The
WARRIOR

Presented By: University of Detroit Mercy

2005 Intelligent Ground Vehicle Competition

May 25, 2005

Faculty Advisors:

We certify that the engineering design of the original vehicle *Warrior*, presented in this report, has been significant and that each undergraduate team member has earned six hours of senior design credit for the work accomplished on this project.

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1 Introduction

The University of Detroit Mercy (UDM) Design Team presents *Warrior* for entry into the 2005 Intelligent Ground Vehicle Competition (IGVC). *Warrior* (shown on the cover) has an Amigo-based platform that has been stripped down and modified, making it more versatile for mounting the subsystems required to participate in the competition. (The Amigo is an electric mobility scooter.) Additionally, the steering system has been modified, making it more suitable for computer control.

The name "*Warrior*" was inspired by the history of the Amigo vehicle at UDM, where it has been used as a vehicle platform for several Senior Design course cycles. "*Warrior*" exemplifies how strong of a competitor this vehicle is and its determination to succeed.

2 Team Organization

Our team consists of five undergraduate EE (Electrical Engineering) students, one undergraduate ME (Mechanical Engineering) student, and one graduate EE student. The team organizational chart is shown in *Figure 1* below.

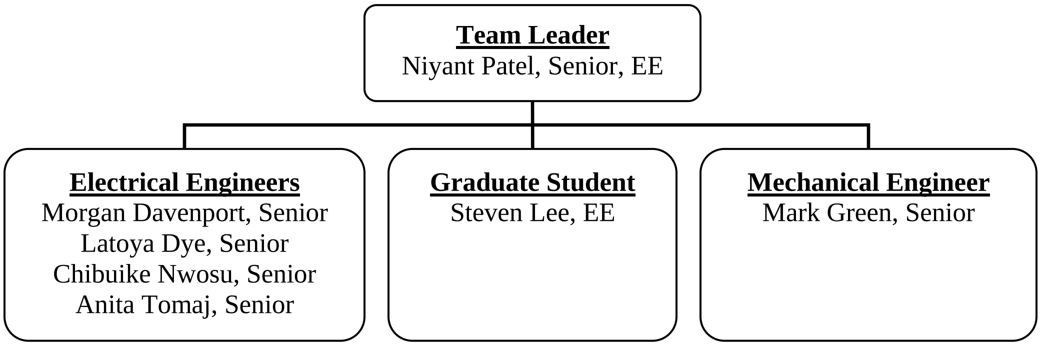


Figure 1: *Team Organization Chart (Team Warrior)*

The graduate student assisted with the advanced image processing and navigation algorithms, while the ME student handled the structural requirements of the vehicle. The EE students handled all the other tasks including steering, drive systems, power distribution, battery management, and sensory systems. Three faculty advisors, Dr. Mohan Krishnan and Dr. Sandra Yost both of the ECE Dept., and Dr. Nassif Rayess of the ME Dept. were in charge of supervising Team *Warrior*. Our project was carried out as part of a 2-course Capstone Design sequence starting in January 2005 and ending in August. The total estimated number of hours worked on the vehicle was 3500 hours.

3 Design Planning Process

Planning for this year's participation in IGVC began as early as the summer of 2004 when, in conjuction with a course on Control Theory, a field trip was organized to the 2004 IGVC competition. Then in Fall 2004, a team meeting was called to identify and distribute reports from earlier UDM autonomous vehicle projects as well as reports from successful teams in previous IGVCs. In addition, the offering of two senior/graduate level courses on Computer Vision and Fuzzy/Neural Systems provided the opportunity for these students to undertake course projects related to IGVC. A select group of the graduate students in these courses were then added to the IGVC team in January 2005. This has been the most comprehensive process adopted so far to prepare for the IGVC.

Along with this, weekly team meetings were conducted with the team members and advisors, allowing for organization and time management within our project. When the vehicle was ready for preliminary testing, a mock course was set up indoors with lanes and obstacles. Once the weather permitted, an outdoor course was simulated on grass in accordance with IGVC rules. This was a great way to ready the vehicle by improving our development of software and overall vehicle performance.

