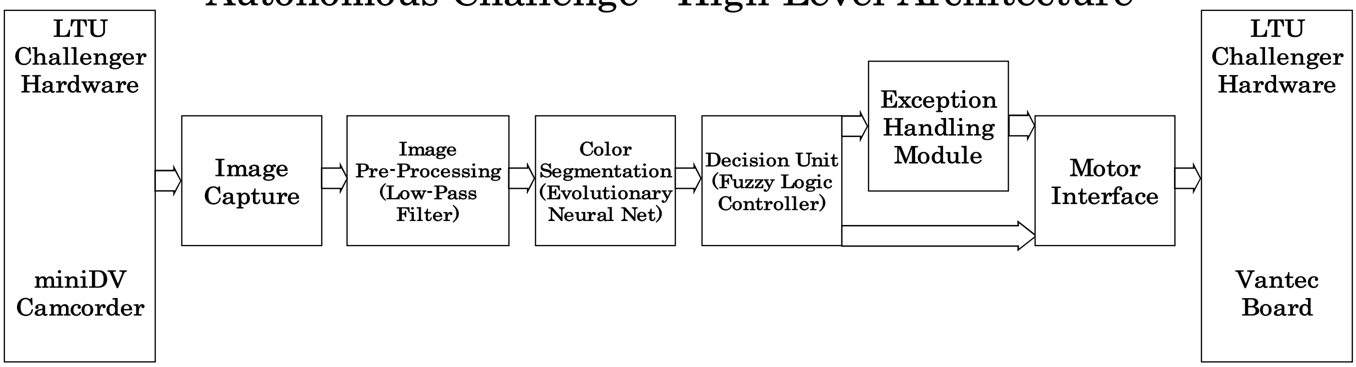


Figure 2

High-level architecture for Navigation Challenge

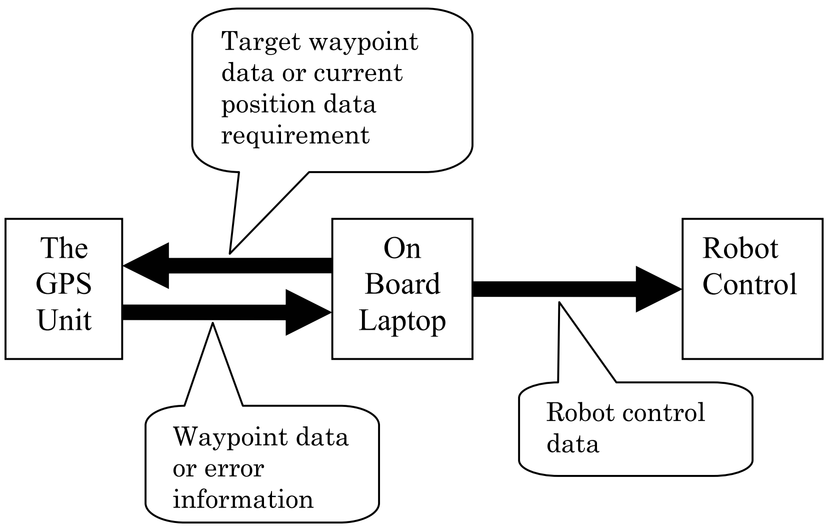


Figure 3

5.2 Image Capture and Processing

Low-level drivers in the Java Native Interface for accessing the IEEE1394 interface and getting data from the camera were written by our team. We apply a custom low-pass filter to every new image to filter out noise and enhance image quality. Next the image is sent to the color segmentation unit, which classifies every pixel in the image into one three of the following categories: red, white, background. The color segmentation unit needs to be trained in the actual environment by presenting it with a few samples from each category. We use evolutionary strategies, namely, ES(1+1) with 1/5 rule, to train the color segmentation unit. The objective function being minimized is the difference between the actual and the expected output of the ANN. Then all red pixels are explicitly converted to white to simplify the fuzzy logic.

5.4 Decision Unit

Next the pre-processed image is split into a grid of 6 cells (2x3). The percentage of white pixels in cell is counted, and the resulting array of 6 floats (C_1 through C_6) is sent to the fuzzy inference system. The output of the FIS is the turn direction (left or right), the amount of time during which the robot should turn in that direction (turn time and direction), and the amount of time during which the robot should travel forward (straight time).

