WunderBot

2004 Intelligent Ground Vehicle Competition

Design Report

Elizabethtown College

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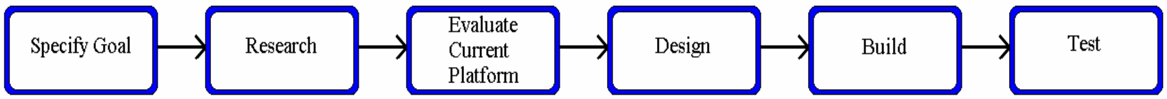
1. Introduction

WunderBot is a versatile autonomous robot platform that has been under development at Elizabethtown College. The 300 lb. robot is driven by two 1.75 HP DC motors and is exceptionally maneuverable. To achieve the necessary level of autonomy, software and hardware redundancy is employed in high and low-level sensor arrays. Using a wireless VLAN, a remote laptop can access the onboard computer and monitor all system parameters in real-time via a custom GUI interface. Specific GUI features include real-time obstacle mapping, path-planning simulation, sensor information, collision and low battery alarms, plus plots of motor current and velocity vs. time. The 12th Annual Intelligent Ground Vehicle Competition (IGVC) will be the first at which WunderBot will compete.

Name	Contribution	Class	Major
Dax Kepshire (Team Leader)	• Mechanical and electrical design and implementation • Vision system development	Senior	CE
Snehesh Shrestha (Chief Programmer)	• Overall design and programming • Path planning, mapping and component integration	Junior	CE
Steve Sanko	• Low level sensors and vision implementation • Path planning	Junior	CE
Jonas Groff	• Digital compass and DGPS implementation	Junior	CE
Joe Marion	• Obstacle mapping	Senior	CS
Matt Barley	• DGPS implementation	Junior	CE
Andy Marzen	• E-stop system	Junior	CE
Dinesh Jeyaram	• Digital compass implementation	Junior	CE
Total Team Hours	**1500**		

Table 1.1 Member Contributions

2. Design Process



2.1 Specify Goals

Our project goal was to fulfill the needs of our customers, namely the IGVC directors, officials, and judges as well as Elizabethtown College. IGVC had several safety requirements in addition to performance standards as specified by the Navigation Challenge and Autonomous Challenge. Elizabethtown College required the robot to remain versatile and implemented size constraints as well as safety regulations.

2.2 Research

Group members selected areas of study and appropriate assignments during the research phase. Several additions as well as mechanical changes were necessary in order to compete at IGVC. Initial research was performed on previous competing vehicles, and further research was completed on sensors, mapping, control, and decision-making. Consideration was primarily given to sonar, infrared, laser, and machine vision. Component research included digital compasses, GPS receivers, machine vision cameras, and supporting parts such as DC-DC power supplies and microcontrollers.

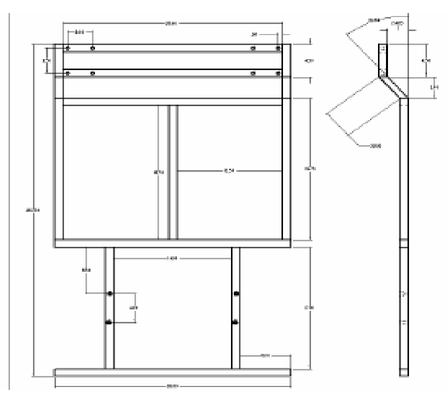
2.3 Evaluate

Upon evaluation of the current platform, a new design was conceptualized through the following guidelines:

- Cost – Fundraising and donations totaled $6000
- Aesthetics – Must be pleasing to technical and non-technical people
- Dimension Constraints
  1) Width: 28 inches – Must be capable of fitting through a standard doorway
  2) Length: 3 to 9 feet – As specified in Autonomous Challenge
- Accessibility – Components must be easily accessed for repair or service
- Maneuverability – Optimize length to width ratio for smooth turns
- Mobility – Performance in grass and sand is critical

- Versatility – WunderBot is a developing platform utilized for research and must remain upgradeable and adaptable.
- Resource Utilization – Preference must be given to previously used components
- Capability – WunderBot must be capable of competing in every challenge at IGVC
- Safety
  1) Components must be protected from electrical shock and disturbances.
  2) Bump switches must be included, but should be removable for competition.
  3) Emergency stop systems must be reliable and visible
  4) Durable and rugged materials must be used to ensure mechanical stability