4 Chassis/Platform

The *Warrior* vehicle platform is the Amigo Deluxe chassis model #350000 seen in *Figure 2*. As previously mentioned, modifications were made to the steering system to enable autonomous steering control; a chain and sprocket mechanism powered by the steering motor is utilized (see *Figure 3*). Also the chair was replaced with a platform to house vehicle subsystems.

Figure 2: *Original Amigo Vehicle*

Before modifying the Amigo chassis, it

weighed 135-lbs with a load capacity of 350-lbs. In its final competition form, the *Warrior* chassis will weigh approximately 215-lbs.

It maintains the underbody ground clearance of 2.5-inches and turning radius of 36-inches. The original Amigo came with two 12V batteries. Currently, these two batteries are used to provide propulsion for *Warrior*.

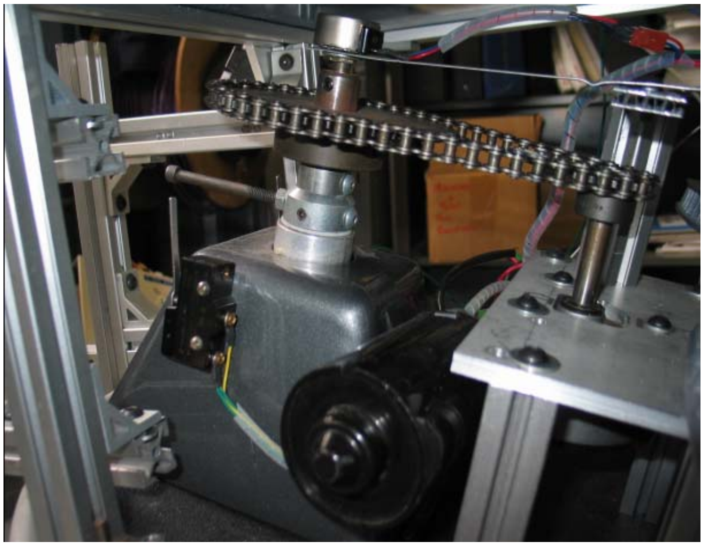


Figure 3: *Warrior Steering System*

4.1. Motors and Controllers

The original Amigo drive motor and controller were retained for controlling the throttle. For the steering system, an Advanced Motion Control 25A8 servo amplifier was chosen. The controller includes a PID (Proportional Integral Derivative) control, which is needed to direct the steering system (refer to *Figure 4*). An analog potentiometer serves as the feedback mechanism for this PID controller, which allows the current angle of the front wheel of the vehicle to be accurately obtained. The controller also has a servo amplifier that will take an input and amplify it so as to power the steering motor. The *Warrior* steering system motor is set up to operate in a -2V to +2V range which is used to direct the front wheel up to a desired angle of ±36°. Right and left steering limit switches have been implemented to prevent over-steering and serve as a safety mechanism.

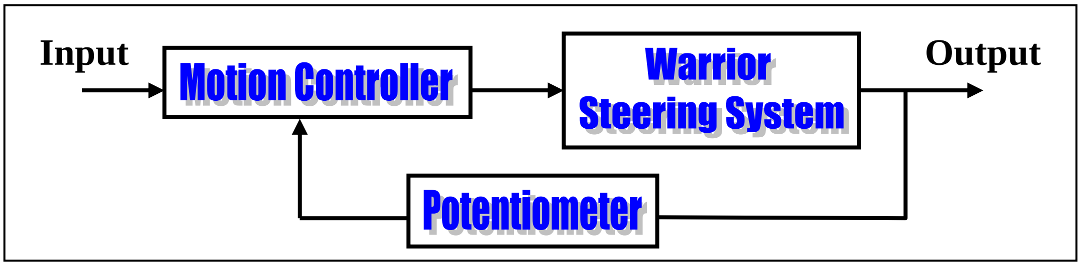


Figure 4: *Steering Controller*

5 Electrical Systems

Figure 5 shows an overall electrical system block diagram. The inclusion of various sensors, an emergency stop (E-Stop), the UDM-WSCB (University of Detroit Mercy - *Warrior* Speed Control Box) (discussed in the later sections), and an efficient power distribution system all help to make this a valuable design.