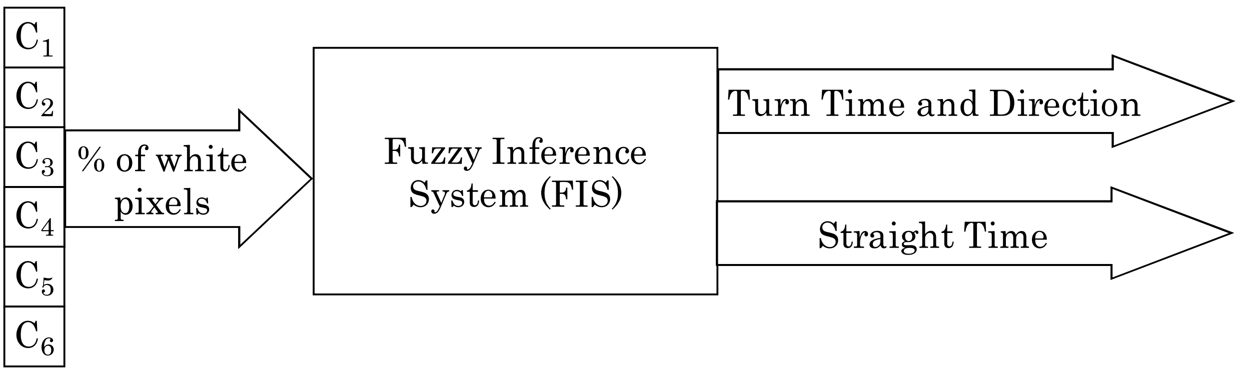


Figure 4

Internally, the FIS consists of two separate fuzzy logic controllers. Both controllers use the Sugeno model for the fuzzification and defuzzification of data and “triangular membership function” to define the data sets. The first controller accepts the percentages of white pixels in the grid and produces the turn time and direction. Each grid in the cell is classified as white or not white according to the following membership function:

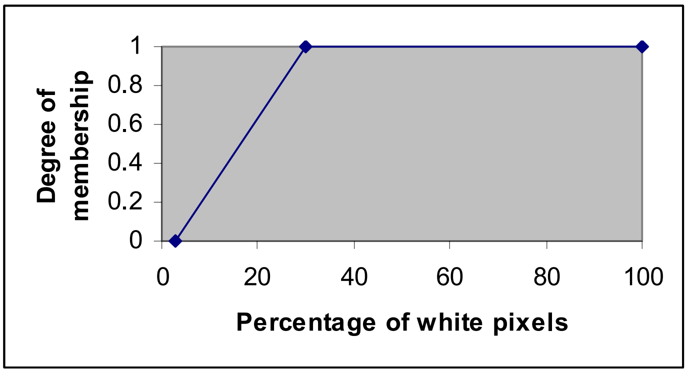
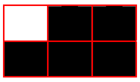
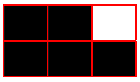
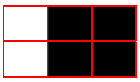
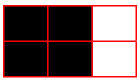
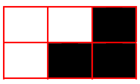
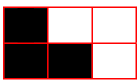
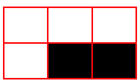
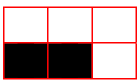
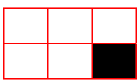
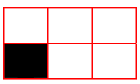


Chart 1

The following table lists the rules for this controller:

Input matrix	Rule	Action
	If C_1 is white and all other cells are not white…	Turn slightly right
	If C_3 is white and all other cells are not white…	Turn slightly left
	If C_1 and C_4 are white and all other cells are not white…	Turn right
	If C_3 and C_6 are white and all other cells are not white…	Turn left
	If C_1, C_2, C_4 are white and all other cells are not white…	Turn hard right
	If C_2, C_3, C_6 are white and all other cells are not white…	Turn hard left
	If C_5 and C_6 are not white and all other cells are white…	Turn hard right
	If C_4 and C_5 are not white and all other cells are white…	Turn hard left
	If C_6 is not white and all other cells are white…	Turn hard right
	If C_4 is not white and all other cells are white…	Turn hard left

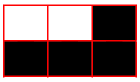
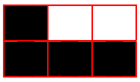
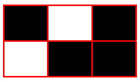
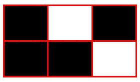
	If C_1 and C_2 are white and all other cells are not white…	Turn hard right
	If C_2 and C_3 are white and all other cells are not white…	Turn hard left
	If C_2 and C_4 are white and all other cells are not white…	Turn hard right
	If C_2 and C_6 are white and all other cells are not white…	Turn hard left

Table 2

The output is a single floating point number, giving the turn time while its sign specifies the turn direction. This number is passed to the second FLC which uses monotonic selection to produce the straight time, inversely proportional to the turn time.

