LTU DEEP BLUE

Design Report

12th Annual Intelligent Ground Vehicle Competition, 2004

Team Members:

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Faculty Advisor Statement

I, Dr. Chan-Jin Chung of the Department of Math and Computer Science at Lawrence Technological University, certify that the design and development on LTU Deep Blue has been significant and each team member has earned credit hours for their work.

Signed, Date

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1. INTRODUCTION

LTU Deep Blue is one of the robots, entering IGVC Competition 2004 for Lawrence Technological University. Deep Blue has different design concepts, special features, and implementation purposes to achieve the ultimate goals. Last year 2003 is the first time that LTU entered IGVC and we won fourth place for our CogitoBot II. LTU Deep Blue inherits the high intelligence of CogitoBot II with totally different design features such as motors, a DV Camcorder, hardware structure and software technology, determined to win this year's competition. LTU Deep Blue will also compete in the Navigation Challenge with GPS Technology and Algorithm. LTU Deep Blue fulfills the excellence and performance in Artificial Intelligence Engineering.

2. DESIGN PROCESS

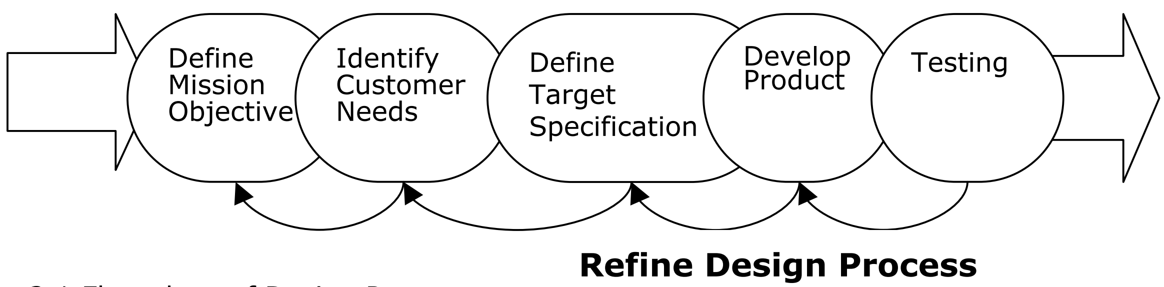

Figure 2.1 Flow chart of Design Process

2.1 Design Planning Process

Define Mission Objective

Our mission is to enter the IGVC competition and make a significant achievement. We studied all the requirements of IGVC, documentation, rules, and videotapes of each year to figure out the objective we needed to achieve.

Identify Customer Needs

We defined our customers as ourselves, Lawrence Technological University, sponsors, and IGVC judges. We would like to build a robot to bring significant contribution to our school with effective solutions to IGVC challenges as well as long-term educational means for the following students in the next semester. We visualized a robot with great performance in IGVC with a minimum cost

Define Target Specification

We studied IGVC rules and analyzed the course to define the specification of each goal while reviewing the resources we had to outline the problem. We specified the strength and weaknesses of the other teams and set a time line for development of the process for each goal.

Develop Product and Testing

We evaluated the requirements of IGVC and the technology we had and found the necessary costs to fulfill the goals in IGVC. We set a one-year deadline to evolve the robot to a mature status using the following stages.

1. In the beginning, we designed a robot with webcams to follow inside the course lanes. At the same time, we developed the image processing classes in Java.
2. We added the obstacles inside the course lanes and added the algorithm to determine the position of the obstacle and how to avoid it.
3. Tested the environment under strong reflections and developed a way to filter the light.
4. Changed the webcam to Digital video camcorder to follow one dashed line.
5. Introduced Fuzzy Logic concepts to the software strategy to follow inside the lane with obstacles. We also changed the motors with speed control feature to match the performance of Fuzzy Logic.
6. Tested the robot under broken lanes with special tools in Matlab for Fuzzy rules and