2.4 Design



2.4.1 Mechanical

Based on our goals, research, and evaluation several mechanical drafts were constructed and the layout was sketched using solid edge design software. The chosen design involved a two tier rectangular frame constructed out of solid aluminum. The raised rear casters are a result of the bump switch requirement desired by Elizabethtown College. Dimensions were optimized based on component size, component placement, and maneuverability. Optimum maneuverability was achieved by creating the length to be 62% of the width [2]. For mobility purposes weight was distributed evenly such that the batteries, electronics, and second level offset the motors, drive wheels, and PC. In order to achieve traction in wet grass and sand, 14" NPC Flat Proof tires are driven by two NPC 1.75Hp motors. Eight-inch pneumonic rear casters were selected to prevent over complicating the drive system. To facilitate proper airflow the ATX PC case was modified, and intake and exhaust fans were added to the fiberglass body.

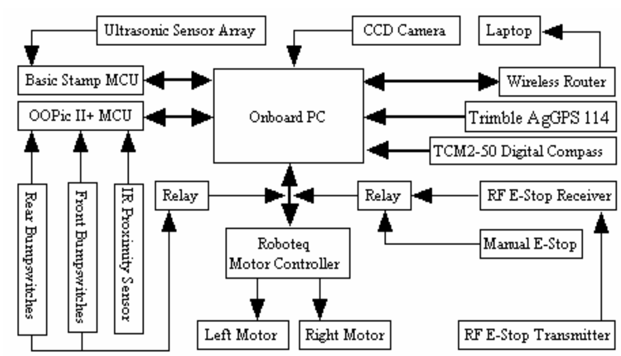
2.4.2 Electrical

Hardware selection was determined through weighted comparisons between device brands as displayed in table 2.1. Component additions to WunderBot included a motor controller, Infrared sensors, GPS receiver, Digital Compass, RF E-Stop, and a Vision System.

Weight	Apendix A Parameters:	Model: Dinsmore 1490 (Current Model)	PNI Vector 2X	PNI Vector 2Xe	PNI TCM2.50	Honeywell HMR 3000
Value	MCU	MCU and design already built				
25	On-board MCU? (Y or N)	N (10 points)	N (10 points)	Y (25 points)	Y (25 points)	Y (25 points)
15	External Clock Required? (N or Y)	Y (7 points)	Y (7 points)	Y (7 points)	N (15 points)	N (15 points)
20	External MCU Required? (Y or N)	Y (10 points)	Y (10 points)	N (20 points)	N (20 points)	N (20 points)
36	EEPROM (Y or N)	N (12 points)	N (12 points)	Y (36 points)	Y (36 points)	Y (36 points)
5	Min. Response Time (ms)					
Total(100)		39 points	39 points	97 points	93 points	93 points
	Power Requirements					
30	Power supply voltage needed (V)	5 (25points)	5 (25 points)	3 (30 points)	5 (25 points)	5 V (25 points)
40	Power Supply (Via PSU / Y or N)	Y (40 points)	Y (40 points)	Y (40 points)	Y (40 points)	Y (40 points)
15	If MCU needed i min (mA)		4 mA (13 points)	4 to 7 mA (15 points)	7 to 13 mA (10 pts)	2 mA (14 points)
15	If MCU needed i max (mA)	30 mA (7 points)	5.0mA (13 points)		15 to 20 mA (10 pts)	35 mA (5 points)
Total(100)		72 points	91 points	85 points	65 points	64 points
	Heading Information					
25	Accuracy (degrees RMS)		2 RMS (18 points)	2 (18 points)	1.0 RMS (22 points)	.5 to 1.5 RMS (25 pts)
25	Resolution (in degrees)		1 (10 points)	0.01 (25 points)	0.1 (20 points)	0.1 (20 points)
5	Repeatability (degrees)		2 RMS (5 points)		0.3 (3 points)	0.2 (3 points)
15	Axis (#)	2(10 points)	2 (10 points)	2 (10 points)	3 (15 points)	3 (15 points)
15	Tilt Range (Degrees)	12 with little error (8 points)	0 (0 points)	0 (0 points)	50 degrees (13 pts)	20 (10 points)
15	Dynamic Range (T)		90 uT (12 points)		(+/-)80uT (11 pts)	0.1 mT(8points)
Total(100)		28 points	60 points	53 points	84 points	81 points
	Ease of Use					
20	Interface (Difficulty)	Easy (15 points)	Easy (15 points)	Easy (15 points)	Very Easy (20 pts)	Very Easy (20 points)
20	Example Code Available (Y or N)	Y (20 points)	N (0 points)	Y (20 points)	Y (20 points)	Y (20 points)
12	VB Language Supported				Y (12 points)	Y (12points)
8	Mounting (Difficulty)	Easy (6 points)	Moderate (4 points)	Easy (6 points)	Moderate (4 pts)	Easy (6 points)
20	Integration with GPS (Y or N)	N (0 points)	Y (15 points)	Y (15 points)	Y (17 points)	Y (17points)
20	PCB Fabrication (Y or N)	Y (7 points)	N (0 points)	N (0 points)	N (20 points)	N (20 points)
Total(100)		48 points	34 points	56 points	93 points	95 points
	Physical Characteristics					
5	Temperature	(negative)20 to 80 Celsius (5 p)	(negative)20 to 70 (4 p)	(negative)20 to 70 (4 p)	(negative)20 to 70 (4p)	(negative)20 to 70 (4p)
5	Solid State (Y or N)	Y(5 points)	Y (5 points)	Y (5 points)	Y (5 points)	Y (5 points)
25	Weight	2.25 grams (25 points)	11.36 grams (12 pts)		45.20 grams (5 points)	92 grams (3 points)
15	Dimensions (Volume)	12.7mm by 16mm (15 points)	1.5in by 1.43 by .39 (5p)	25.4by25.4by11.55mm(10)	2.5 * 2 * 1.35 in (5 p)	1.5 X 4.2 X .88in (5p)
50	Cost	Free (50 points)	50 (40 points)	55 (35 points)	799 (3 points)	750 (5 points)
Total(100)		100 points	77 points	57 points	22 points	27 points
	Total Overall(500):	287 points	296 points	330 points	325 points	370 points

