Oakland University
Multi-purpose Autonomous Robotic Construct
MARC

Technical Report
June 2003

10th Intelligent Ground Vehicle Competition

Abstract

The Multi-purpose Autonomous Robotic Construct (MARC) will be an Oakland University entry into the 11th Intelligent Ground Vehicle Competition. The system design enables the vehicle to perform various mission modules given the appropriate algorithm. MARC will compete in the competition's Autonomous, Navigation, and Follower Challenges.

1. Introduction

The Multi-purpose Autonomous Robotic Construct (MARC) is an Oakland University entry into the 2003 IGVC competition. MARC was a first year entry into the 2002 IGVC competition and featured a custom designed frame, electrical system, sensor suite, and software. This year's vehicle has had design changes to the hardware, software, and electrical systems. This year's team was reduced to two individuals and a few volunteers due to the graduation of last year's members. The focus of this year's team has been to increase the capability of the software while making minor mechanical changes to improve the vehicles overall performance. New capabilities have been introduced such as the portable operators control unit that bring an entirely different dimension to the overall system design and capability. This paper will focus on the design changes made to the MARC vehicle for the 2003 competition and will contain the much of the same overall system operation as presented in lasts years paper.

2. Design Process

Given that lasts years paper did not elaborate on the design process used in the creation of the MARC below is the block diagram detailing the process employed.

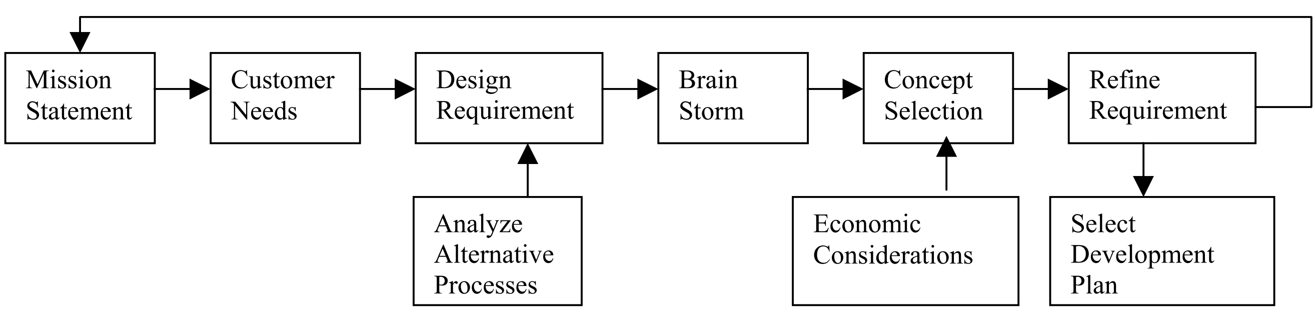

Figure 1: Design Process Block Diagram

The project starts with the mission statement, which in this case was to design an autonomous mobile robot for the IGVC competition. The next step was to determine customer needs, with the customer being the competition: Compete in the Autonomous, Navigation, Follower, and Design competitions. Next we looked at our design requirements; what capabilities we would need meet in order to satisfy our customer: Detect Lanes, Detect Obstacles, Path Planning, Follow GPS waypoints, etc…. We then began to brainstorm how to meet those requirements, would we need LADAR, GPS, Monocular vision, Stereo vision, RADAR, SONAR, two wheeled chassis, four wheeled chassis, electric motor, gas motor, exc… Eventually a concept was chosen for each of the different systems of the vehicle, taking into account the mission statement, customer needs, design requirements, brain storming results, and also economic considerations. Cost and availability of items where major decision aids that affected the concept selection of each of the major systems. Next step was to review and refine the requirements that drove the team to each of the concepts that where chosen. Essentially this was the reflection step where the final concept was either selected as the development plan, for each system, or was sent back to the drawing board starting at the mission statement. This design process is an iterative process that has continued throughout the entire development and fabrication of the vehicle. One major change that affected this year's vehicle was the addition of the operators control unit. When it was decided to include this option as a part of the vehicle allot of the software systems needed to have their requirements refined requiring us to go back to step one starting with the mission statement.