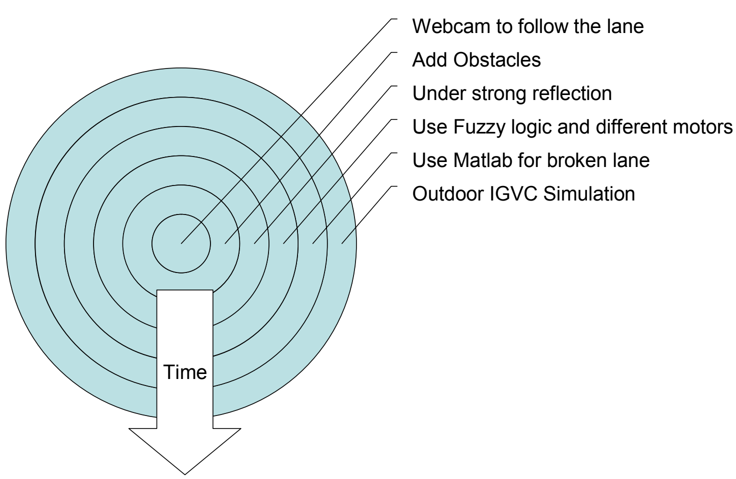

Figure 2.2 Evolution of Design Process

image processing.

7. We simulated the outdoor IGVC environment and tested the robot under sunlight to determine potential challenges faced in IGVC.

These stages are illustrated in Figure 2.2.

Refine Design Process

We introduced new features such as sonar sensors, Artificial Neuron Network for image processing, remote control for E-Stop, GPS technology and joystick control. We utilized many new ideas to refine LTU Deep Blue to achieve maximum performance in consideration of safety, reliability, and durability in IGVC.

2.2 LTU Deep Blue Team Organization Table

Jason Chien Tai Lo, Maurice Tedder and Shan Tseng are graduate student in Computer Science Department of Lawrence Technological University. We spent at least two semesters to develop this project for IGVC. We took Artificial Intelligence Ⅰ&Ⅱcourse as one of the requirement concentration area for Masters in Computer Science. Some of us also took Robotics Programming and work in Robotics Laboratory of Lawrence Technological University.

Team Member	Duties	Hours Per Person	Major
Jason Chien Tai Lo	Camera, Software strategy – Lane following & Trap escape algorithm, Motion control, Sensors, Design Process, Team Organization, Documentation	**430**	Masters in Computer Science
Shan Tseng	Software Design – Image Processing, Data Collection, Testing, Documentation	**410**	Masters in Computer Science
Maurice Tedder	GPS, Electrical/Electronics systems, vehicle frame (hardware), Software Design – Matlab Implementation, Motion control, Documentation	**450**	Masters in Computer Science

Table 1 Team Organization

3. HARDWARE DESIGN

The main objective for the hardware design of LTU Deep Blue was to improve the performance of the previous 2003 IGVC Cogitobot series of robots. A number of performance improvements were identified and implemented in the new 2004 IGVC robots. The new robot vehicles were built from all new hardware.

3.1 Robot Structure

The basic configuration of the 2004 robot is similar to the 2003 version with a three wheel base vehicle and tank style differential steering with a rear caster wheel. Figure 3.1 shows a picture of the overall vehicle configuration. We maintained our design philosophy of a simple and robust design capable of being easily manufactured at a low cost from off the shelf components. Our robot vehicle has the dual purpose of competing in the 2004 IGVC and providing a low cost mass-produced robotic platform for Computer Science education.

Medium Density Fiber (MDF) board was used as the main structural component. This material is easily machined and processed using standard household power tools. One of the design improvements implemented for the new robot structure was to use a thinner .25-inch MDF thickness on the 2004 robot to reduce the basic structure weight by 33%. The previous 2003 version .50-inch MDF material thickness was determined to be unnecessary for the 2004 version. The new lightweight structure maintains the structural ability to carry a 20-pound payload. The simplicity of the robots structural design has the advantage of being mass produced at low cost because fabrication of a robot consists of cutting the MDF panels to the desired shape and drilling holes to fasten the various components together with bolts and PVC spacers.

3.2 Drive Train

One of the improved performance features of our new drive train design is the use of higher speed 12-volt electric motors. The 2003 IGVC robots were only capable of a speed of 1 mph, which limited our team’s ability to be more competitive in the follow the leader and navigation challenge events. The new motors are Fisher Price Hot Wheels toy gearbox motors. These motors are used on the Fisher Price Hot Wheels Ninja cycle toy vehicles and are capable of carrying 70 pounds at speeds up to 5 mph. Our robot is equipped with two of these motors. The actual speed of the vehicle is limited by software to 5 mph in accordance with the IGVC maximum speed requirement. Table 3.1 summarizes the main performance specifications of the drive train. Each motor has independent speed and direction control. Each is also directly connected to a wheel on a fixed axle and differentially steers the robot giving it zero turn radius capability.