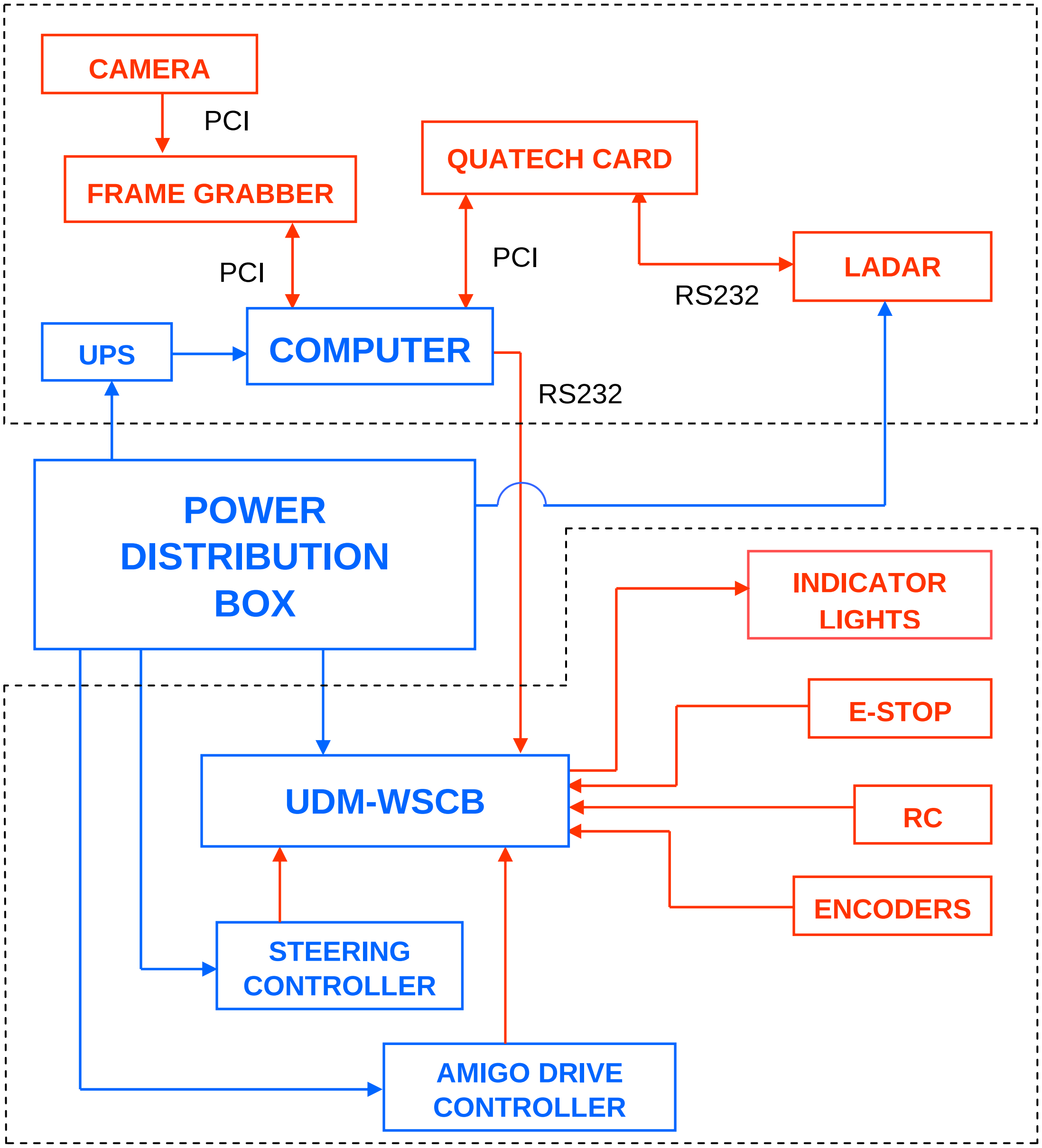


Figure 5: *Overall Electrical System Block Diagram (power connections – blue, signal connections – red)*

5.1. Power Distribution System

The original Amigo batteries power the *Warrior* drive motors and two Die Hard 12-volt batteries (configured in series to provide a 24-volt source) power the other system components. The overall power/current draw for main components in the vehicle is shown in *Table 1*, along with the expected runtime of each battery pack.