2.2 Design Tools

The frame of the MARC was first designed using Auto CAD. The frames layout and dimensions where determined using this software before any fabrication took place (see Figure 2). A custom designed FMEA program was used to determine key stress point on the frame which where noted and accounted for in the remainder of the vehicle design. Card board cutouts where used to model of the vehicles shell before the fabrication of the shell took place. The cutouts where then used as templates during the cutting and bending of the actual aluminum shell.

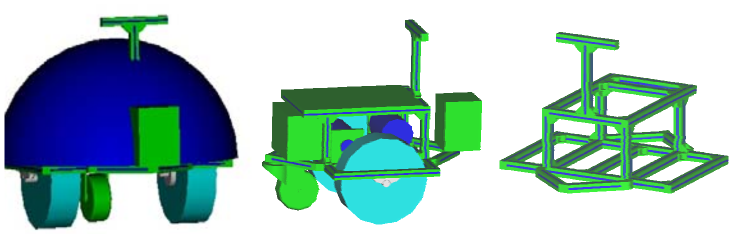

Figure 2: Sample MARC CAD designs

2.3 2003 MARC Design Team

The 2003 IGVC MARC team is made up of the students listed in table 1. Only two students are members of this years MARC team due to the graduation of the rest of last years team and the lack of interest, with the remaining two members, to solicit for additional help. Given that it was predicted that a majority of the remaining work on the MARC would be software related it was decided that additional team members would not be required. Logistics also played a large role in the decision not to actively seek additional team members.

Table 1 - MARC Design Team

Graduate Students	Degree Program	Focus
Robert Kania	PhD	Robotic Systems
Philip Frederick	MSE	Robotic Systems

3 Mechanical Design

3.1 Frame

The vehicle frame is composed of Bosch aluminum structural framing. The "easy-connect" feature of this material allows for quick and clean assembling/dissembling of the different layers of the vehicle (Figure 3A & 3B). The rectangular shape of the layers and appendages of the frame was chosen to provide load support, room for components, and simplicity of design. Mounting plates were designed from ¼" stock aluminum to support the motors, speed controllers, sensors, and different electrical components of the vehicle. The computer was mounted to the top of the second layer of the vehicle with standoffs and shock absorbers. The design and connecting components of the frame were designed to support a total load of 500 lbs.

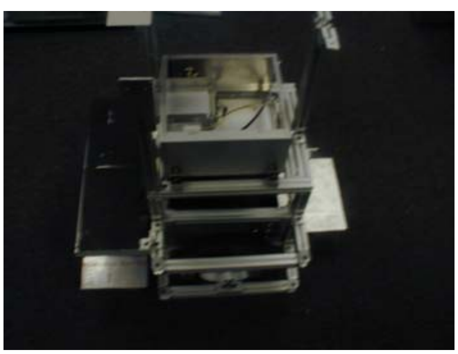

Figure 3A: MARC Frame (Top View)

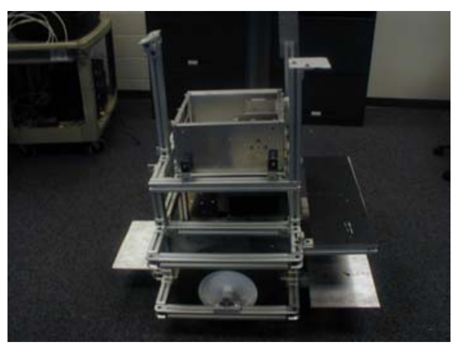

Figure 3B: MARC Frame (Side View)

3.2 Drive System

The drive system of the vehicle was designed to handle a total vehicle weight of 500 lbs. No suspension was designed for the vehicle since its intended goal is not to transverse rough terrain. The vehicle drive system is composed of the following components. Some of these components are shown in Figures 4A and 4B.