Performance	Results
Length x Width x Height	36″ x 16″ x (19″ – 69″)
Weight	40 lbs.
Motor Voltage	12V
Motor Stall Current	15A
Torque per Wheel	10 ft.-lbs
Gear Ratio	111:1
Wheel Diameter	~10″
Motor RPM	144

Table 3.1 Robot Performance Parameter

3.3 Wheel design

A unique design feature of our drive train is that the motors and wheels are easily removed and changed by simply removing the retaining cotter pin on the axle and separating the wheel from the motor. This ability allowed our team to test different wheels for the best traction and performance. A custom coupling plate was needed to connect the Fisher Price motors to the wheels because the motors are specifically designed to mate with the Hot Wheels vehicle wheels. Our test proved that these original Hot Wheels vehicle wheels did not provide the needed traction for outdoor use on grass, a wooden ramp, or sandy terrain. A wide variety of wheel assemblies can be used to satisfy different traction requirements because of the wheel adapter coupling plate. The best traction was obtained by using a 10-inch pneumatic mini bike wheel as the selected wheels for our vehicle. We designed a

wheel adapter plate and our Ford Motor Company sponsor manufactured it. A rapid prototype plastic part was made to test the coupling plate design, and a Water jet cutting machine was used to cut the final part from a .25-inch aluminum plate as shown in Figure 3.2.

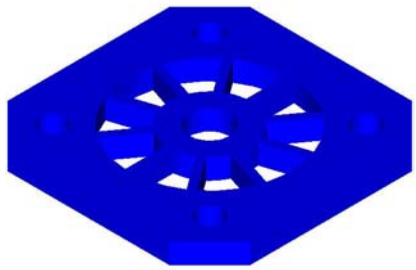

Figure 3.2 Wheel Adaptor Plate CAD Drawing

3.4 Motor Control

The Vantec CDFR-21 motor controller proved to be very reliable and effective for the 2003 robots and also serves as the motor controller for the 2004 robots. This motor controller is interfaced to the main robot computer via the parallel port. Parallel port control make the Deep Blue robot independent and portable to many hardware and software platforms as long as parallel port communication is supported. The CDFR-21 is capable of controlling two electric DC motors with a PWM output voltage range of 5 – 30 volts and continuous operating current of 14 amps per channel and 45 starting amps per channel, which is more than sufficient to control our robot motors. The extra capacity of the Vantec CDFR-21 is available for future expansion or motor design changes. An improved use of the Vantec CDFR-21 for the 2004 robots is that we increased the PWM rate from 338 Hz for the 2003 robot to 21.6 KHz rate for the 2004 vehicle. This increases the speed control resolution and gives the robot control software finer control over the motor speed, which greatly improves the turning and speed precision.

4. ELECTRICAL SYSTEM

4.1 Vision Sensors

Our current autonomous challenge software strategy requires only a vision sensor as provided by a Canon DV camcorder with an IEEE 1394 Firewire computer interface. This camcorder is used to detect lines, potholes, and obstacles. Rather than use two camcorders to increase the field of view for the robot, a .5X wide-angle lens was successfully used on the camera to provide an increased field of view at a lower cost than using additional cameras. An increased field of view improved the amount of visual data available to the control software, which improved the accuracy of the lane following algorithm. Adjusting the camera tripod mounted on the robot, which provided camera height, tilt, and direction adjustments. This can make additional field of view adjustments.

A DV camcorder was selected for the 2004 robot because the web cameras used on the 2003 robot could not adapt to the changing lighting conditions of the IGVC course. More specifically, the robot would interpret the sunlight reflections on the ramp as a white line and would consistently leave the course based on this false data. The new 2004 camcorder has an adjustable iris that automatically adjusts the camera to compensate for ramp reflections and adapts to changing lighting conditions to climb the ramp successfully. Camera frame rates increased from 7 frames per second in the old webcams to 15 frames per second using the IEEE 1394 Firewire interface.

4.2 GPS Sensor

The Garmin eTrex Venture handheld Wide Area Augmentation System (WAAS) enabled GPS unit was selected as the GPS sensor for the navigation challenge portion of the IGVC. This GPS unit was selected because it provides a wide range of features at a reasonable price. The embedded features of the eTrex GPS unit provide all the functions necessary to set the destination waypoints. It also continuously provides direction and distance to the desired waypoint feedback. All that is

needed to use the navigational features of the eTrex unit is to interface using the RS-232 serial port and one of the various protocols built into the etrex unit for sending and receiving data from the eTrex GPS unit. The advertised accuracy of the GPS unit in WAAS mode is less than 3 meters, which is the actual accuracy of the robot.