Subsystem	**Voltage (V)**	**Current (A)**	**Power (W)**
Die Hard Pack			
Computer	24	10	240
SICK LADAR	24	1	24
Camera	12	0.3	3.6
UDM-WSCB	12	0.5	6
E-Stop Module	12	0.2	6
Indicator Lights	12	1	12
Regulators/Box	24	1	24
LCD Display	12	4	48
Total		**18**	**363.6**
Amigo Pack			
Amigo Drive Controller	24	0.4	9.6
Steering Controller	24	5	120
Drive Motor	24	5	120
Ventilation Fan	12	0.2	2.4
Regulators/Box	24	2	48
Total		**12.6**	**300**

	Die Hard Pack	**Amigo Pack**
Current (Amps)	55	26
Current Draw (Amps)	18	12.6
Run-Time (Hrs)	3.06	2.1

Table 1: *Overall power/current draw for main components in vehicle*

Battery charging for the Amigo pack will be done using the built-in 24V charger; this system allows for a full charge in 3 hrs. Charging for the Die Hard pack will be done using a separate 12V battery charger, which has the ability to complete charging in about 3 hrs. A secondary set of the Amigo and Die Hard batteries will be on hand during the competition to allow a quick and easy battery swap, once the charge level is below 20%. The power distribution box (shown in *Figure 6*) has a battery level indicator that will alert the users once the battery level is at about 20%, ensuring the *Warrior*'s batteries will not die during competition.

As for the Amigo pack, the scooter's built-in charge indicator has an LED (Light Emitting Diode) display providing charge status indication.

The implementation of the power distribution box is a feature for the power system that allows multiple power, single point access that makes diagnostic testing easy. It contains regulators and fuses that protect the individual subsystems. There is also a LED that corresponds to each switch indicating whether or not the corresponding subsystem is activated, or if its fuse has been blown.

Figure 6: *Warrior Power Distribution Box*

5.2. Controller Box

To make the *Warrior* vehicle design more efficient, Team *Warrior* designed and built the UDM-WSCB (refer to *Figure 7* and *Figure 8* to view the interior and exterior part of the UDM-WSCB, respectively).

Its main purpose is speed and steering control; however, it has other attributes that are used for the radio control (RC), encoders, and the E-Stop relay. It also has a LCD (Liquid Crystal Display) screen to view any diagnostic error messages. The implementation of this box is a cost savings feature because it eliminated the use of a DAQ (Data Acquisition) card. The UDM-WSCB includes a Freescale HS12 microcontroller and runs with a serial port, which allows a stand-alone speed control system if needed.

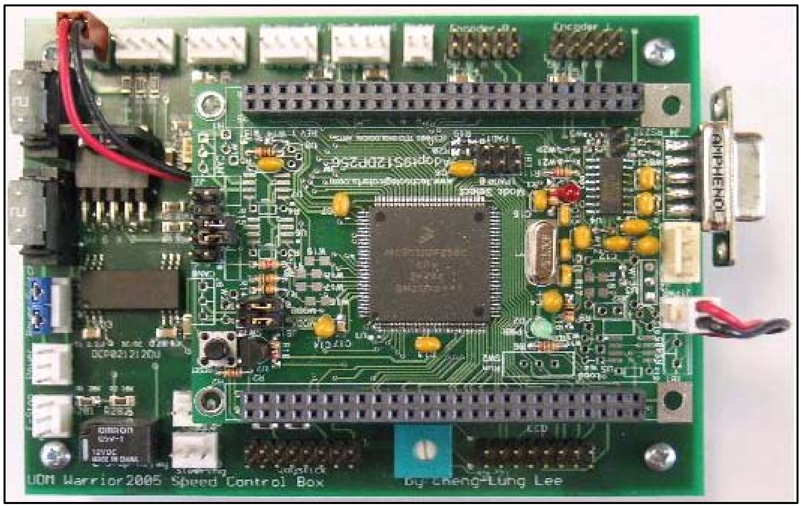


Figure 7: *UDM-WSCB (interior)*

Figure 8: *UDM-WSCB (exterior)*

5.3. E-Stop/Manual Drivability Mode

As per the competition rules, both a wireless and manual E-Stop system has been implemented on this vehicle. The measured range for the wireless E-Stop is 200 ft. Both of the E-Stop systems stop the vehicle by grounding the input of the drive controller. For the wireless E-Stop an automotive remote keyless entry system, donated by Bosch, is implemented in the design.