Table 2.1 *Digital Compass Comparisons*

3. Electronics and Electrical System



Safety, reliability, and accessibility influenced the layout of the electrical system. Fuses prevent component damage as well as electric shock. Project boxes securely contain electronics and a waterproof fiberglass body ensures safe operation in wet conditions. All sensor components communicate directly to the PC or their respective information is relayed by microcontrollers. All communication data is passed through serial ports.

3.1 Power

Two 12V 60-amp hour batteries connected in series, provides approximately two hours of operating time. A 300W 24V DC-DC ATX power supply provides voltage regulation for the onboard PC and all system components.

3.2 Control

Motor control was a source of numerous setbacks in previous WunderBot designs. Due to the critical operation of this component, a RobotEQ AX2550 motor controller was purchased. RS-232 serial communication transmits and receives information and instructions between the onboard PC and motor controller. Two independent channels allow control of each motor individually. Wunderbot's main PC control program monitors several built in sensors such as temperature, battery voltage, and current draw in order to ensure safe and dependable operation. Advanced safety features provided by the motor controller include automatic shutdown due to electrical or software failure, programmable output current limit, and emergency stop notification.

3.3 Emergency Stop

The Emergency Stop System includes an onboard push button and a RF remote stop. The RF receiver board controls a power relay, which along with the push button is placed in parallel between the control line of the motor controller and ground. When the e-stop is pressed or the relay tripped, the control line is shorted, the motors are halted, and the motor controller shuts off immediately. This system was thoroughly tested and has proven to be reliable.

3.4 Sensors

Sonar sensors are used for obstacle detection in conjunction with the vision system. Three Devantech SRF04 sonar devices detect obstacles within 8 feet. A microcontroller operates each device and relays data via serial link to the onboard PC.   Although the sensors provide accurate information, multiple obstacle situations are difficult to interpret. These situations require additional information provided from a vision system. The vision subsystem is comprised of a USB camera and LabVIEW software.

Infrared proximity detectors are mounted near each wheel for drop off detection and pothole avoidance. Changes in terrain are monitored, and upon detecting a drop off, a signal is sent by a microcontroller to the onboard PC. The pothole location is treated as an obstacle in the path planning process.