5.5 Dead Ends, Traps and Potholes

Occasionally, he FLC is unable to match the input matrix with any of the predefined rules with a sufficient degree of certainty. When the certainty factor falls below an established threshold, the FIS is relieved from directing the robot and the exception handling module is activated. This module tries to resolve the situation by turning the robot left and right and by checking if the FIS is ready to resume the control. Otherwise, the exception module will replay the robot's movements in the opposite direction, constantly checking for an alternative path until one is found.

5.6 GPS Data Processing

The figure below shows the key elements involved in the GPS data processing for Navigation Challenge.

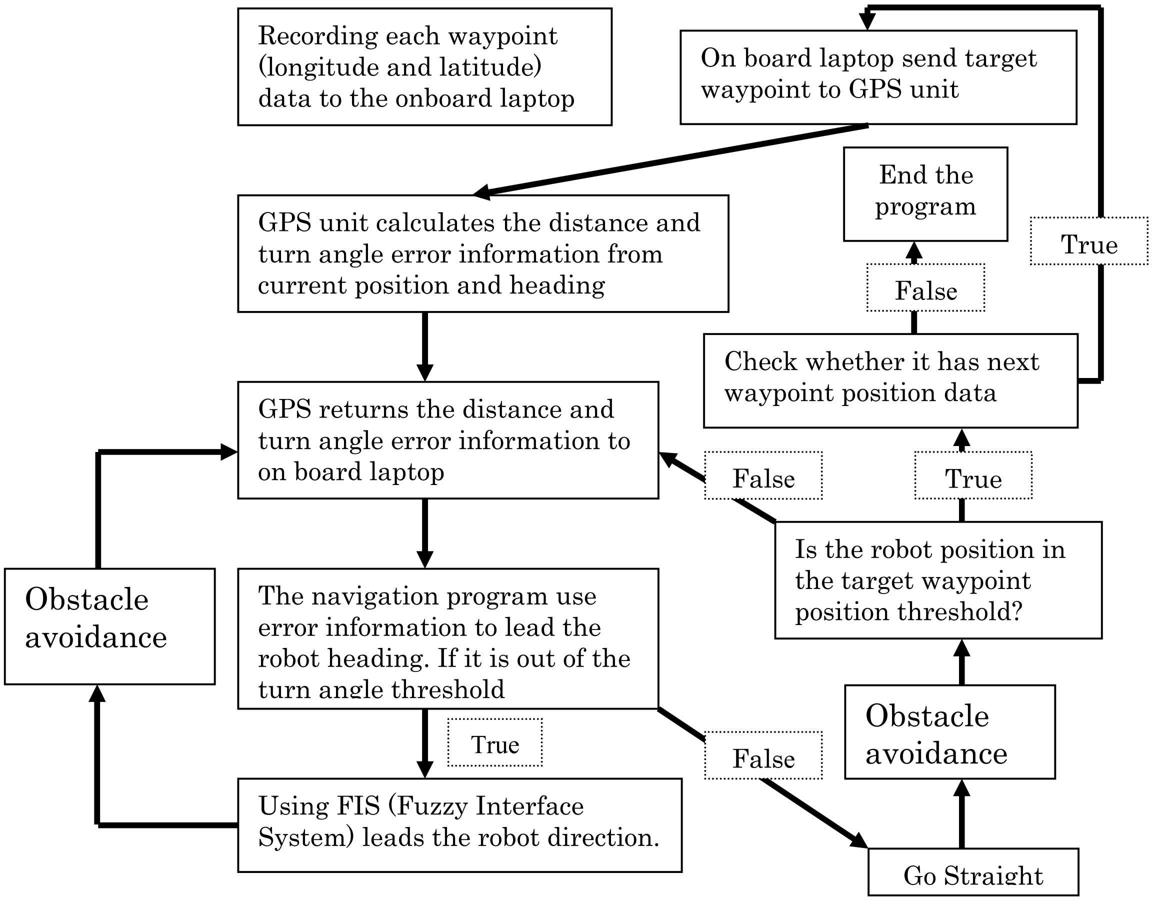

Recording each waypoint (longitude and latitude) data to the onboard laptop
On board laptop send target waypoint to GPS unit
GPS unit calculates the distance and turn angle error information from current position and heading
End the program
True
False
Check whether it has next waypoint position data
GPS returns the distance and turn angle error information to on board laptop
False
True
Is the robot position in the target waypoint position threshold?
Obstacle avoidance
The navigation program use error information to lead the robot heading. If it is out of the turn angle threshold
Obstacle avoidance
True
False
Using FIS (Fuzzy Interface System) leads the robot direction.
Go Straight

Figure 5

If the turn angle is below -6° or above 6°, the FIS determines the robot's direction as follows:

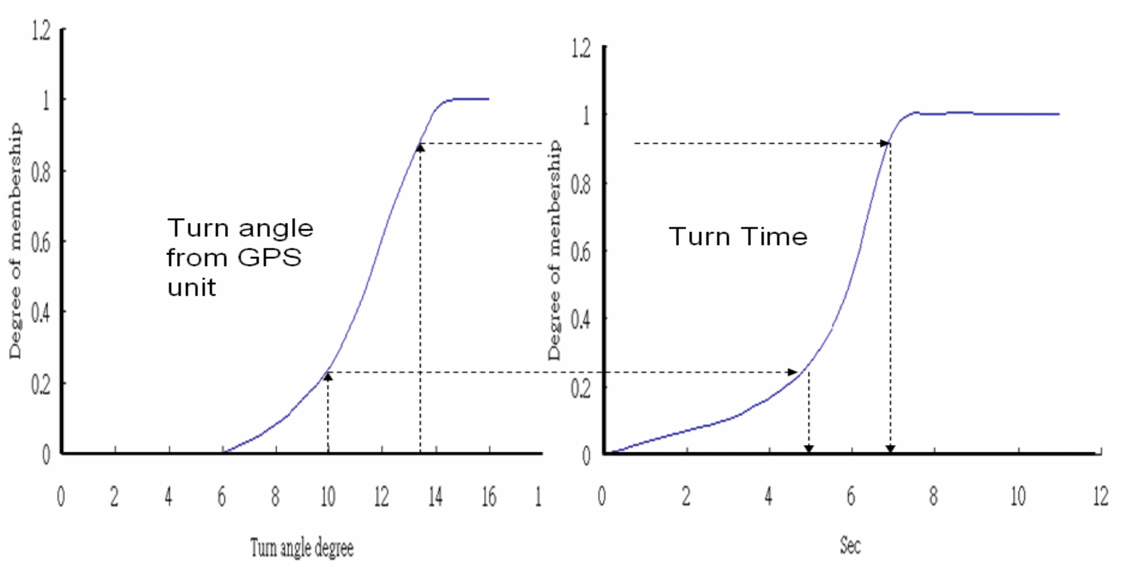


Figure 6

The FIS uses monotonic selection which is based on a relationship between the turn angle value from the GPS unit and robot turn time, expressed as a single fuzzy rule:

IF the turn angle is large

THEN turn time is large

The value of the output or a truth membership grade of the rule consequent can be estimated directly from a corresponding the truth membership grade in the antecedent. Figure 6 shows how various turn times are derived from different turn angles from the GPS unit.

5.7 Motor Interface

The direction of LTU Challenger is controlled by the direction of each motor. The motor interface software functions take the action name, such as "left" or "forward", and the duration of that action.

6. Predicted Performance

6.1 Speed

The top speed of the robot is 12 m.p.h. It is limited by the software to 3 m.p.h.

6.2 Ramp Climbing Ability

The maximum incline our vehicle is capable of traversing is highly dependent on the surface of the incline. However, we have tested our robot and found it capable of climbing 15 degree inclines.

6.3 Reaction Times

The robot can react to the changes in its environment within 0.5 – 2.0 seconds.

6.4 Distance at Which Obstacles Are Detected

The maximum distance at which obstacles are detected is approximately 5 feet and depends on the camera angle.

6.5 Battery Life

Based on experimental test data we found that our main battery, laptop batteries and camcorder batteries can last for one hour.