- 2 - Wheel Barrel Wheels
- 2 - 24V 650A Mosfet speed controllers
- 2 - 24V series-wound DC motors
- 1 - 6' Steel Chain
- 2 - 9'' Steel Gears
- 2 - 5/8 bored sprockets


Figure 4A: MARC Gear & Wheel

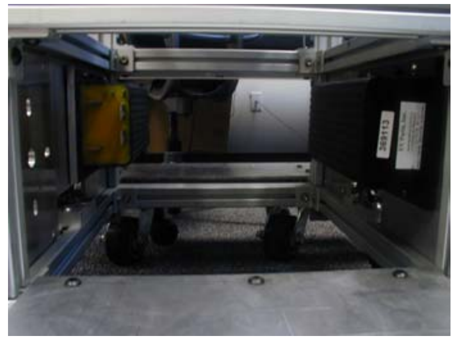
Figure 4B: MARC Speed Controllers

¼' Aluminum sheet metal was machined to mount the motors, speed controllers and batteries to the vehicle.

3.3 Shell

The outer shell of the vehicle was composed of 1/16'' aluminum sheet metal. The aluminum shell was chosen since the material was readily available and easy to work with. A cardboard model of the outer shell was generated for concept testing and the individual pieces were used as templates to cut and bend the final aluminum sheets. The outer shell mounts flush to the vehicle frame.

3.4 Mechanical System Improvements

As stated in the introduction not many design changes where made to the mechanical system of MARC. The only design change that was made to the vehicle's mechanical system was to add extra support, in the form of support cables, to the two spots on the vehicle where the batteries reside. One point of clarification, from comments received on last year's paper, is that the frame of MARC is designed to support a total load of 500 lbs. This statement does not indicate that the vehicle was designed to support a payload of 500 lbs. but rather a total sensor/battery/frame/motor weight of 500 lbs. It was determined early on in the design process that the vehicle was going to be heavy given the materials that where going to be used in its fabrication and the other applications the vehicle was going to be used for other than the IGVC competition.

4. Electrical Design

4.1 Components

The major components of the electrical system consisted of the following items

- 1 - 20-30V DC to 12V DC Converter
- 1 - 20-30V DC to 110V AC Inverter
- 3 - 24V AC chargers
- 1 - 110V AC to 24V DC Power Supply
- 6 - 12V Marine Deep Cycle Batteries

The remaining components of the system consisted of various gauges of wire, relays, switches, and connectors. The majority of the electrical system was mounted to the second layer of the frame and attached to a aluminum platted perf-board. The major components described above are shown in Figure 5A and the batteries are shown in Figure 5B.

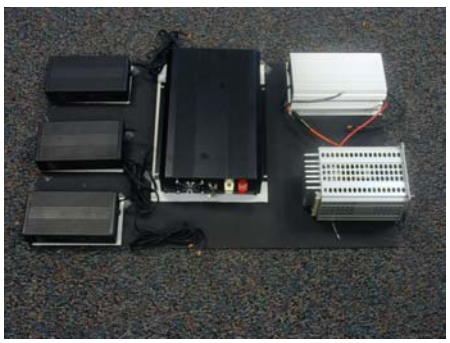

Figure 5A: Power Distribution System

Figure5B: 12V Marine Deep Cycle Batteries

4.2 Power Distribution System

The MARC power distribution system has three main power buses 24V DC, 12V DC, and 110 V AC. The system is designed to be a self-contained charging unit when connected to a standard 110V AC wall outlet. The sensors, motors, and computer all draw power from one of the three buses on the vehicle. The electrical schematic for the vehicle is shown below in Figure 6.