A PNI TCM2-50 Digital Compass provides direction-heading feedback. The compass uses a highly advanced magneto-inductive magnetometer to detect the Earth's magnetic fields. It is constructed of a single winded solenoid, and offers high accuracy at low power. Built in algorithms to compensate for the presence of soft and hard iron materials ensures accurate readings once properly calibrated. Operation occurs on five axes: x, y, z, pitch and roll. The compass gives feedback of lateral deviation, resulting in closed loop control over direction heading via the onboard computer.

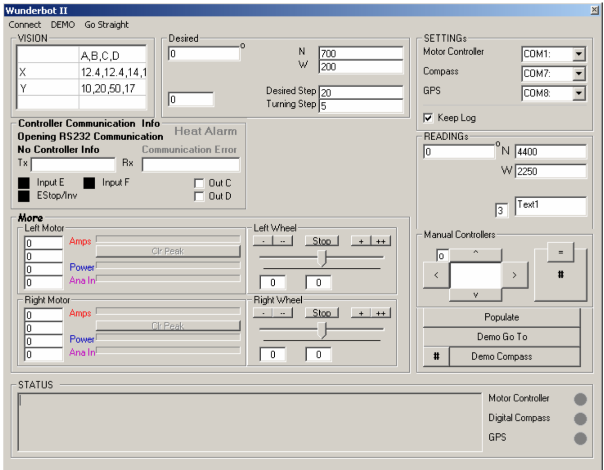
The Trimble AgGPS 114, a differential GPS receiver, offers positional output accurate within 30 centimeters. Important information about location, speed, and distance is interpreted from GPS data.

Parameters for the onboard computer included cost, efficiency, and expandability. The system consists of an AMD Athlon XP Barton 2500+ CPU, 512MB of DDR Ram, 40GB IDE hard drive with 8mb cache, and a Netgear wireless router. Wireless access provides monitoring capabilities and critical debugging information.

4. Software

Visual basic was selected due to the effective simplicity of ActiveX components. Difficulty was encountered while developing data mapping techniques, and for this reason, Visual C was integrated in the path-planning and mapping program. In addition to VB and VC, LabVIEW and IMAQ software are used for all image-processing techniques. LabVIEW is a graphical programming environment that can be used for test and measurement, data acquisition, instrument control, data logging, measurement analysis, and report generation [1]. IMAQ Vision Assistant predefines the most useful functions for image processing such as threshold, filtering, and edge detection in LabVIEW format.

4.1 GUI



The graphical user interface consists of monitoring information, manual controls, sensory information, and configuration settings. Monitoring information read from the motor controller provides voltage, current, and power graphed in real-time.

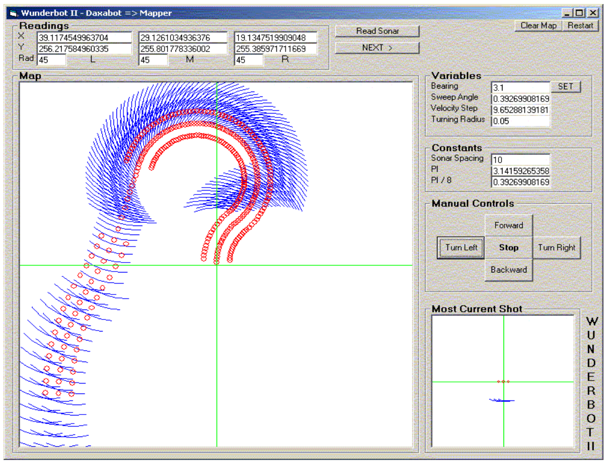
4.2 Mapping and Path Planning

All obstacle locations are stored in a multidimensional matrix that can be visually represented as a grid system. The key aspect of the grid system is its ability to adjust resolution. A 2 x 2 grid can be comprised of four 2 x 2 grids therefore possessing a resolution of 16 blocks. Each block represents a specified *real world* area. Each grid can contain yet another grid, leaving the only limiting factor the amount of memory in the system. Dimension representation is programmable and in this way an adaptable mapping process is achieved. Utilizing GPS position, mapping techniques assign GPS coordinates to obstacles based on vision system calculations.