4.3 Power System

Figure 4.1 shows the schematic diagram of our robot electrical power system. A 12volt 7 amp hours sealed lead acid rechargeable battery produces the main electrical power. Other notable safety features of the robot's electrical system is the circuit breaker panel which provides 15 amp over current protection for each motor and the 30 amps for the overall system.

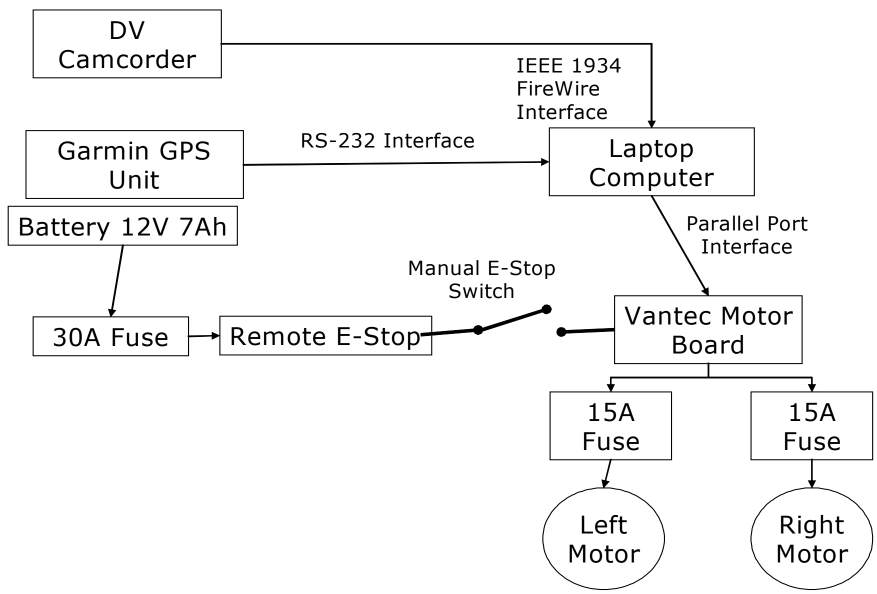

Figure 4.1 Power System and System Integration Diagram

4.4 Computer Hardware

All computer processing is performed by one Hewlett Packard Omnibook xe4500 laptop computer. Figure 4.1 shows the computer system integration with the other robot components. An important feature of Deep Blue's system design is the Plug and Play capability designed to allow any computer to be used as the central computer. This feature allows any team member to develop software for the robot offline using his/her own laptop computer and simply "plug" that laptop into the robot system. This design feature was achieved by using the Java Software Development Environment and designing a robot that only requires standard commodity interfaces such as RS-232, IEEE 1394, and parallel port interfaces. The laptop processes video image and GPS data, intelligence, and motion commands. The **Computer** we use here is Pentium 4 1.6MHz processor with 256 MB RAM on Windows 2000 Professional OS.

5. SOFTWARE DESIGN

5.1 Software Design Objective

For the programming of our robot, we decided to use the Java programming language. Java allows us to easily add new features to our program and allows our program to be platform independent. Java provides the central interface to the robot motion control and image acquisition components. We also developed JavaDV as an interface that allows Java programs to capture frames from digital video (DV) devices. JavaDV supports all DirectShow devices including DV camcorders. Design of this system involved writing an image-processing algorithm using Matlab image processing functions and neural network toolbox to extract the feature vectors from the scene. A fuzzy inference system was designed using the Matlab fuzzy logic toolbox. This provides the intelligence component.

5.2 Autonomous Challenge Image Processing

The processing procedure involved first extracting white lines, potholes, and orange barrels from the captured image by using HSB (hue, saturation, and brightness) color filtering. The filtered image is then converted to black and white for additional processing. Visual sensory input data is provided by a DV camcorder at 160 x 120 pixel resolution. The Matlab image processing toolbox is used to extract the feature vectors from the scene image data. Figure 5.1 shows the barrel and line after image processing. The position of the objects on the processed 3 X 3 grid is used by the fuzzy inference system to determine the ultimate route for the best path to avoid obstacles.