7. Safety

As required by IGVC contest rules, a remote and mechanical emergency stop switches are required to stop the robot. To maintain the off the shelf design philosophy a low cost automotive keyless entry switch with a 50 feet range was selected as the remote E-stop component. The remote E-stop controls a relay that is in series with the mechanical push-pull E-stop and the Vantec motor controller main power. Both of these switches must be closed to before electrical power can be supplied to the Vantec motor control board. Another notable safety feature of the E-stop systems is that the robot main power can only be restored after remote E-stop shutdown by manually resetting the robot by cycling the mechanical push-pull switch off, then on again. This prevents the robot from being restarted until a human in close proximity decides whether conditions are safe to restart the robot.

8. Future Improvements

While the overall system performance is quite solid, the response time could be improved. Also, sensors could be expanded to include sonar/radar to handle dead ends and traps. In addition, an alternative HSB internal color representation should be considered to replace RGB for improved performance in bright lighting conditions. Finally, it would be interesting to be able to modify the FLC rules on the fly or to even evolve them.

9. Cost Summary

Part Description	Vendor	Unit Price	Quantity	Total
Chassis				
MDF board 16" X 36" X .25"	Lowes	$3.00	2	$6.00
Video ripod	Microcenter	$19.99	1	$19.99
Stratocore clear corrugated plastic board	Utrecht	$4.29	1	$4.29
Drive Train				
12V power wheels gearbox motor assy	Power Wheels Service Ctr	$15.00	2	$30.00
4" tire & wheel assembly	Recreational Leisure Corp.	$23.99	2	$47.98
Wheel axle	Lowes	$8.47	1	$8.47
Swivel caster wheel (4" x 2")	General Caster Service	$12.00	1	$12.00
Wheel adapter plate and axle bearing spacer	Fabricated by Ford Motor Co	$0.00	4	$0.00
Cotter pin 1/8 X 1" - wheel retainers	Lowes	$0.24	2	$0.48
5" corner brace (axle supporters)	Lowes	$1.32	2	$2.64
Sensors				
DV camcorder	Wal-Mart	$412.66	1	$412.66
.5X wide angle conversion lens	Circuit City Stores	$39.99	1	$39.99
Garmin GPS 76 unit	Gps City	$179.95	1	$179.95
IEEE1394 FireWire cable	Best Buy	$15.00	1	$15.00
Electrical				
Vantec electric motor speed controller	Vantec	$230.00	1	$230.00
Emergency stop push pull switch	Autozone	$3.99	1	$3.99
12 Volt 7 Ah battery	Rage Battery	$11.95	1	$11.95
Remote control keyless entry switch	Bulldog Security	$37.85	1	$37.85
5' #14 - 2 conductor grey speaker wire	Home Depot	$0.22	5	$1.10
DPDT relay plug-in relay	RadioShack	$7.99	1	$7.99
Fuse panels and circuit breakers	Donated By Connector Concepts	$0.00	4	$0.00
8"X6"X3" project box	RadioShack	$6.99	1	$6.99
Electrical Hardware				
D-Sub connector - D25 solder plug (Male)	RadioShack	$1.69	1	$1.69
D-Subminiature D25 connector hood	RadioShack	$2.29	1	$2.29
25 Conductor ribbon cable (per ft.)	RadioShack	$0.19	5	$0.95
Buchanan spade terminals	Home Depot	$0.06	10	$0.65
Buchanan female disconnects	Home Depot	$0.07	12	$0.84
Camera Tripod Mounting Hardware				
3/4" conduit hanger with speed thread	Lowes	$0.38	3	$1.14
2-1/2" corner braces	Home Depot	$0.54	4	$2.16
Corner brace fastener machine screws	Lowes	$0.20	6	$1.19
Tripod clamp machine screws	Lowes	$0.20	3	$0.60
Misc Hardware (nuts, bolts, etc...)				$6.12
Laptop Computer	LTU	$0.00	$1.00	0
Total Robot Cost				**$1,096.95**

Table 3

10. Conclusion

The LTU Challenger team met most of its major design requirements and developed a fully autonomous robot. The platform was developed with safety, reliability, and versatility in mind. The mechanical and electrical systems were created with the intent of both indoor and outdoor operation in a variety of environments. The software and high-level control systems were designed for lane following, obstacle detection and avoidance, and GPS navigation challenges. The LTU Challenger is participating in the Intelligent Ground Vehicle Competition for the first time and plans to continue attending the IGVC in the future.