Initial Path Planning calculations determine a desired direction vector using all available sensor data. In general this vector is determined from obstacle information and desired bearing, which is calculated from waypoint coordinates or white line locations. Once a desired direction vector is determined and obstacles are encountered, avoidance code is executed, and deviation from the desired direction vector is monitored. This information is then used to direct WunderBot back to the initial direction vector once the obstacles are evaded. Avoidance code is dependent on the type of sensor reporting data and location of the obstacle.

4.3 Simulation

Sonar operation and path planning were tested through a custom made graphical simulation. Three circles represent the sonar devices and readings are displayed as blue

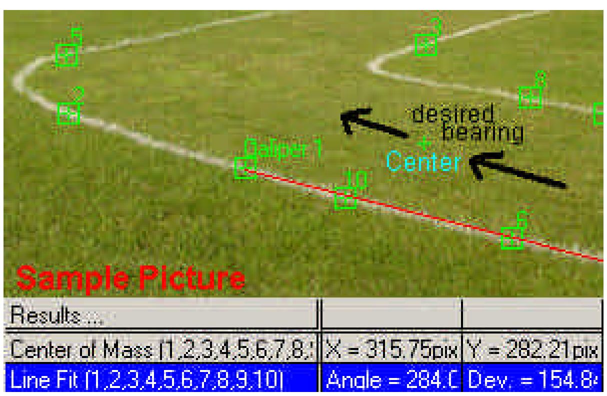


arcs. The most current sonar reading is displayed in the lower right corner along with direction heading. Similar to the GUI, variables and dimensions can easily be manipulated for experimentation.

5. Autonomous Challenge

The Autonomous Challenge requires a robot to traverse an obstacle course while remaining between two white boundary lines and carrying a payload of 20lbs. All subsystems are utilized during this challenge. Key components include Digital Compass, GPS, Vision System, Sonar System, and Infrared drop-off detection.

5.1 Boundary Limits and Bearing



White boundary lines are discovered through white and green pattern matching. The image is scanned for a specified template, and corresponding areas are noted based on pixel location. Line fitting is then applied through the points in order to determine whether one line is detected or both boundary lines are detected. If the line fits with negligible pixel deviation, only one line is in view. In this case, direction heading is adjusted using previous direction and line location. Movement is made in an attempt to view both lines while advancing along with course. Upon recognizing two lines, the midpoint between each line is calculated. Based on orientation of this midpoint, a desired direction vector passing through the center of the two boundary lines is fixed. WunderBot uses this desired bearing in the path planning logic described in section 4.2.

5.2 Drop off detection

Actual potholes will be detected by infrared proximity sensors, which monitor changes in terrain. Once located, potholes are treated as obstacles and are avoid in the same manner. This solution was applied in order to reduce image processing overhead.

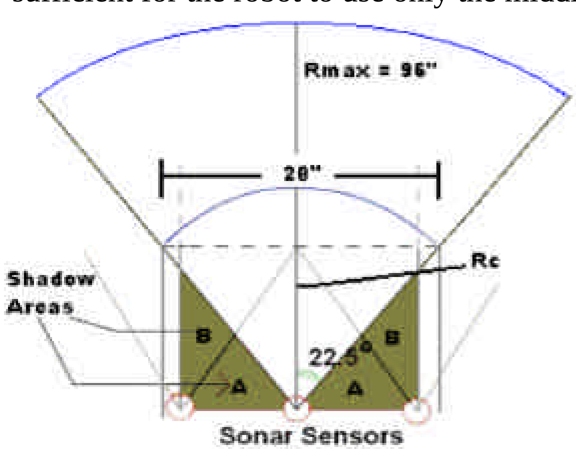
5.3 Near Object detection

ds	ps	ErrC	ang
Dist. Between Sensors	Dist. from side sensors to side of robot	Error Consideration	Angle of sonar beam
10 inches	4 inches	2 inches	p/8

Sonar data is relied upon during close obstacle situations. In most cases data provided from the vision system will prevent close encounters with objects. However, the sonar array was developed as a reliable counterpart to the vision system. As depicted in the beam diagram, sonar calculations approximate the beam pattern as a perfect arc with a 45º angle. The middle sonar sensor determines velocity and utilization of the side sonar sensors. The distance to an obstacle as detected by the middle sensor is compared to the radius at which sufficient space is available for the robot's clearance, R_C:

$$R_c = [(ds + ps + ErrC) / Sin(ang)] + ErrC = 44 \text{ inches}$$

Robot velocity is a function of object proximity. If obstacles are not found inside R_C, it is sufficient for the robot to use only the middle sonar sensor. Once the middle sonar sensor detects something inside of R_C, the values from the side sonar sensors are taken into consideration.