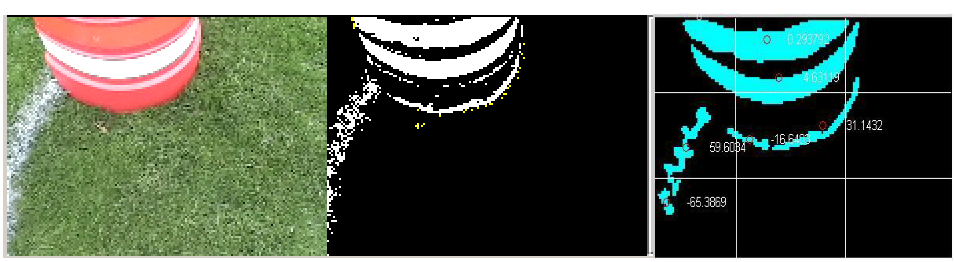

Figure 5.1 Matlab Feature Extraction of Camera Image

5.3 Lane Following and Obstacle Avoidance

With the processed image the robot is able to determine how it should move itself.

The Matlab image processing toolbox was used to extract the feature vectors from the scene image data. These feature vectors are then mapped to linguistic variables that describe the objects in our world model. These linguistic variables act as inputs to a fuzzy logic controller designed using the Matlab fuzzy logic toolbox. The fuzzy inference system provides the knowledge and intelligence to achieve the desired goal by producing robot motion control commands to steer the robot.

Figure 5.2 shows the entire control architecture. We received the digital image data trough JavaDV Driver from the Camcorder, then process the image using Java HSB color method to filter different colors. We are also developing a proposed artificial neural network color filter to compare to the HSB method. Matlab image processing functions extract the centroid, area, and orientation of the connected regions feature vectors from the scene which are inputs to the fuzzy controller designed using the Matlab fuzzy logic toolbox. The fuzzy inference system applies the course following knowledge rules and returns turn direction values to control robot.