The keyless E-Stop system is designed to be highly immune to RF (radio frequency) noise. However, in earlier competitions it was noted that RF-based E-Stop systems did not operate reliably in the EMI (Electromagnetic Interference) environment prevalent; therefore, a backup DTMF (Dual-Tone-Multiple Frequency)-based E-Stop system has been incorporated in our design. This system is completely dependent on audio rather than RF transmission and is expected to function reliably even when the main E-stop system does not. In a DTMF tone generator there are 16 distinct tones corresponding to the buttons on a telephone keypad and each tone is the unique sum of two frequencies, one from a low and one from a high frequency group. The receiver, which will be on *Warrior*, consists of a decoder whose output will trip the relay in a similar fashion as the RF-based or onboard E-Stop systems if the correct code is sent.

For manual drivability of the vehicle, so that it can be moved easily when not operating autonomously, an RC-joystick-based system has been implemented. This system allows control of the vehicle over a range of 150 ft. Once again, to protect against failure due to EMI, this system is complemented by an onboard analog joystick, which can also be used to drive the vehicle when it is not in autonomous mode.

5.4. Sensors

Warrior uses several sensors in order to make the vehicle autonomous; a brief description of each is in the following sections.

5.4.1. Camera - Panasonic GP-KR222 Camera

Figure 9: *Camera*

To provide input to the vision system the Panasonic GP-KR222 Digital Signal Processing Industrial Color CCD (Charged Coupled Device) camera shown in *Figure 9* was chosen. The image will be used to detect the location of boundary lines and potholes. The camera utilizes a 1/2-inch interline CCD image sensor having 752 by 582 pixels in order to produce high picture quality and resolution.

5.4.2. LADAR - Laser Measurement System, LMS 200

The LADAR shown in *Figure 10* is used to detect obstacles that may not be specifically identified by the vision system. Its main benefits are that objects in its field are detected independent of their color and surface texture, and it is a reliable means of detecting these objects. The LADAR detects the presence of obstacles in a 180-degree viewing field in front of the vehicle at either a 0.5 or 1-degree resolution out to about 80 meters. For the *Warrior* the LADAR will be configured for 0.5-degree resolution that will provide a data transfer rate of 38400 baud (refer to *Figure 11* for a graphical view of the LADAR scanning pattern).