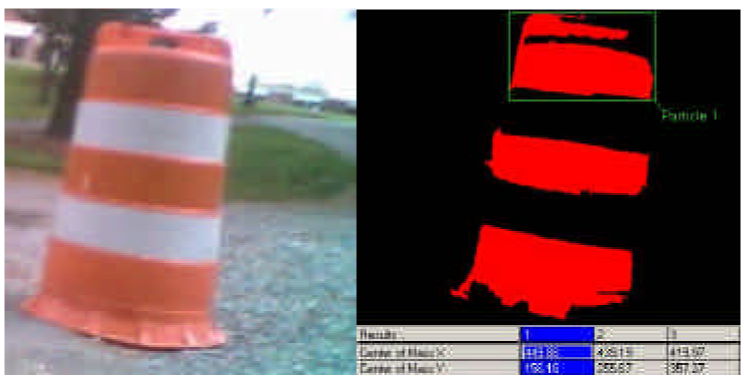
The left and right sensors determine direction bearing. This calculation depends upon a comparison of the distances of obstacles that are detected by each side sonar device. The radii to each obstacle are compared with R_C and a value is added to or subtracted from the direction bearing of the robot. In this way, the robot turns to the right if the obstacle detected by the left sensor is closer than the obstacle detected by the right sensor (and vice versa).

A *Panic Code* is initiated once an obstacle is detected inside of R_{MIN}

$$R_{min} = [(ps + ErrC) / Sin(ang)] + ErrC = 13 \text{ inches}$$

WunderBot pauses once it detects an obstacle within R_{MIN}. The robot turns to the left and then to the right and finally chooses a direction towards either the furthest obstacle, or an obstacle free path. In this way all three sensors are utilized, and as the robot moves closer to an obstacle the velocity decreases. The slower velocity enables more precise turning and gentler movements. In addition to obstacle proximity, line location is also considered when maneuvering around obstacles by closely monitoring the desired vector and actual direction heading.

5.4 Distant Object detection and simulated potholes



Construction barrel location will be determined based on the relationship of varying image size and distance. The construction barrels are of uniform size and therefore measuring height or width can lead to barrel distance with respect to the robot. The barrel orientation is calculated based upon the location of the barrel in the image. Each object is recognized through a sophisticated process of threshold, filter, and analysis. In the image, the orange pixels are isolated, distance between orange bands measured, and based on a reference ratio of pixels to inches, distance to the barrel is calculated. Once a barrel is recognized, the center can be located and based on the pixel coordinates, a bearing to the obstacle can be calculated. Bearing information along with radial distance will be used to approximate the GPS coordinate of the barrel. This coordinate will be used in mapping and path planning. White 5-gallon pails will be detected in a similar manner. In the instance of several barrels side by side, a significant area of orange pixels will be isolated. When this information is recognized, a new direction heading away from the trap is calculated. This direction calculation is once again based on pixel coordinates. In this way, a concentration of pixels is avoided and open space is sought out. Potholes are specified to be 2 feet in diameter and can be simulated by white circles. The vision system detects simulated potholes through threshold and pattern matching. Once detected, diameter based on pixel length is measured, and distance to a pothole is determined through utilizing a reference ratio of pixels to feet.

6. Navigation Challenge

The Navigation Challenge requires a robot to meet specified waypoints and return to a home coordinate while avoiding obstacles. WunderBot's digital compass and differential GPS are key components in this challenge. Based on current GPS location, current direction bearing, and waypoint location, WunderBot is directed toward the nearest GPS coordinate using simple trigonometric relations. As WunderBot moves and the relative GPS coordinate changes, a new desired bearing is calculated every second. In this way the path remains direct. To prevent returning to home base accidentally, a flag is set as WunderBot approaches the home coordinate. If additional coordinates need to be met, WunderBot avoids home base and continues toward the necessary waypoint. All previous obstacle avoidance measures are in use. Once all locations have been met WunderBot is directed home.