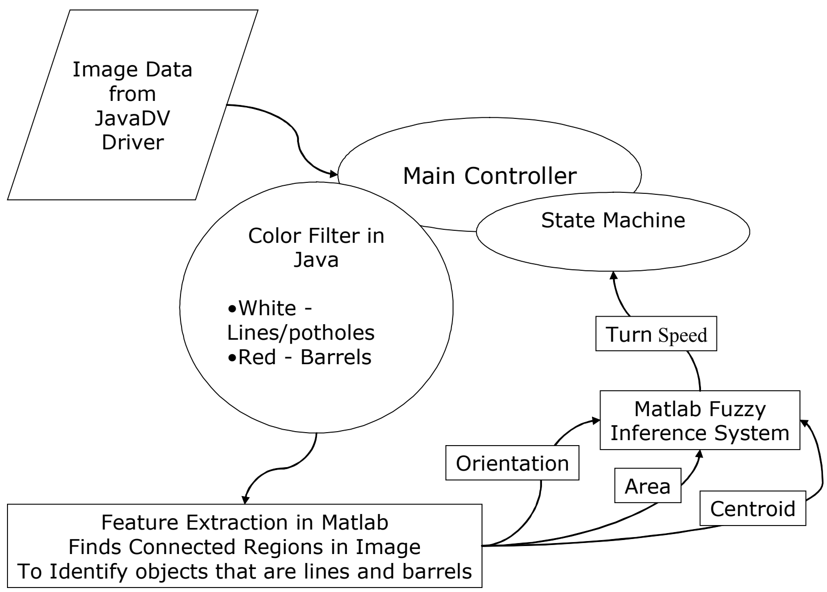

Figure 5.2 Software System Control Architecture

5.4 Algorithm for escaping dead ends, trap, and potholes

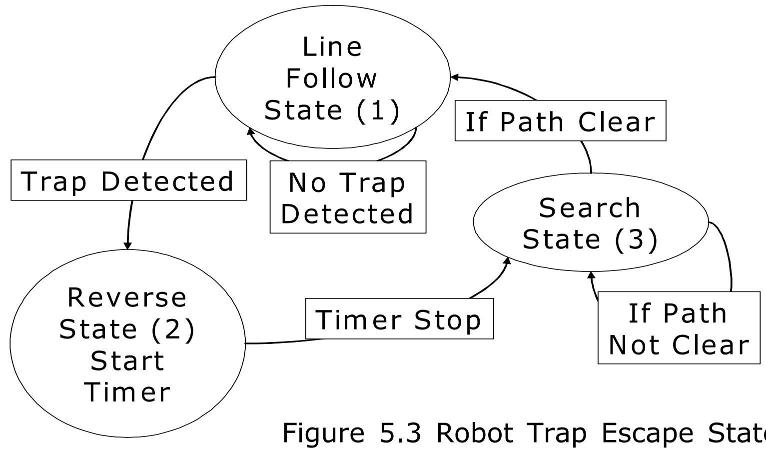

Figure 5.3 Robot Trap Escape State Diagram

The initial state of the Motion control is line mode, which processes barrels, potholes and white lines. Whenever the robot is too close to barrels, it will enter the barrel trap state and move backwards until there is a clear path identified by the position of white line and barrels it sees. Figure 5.3 shows the trap escape state diagram.

1. Line state: Uses commands from fuzzy system
2. Reverse state: Barrel trap detected triggered by the distance of obstacle Robot sees on the screen then go backwards and start timer
3. Search state: Robot compares the values and position of barrels and white lines to search a clear path. If there is a clear path, it goes to step 1, if not, it goes to step 3

5.6 GPS Navigation

Figure 5.4 shows a flowchart the navigation algorithm used by DeepBlue to autonomously navigate the navigation Challenge course. In the 2003 IGVC competition LTU Cogitobot II used a simple computer logic feedback control loop to minimize the distance and angle error to the waypoint. This approach was difficult to tune. Deep Blue's approach is similar to Cogitobot II with respect to using a GPS sensor to return distance and angle error information. The key innovation for the new algorithm is the use of a fuzzy logic controller to control robot motion based on distance and angle error data from the Garmin GPS unit. The angle error data from the GPS unit and obstacle position data from the camera are inputs to the fuzzy inference system, which applies the fuzzy logic rules to create the intelligence component that guides the robot towards the target while voiding obstacles.

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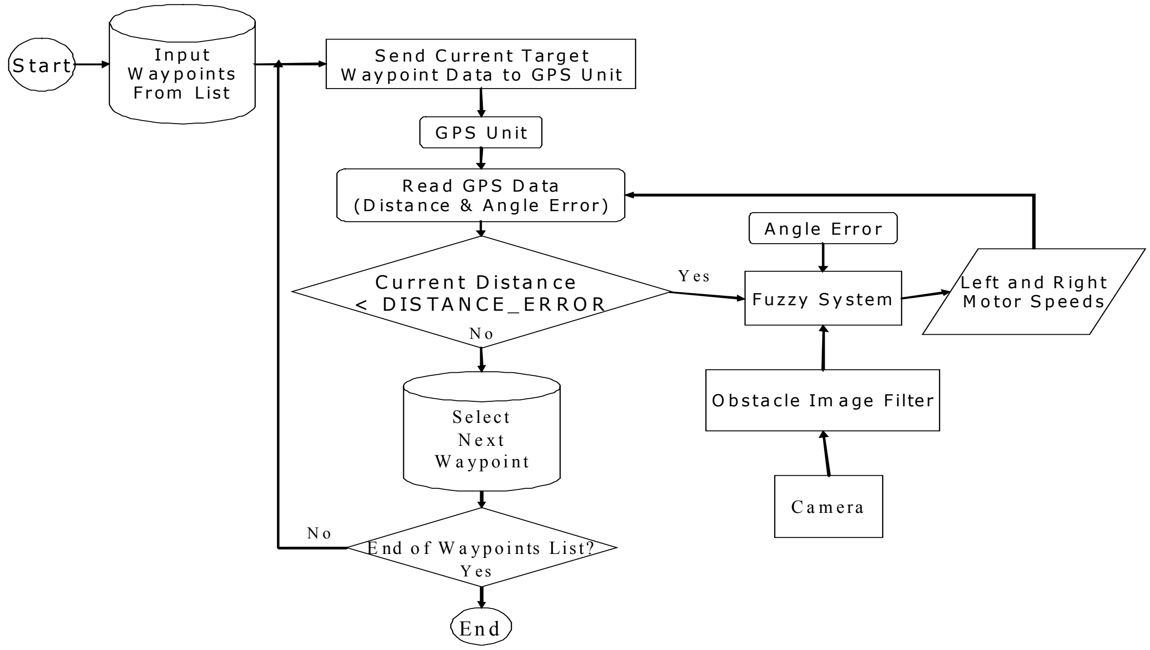

Figure 5.4 GPS Navigation Algorithm

6. PERFORMANCE RESULT ANALYSIS

Table 6.1 summarizes the predicted results and the actual experimental results obtained from testing. Final performance results show that Deep Blue is capable of meeting the requirements for all IGVC competition events.