Figure 10: *LMS 200 LADAR*

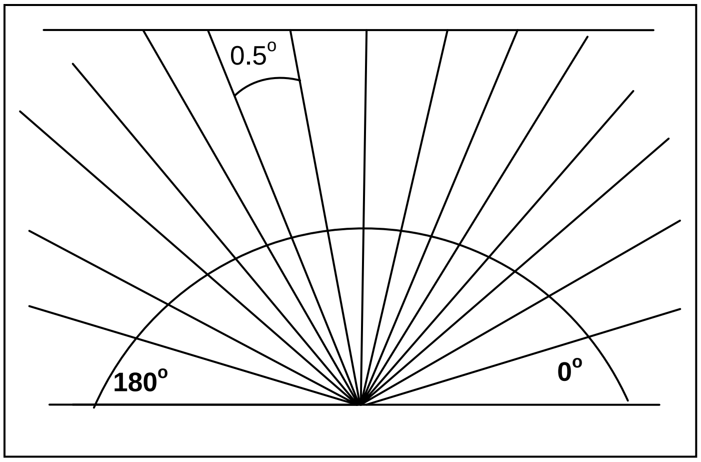


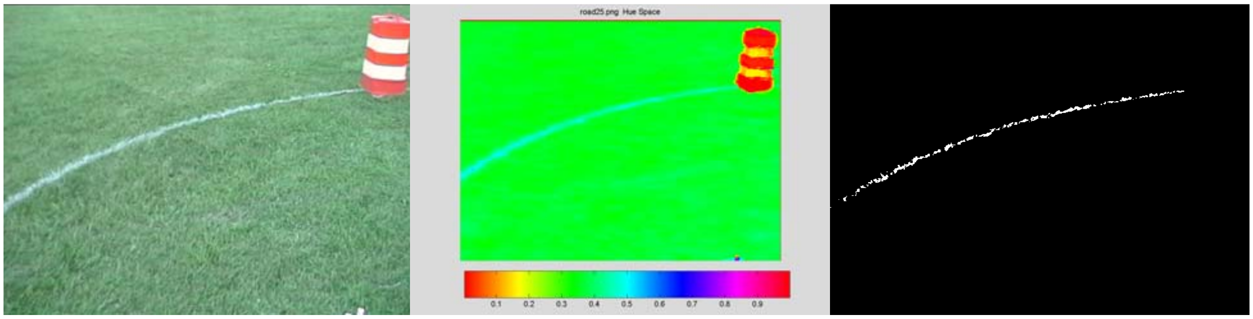
Figure 11*: LADAR scanning pattern*

The LADAR is mounted to the *Warrior* in a way that enables it to be easily removed and transferred to the other UDM vehicle that is participating in IGVC (see *Figure 10*). This mechanical feature serves as a cost saving because the LADAR can be used for both vehicles.

6 Software Implementation

The algorithms developed for the *Warrior*'s image processing and navigation subsystems were constructed using Matlab/Simulink software running on a PC, while the speed and steering controls were implemented on a Motorola HS12 microprocessor programmed using the FORTH language. The *PC is* a 3.4 GHz, Pentium 4, 1GB RAM computer running Windows XP. This computer communicates with the camera and the UDM-WSCB through a Quatech serial port card as previously shown in *Figure 5.*

In order to process the image for the autonomous challenge, the image is captured through the Panasonic GP-KR222 camera, *Figure 12a*. For color segmentation the image is converted into the HSV (Hue-Saturation-Value) format. By using color segmentation we allow the computer to separate red or orange construction barrels from the green grass and white, which represents potholes or lines, *Figure 12b*. The final image (see *Figure 12c*) is then developed through a thresholding technique. This image is then further analyzed in the image processing algorithm to determine an angle of travel to assist in the final navigation algorithm.



(a) *(b)* *(c)*

Figure 12: *Image processing: (a) Original camera image, (b) HSV, color segmented image, and (c) Threshold - Final image*

The Fuzzy Inference System (FIS) techniques on which the navigation algorithm is based combines the calculated inputs from the LADAR and image processing as described above. It finds the location of the boundary lines and obstacles when combining the results from the two sensor systems. The corresponding angle is then sent to the steering controller, and the vehicle is steered in the optimal direction.

7 System Integration

The *Warrior*'s complete system is comprised of various subsystems that are integrated to allow for a capable autonomous vehicle to compete in the autonomous competitions. In the end, Matlab/Simulink served as a more efficient form of system integration. Therefore this software system serves as the major component in this systems overall implementation.

8 Predicted Performance & Actual Results

In the following sections, various performance predictions for the *Warrior* will be discussed. The actual results obtained at the time of the submittal of this report are also provided.

8.1. Speed

The predicted speed for the *Warrior* was found in the original Amigo owner’s manual. The throttle components were not altered; therefore, the speed is the same as the manufacturer’s specifications, which is a speed of 0-5.3 mph.

8.2. Ramp Climbing Ability

The ramp climbing ability was also obtained through the original Amigo owner’s manual. This states that the vehicle will meet the Federal standards for wheelchair ramps. The standard is “one inch rise per one foot”, which is an 8.33% gradient. Further tests were conducted with *Warrior* and a 15% gradient was met as per competition requirements.

8.3. Reaction Time

The image processing system is able to process about 8 frames per second and the motor command refresh is 100 ms. The LADAR system provides roughly 5 frames per second making the overall refresh rate for the system 5 frames, which is the slower of the three, and thus the limiting factor. Therefore, the *Warrior* has a 200 ms reaction time.