7. Performance

Category	Required Results	Expected Results	Confirmed Results
Speed	5 mph	5mph	5mph
Ramp Climbing	15° slope	45° slope	30° slope*
Stopping Distance	6 feet, 15% incline	Immediate	Immediate
E-Stop Range	50 feet	1000 feet	Over 100 feet*
Payload	20 lbs	Over 20 lbs	Over 100 lbs*
Battery Life	30 minutes	2 hours	1 hour*
Sonar Detection Dist.	8 feet	10 feet	10 feet
Vision Detection Dist.	25 feet	100 feet	100 feet

* Indicates maximum performance was not measured

The performance table includes results required, expected, and confirmed. In few cases the maximum performance was not measured since the confirmed result exceeded the required.

8. Budget

W I	W II	Product	Qty.	Act. Total	Our Total	Savings
?		NPC T-74 Motor	2	$598.00	$598.00	$0.00
?		NetGear Wireless USB Adapter	1	$49.99	$49.99	$0.00
?		NetGear Wireless PCI Adapter	1	$59.99	$59.99	$0.00
?		Linx RF Development Boards HP-II Series	2	$298.54	$298.54	$0.00
?		Devantech SRF04 Sonic Ranger	3	$99.00	$99.00	$0.00
?		USB Web Camera	1	$40.00	$40.00	$0.00
?		Basic Stamp Microcontroller BS2SX	1	$59.00	$59.00	$0.00
	?	Basic Stamp Carrier Board	1	$24.00	$24.00	$0.00
	?	MK M34 Batteries	2	$500.00	$147.20	$352.80
	?	Trimble AgGPS 114	1	$3,000.00	$0.00	$3,000.00
	?	On-Board PC	1	$550.00	$550.00	$0.00
	?	Roboteq AX2550 Motion Controller	1	$495.00	$468.00	$27.00
	?	OOPic II Plus Starter PKG	1	$74.00	$74.00	$0.00
	?	Devantech SRF04 Ultrasonic Housing	2	$19.00	$19.00	$0.00
	?	Sharp IR Sensors R48-IR12	3	$34.50	$34.50	$0.00
	?	PNI TCM2-50	1	$769.00	$0.00	$769.00
	?	Over-Current Protection	1	$31.55	$31.55	$0.00
	?	80A Connectors & 8 AWG wire	1	$95.64	$95.64	$0.00
	?	6061 Aluminum Frame	1	$550.00	$350.00	$200.00
	?	NPC PT-5306 Flat Proof Wheel	2	$146.00	$146.00	$0.00
	?	8" Pneumatic Caster (Series 5000)	2	$133.66	$133.66	$0.00
	?	24-12V Power Supply Unit	2	$400.00	$400.00	$0.00
	?	Omnistar DGPS Subscription	1	$800.00	$0.00	$800.00
	?	LabVIEW Prof Dev System	1	$3,495.00	$0.00	$3,495.00
	?	NI Vision Development Module for LabVIEW	1	$2,595.00	$0.00	$2,595.00
	?	(Book) Img Processing with Labview and IMAQ	1	$80.00	$0.00	$80.00
	?	Laptop for remote monitoring	1	$1,500.00	$0.00	$1,500.00
	?	Silicon 8ga Wire (Black)	15	$22.50	$22.50	$0.00
	?	Silicon 8ga Wire (Red)	15	$22.50	$22.50	$0.00
	?	Hella Contour Master Power Switch	1	$21.49	$21.49	$0.00
	?	Replacement Soldering Tips	4	$20.24	$20.24	$0.00
	?	OOPic II + Microcontroller	1	$26.00	$26.00	$0.00
	?	OOPic II + Replacement EEPROM	1	$4.95	$4.95	$0.00
	?	12 V 10A Battery Charger	1	$100.00	$100.00	$0.00
	?	Misc Frame and Body Materials	1	$527.49	$527.49	$0.00
		Total		$16,519.37	$3,700.57	$12,818.80

9. Conclusion

All project goals were achieved as well as customer requests through thoughtful design, quality parts, creative programming, and a variety of features. The result is a sophisticated project that is fully capable of participation at IGVC.

References

[1] National Instruments, "LabVIEW 7 Express User Manual," Austin Texas: National Instruments, April 2003.

[2] P. E. Sandin, "*Robot Mechanisms and Mechanical Devices*" New York:McGraw-Hill, 2003, pp..237.