Performance Measure	Performance Prediction	Performance
Max. Speed	5 Mph	4.3 Mph
Maximum Ramp Climbing Ability (μ = .3516)	58 Degree Incline	18 degree Incline
Reaction Time	.5 senconds	.7 seconds
Battery Life	1.75 hours	1 hour
Object Detection	4.0 feet	3.6 feet
Dead-ends and Traps	Chosen paths are clear	95% Successful Rate
Waypoint Accuracy	< 10 feet	< 10 feet

Table 6.1 Performance Results Analysis

7. OTHER DESIGN CONSIDERATIONS

7.1 Safety

Safety is the most important part we considered before we build the robot. As required by IGVC contest rules, 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 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 resetting the robot. To reset the robot cycling the mechanical push-pull switch off then on again. This prevents the robot from being restarted until a person is in physical proximity and can decide to restart the robot.

7.2 Reliability

We have noticed this important issue from studying the results of other teams in the past. Therefore we strengthen our camcorder with special settings to adjust the visibility to various light conditions. We also experimented with different angles of sonar sensors and camera for reaction ability. We modified the architecture of wheels to make sure the turning of the robot will be smooth, thus the robot can avoid the obstacle successfully.

7.3 Durability

The simplicity of the Deep Blue robot design insures a degree of durability because the motors, electronics, and structure are made from durable off-the-shelf components. After system integration, the entire vehicle was repeatedly tested during software development with the robot to identify any durability concerns. The motors are from a very durable toy vehicle that is designed for the rigors of child's play that the Deep Blue vehicle will not experience. The motor controller and structure materials were proven durable in the previous year's vehicle and should continue to be durable in the current vehicle design.

8. VEHICLE COST SUMMARY

Part Description	Vendor	Unit Price	Quantity	Total Price
Chassis				
MDF Board 16" X 36" X .25"		$3.00	2	$6.00
Video Tripod	Microcenter	$19.99	1	$19.99
Stratocore Clear Corrugated Plastic 20"x30" Board	Utrecht	$4.29	1	$4.29
Drive Train				
12V Power Wheels Gearbox Motor Assy.	Power Wheels Service Center	$15.00	2	$30.00
4" Tire & Wheel Assembly - 10.5" Knobby Tire	Recreational Leisure Corp.	$23.99	2	$47.98
Wheel Adapter Plate	Fabrication Sponsored by Ford Motor Co.	$0.00	2	$0.00
Wheel Axle Bearing Spacer (7/16" ID X 5/8" OD X 2-1/4")	Fabrication Sponsored by LTU Machine Shop	$0.00	2	$0.00
Swivel Caster wheel (4" x 2")	General Caster Service	$12.00	1	$12.00
Sensors				
DV Camcorders	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
Main Battery 12 Volt 7 Ah Power Sonic Sealed Lead Acid	Rage Battery	$11.95	1	$11.95
Remote Control Keyless entry Switch	Bulldog Security	$37.85	1	$37.85
Bussmann Fuse Panels	Donated By Connector Concepts	$0.00	1	$0.00
15-amp Mini Circuit breakers	Donated By Connector Concepts	$0.00	2	$0.00
30-amp Mini Circuit breakers	Donated By Connector Concepts	$0.00	1	$0.00
Emergency stop push pull switch	Autozone	$3.99	1	$3.99
Electrical Hardware & Miscellaneous Hardware (nuts, bolts, etc...)				$48.34
Laptop Computer	LTU	$0.00	1	$0.00
		Total Robot Cost		**$1,099.99**

Table 8.1 Vehicle Cost Summary

9. Conclusion

We emphasize the entire design process under value engineering. We utilized all the resources to accomplish quality performance for our customers. We minimized the overall costs at the same time strengthened the robot architecture by deliberate engineering. We have high level and complex software intelligence. Matlab image processing functions ensures the accuracy of the position of the objects on the screen. Matlab Fuzzy Logic contributes the smoothness of the vehicle motion. The other advantage of our robot is the height and flexibility of the camcorder; we can adjust its angle and height according to the Sun light condition to our advantage. We believe Image processing is the most important part for good results. There is a proverb: If you can see it, you can have it.