8.4. Battery Life

The estimated battery life for the two Die Hard automotive 12-volt batteries (configured in series to provide a 24-volt source) is 1.8 hrs. As for the original Amigo batteries that are being used for throttle, the Amigo owner's manual states that the range was 25 miles per charge. This range was based on a 180 lb driver (in addition to the original weight of the vehicle) driving on a flat surface. The range depends on the battery type, driver weight, terrain traveled, and ambient temperature. The approximate run-time as determined experimentally by the *Warrior* team was approximately 2.1hrs.

8.5. Obstacle Detection Distances

Warrior vehicle will use the SICK LMS-200 LADAR to detect obstacles along with the Panasonic camera). The LADAR is configured to scan up to approximately 8 meters, although only the data that is in the 2-meter range will be considered because we are only interested in the obstacles that are immediately in front of the vehicle. The vehicle vision system is meant to detect course lines and potholes as well as the presence of obstacles; however, it does not serve as a precise means for determining the distance of an obstacle from the vehicle.

8.6. Vehicle Reaction to Potholes, Traps, & Dead Ends

Warrior has been designed to maneuver around potholes. Once the Image Processing algorithm has detected the pothole, the vehicle's vision system will determine the width of the pothole and in conjunction with the navigation algorithm an angle will be calculated. In the event that the vehicle encounters a dead end or trap the vehicle will reverse its direction, but the algorithm is designed to avoid such a situation.

8.7. Comparison of Results

Since *Warrior* has an Amigo-based platform, the team was able to make more reliable estimates for the vehicle's performance using information from the original Amigo owner's manual. While navigating through the indoor course the vehicle seemed to navigate the course well. The outdoor course had several environmental challenges that hampered the vehicle's vision system, such as bright sun and faint lines due to grass growth. Overall the vehicle testing revealed that *Warrior*'s autonomous navigation algorithm required slight modifications due to its inability to initially complete the outdoor course.

9 Budget

Refer to the table below for a budget analysis of the major components used in the *Warrior* vehicle (*Table 2*).

Item	**Retail Cost**	***Warrior* Cost**
Die Hard Batteries (2)	$180.00	$180.00
Amigo Batteries (2)	$150.00	$150.00
Encoders (2)	$90.00	$90.00
SICK LMS200	$7,000.00	$4,305.00
LMS mounting hardware, PLS-MB1, PLS-MB2	$267.00	$267.00
LMS PLS-K13 Cables	$38.00	$38.00
Matrox Meteor II Image Capture Card	$595.00	$595.00
UDM-WSCB	$200.00	$200.00
Power Box	$75.00	$75.00
Computer	$1,200.00	$1,200.00
Camera	$600.00	$600.00
Miscellaneous	$150.00	$150.00
Steering Motor	$50.00	$0.00
Steering Controller	$200.00	$200.00
E-Stop Module/Key Fob	$80.00	$0.00
DC-DC Power Supply	$49.00	$49.00
Quatech RS232 Card	$100.00	$100.00
Amigo Scooter	$3,345.00	$0.00
Body Frame/Cover	$500.00	$100.00
Total Cost	**$14,869.00**	**$8,299.00**

Table 2: *Overall budget analysis of major components used in the Warrior vehicle*

10 Summary

In designing the *Warrior* vehicle it was important to devise a plan that would incorporate graduate level experience with that of undergraduate electrical and mechanical engineering students to successfully complete the vehicle. This vehicle began development in previous UDM

Senior Capstone design courses. Through the test of time *Warrior* has evolved into a fully autonomous vehicle capable of competing in the 2005 Intelligent Ground Vehicle Competition.

Several noteworthy modifications where made to the original Amigo scooter to make it autonomous. The original manual steering system was retrofitted with a chain and sprocket mechanism driven by a ,motor. The vehicle has been designed with a high degree of modularity to make diagnostic testing convenient, such as the power distribution box and also the UDM-WSCB. Both were designed and built by the team members. The UDM-WSCB (UDM – *Warrior* Speed Control Box) is equipped with a microcontroller that serves as the "brain" for this interface board offering several I/O and PWM pins to meet the design requirements for the vehicle. The addition of a backup DTMF-based E-stop ensures an emergency stop where electromagnetic interference may pose a problem for the main RF-based system.

Preliminary testing suggests that the vehicle will perform satisfactorily in the competition. The image processing and navigation algorithms are currently being optimized.