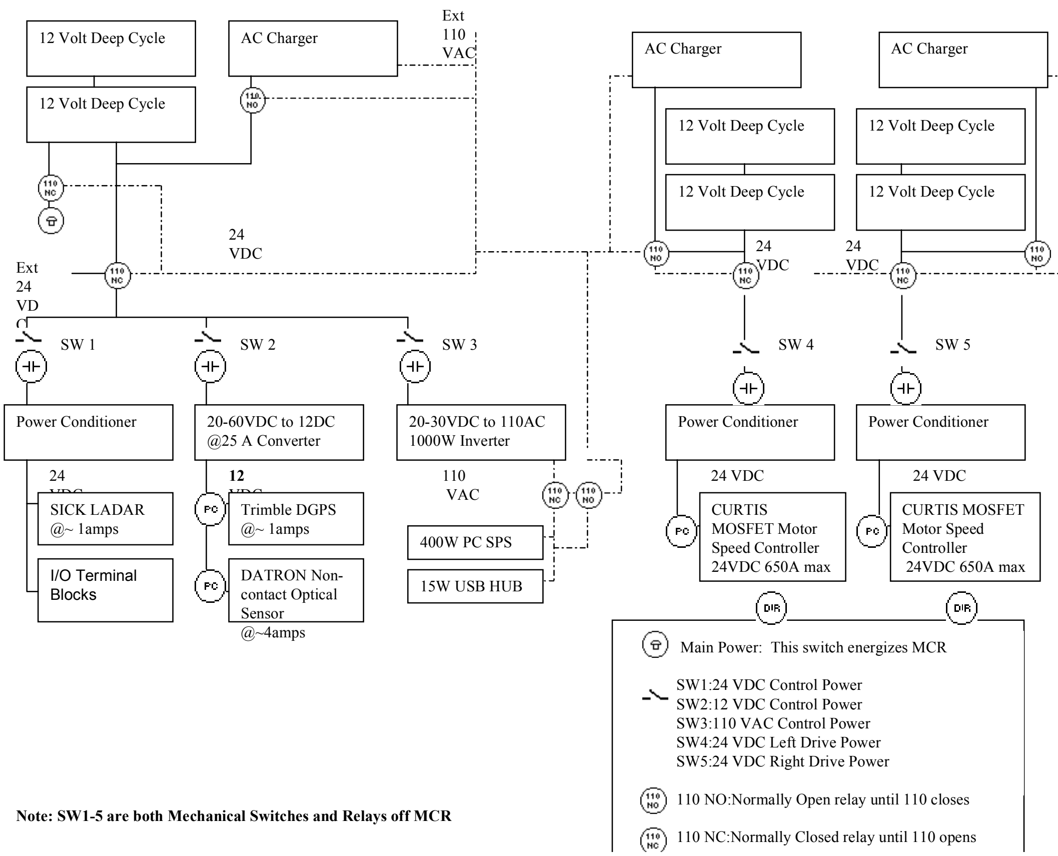

Figure 6: MARC Power Distribution Schematic

4.3 Electrical System Improvements

Two major changes where made to the electrical system of MARC. First, the drive electronics of the vehicle where redesigned to incorporate custom made driving circuits that lessened the load on the power relays which provide power to the vehicles three busses and motors. It was determined, through testing, that a large load was being put on the power relays and they could fail/burnout at any time. To alleviate this problem it was decided that either different relays would need to be acquired or the same relays currently used on the vehicle would need to be restocked and drive circuitry developed to deal with the problem. Going back through the design process we came to the conclusion that developing drive circuitry would be our best course of action given the time it would take to find, acquire, remount, and rewire new relays into the electrical system. The drive circuitry is composed of a 555 timing chip and other related support circuitry. The new timing circuit pulses a 12V control signal to the relays every five seconds after the coil is energized rather than providing a constant voltage. No deterioration in performance has been identified in the vehicles performance due to the addition of these six timing circuits.

The second major change to MARC's electrical system was the addition of power disconnects to the vehicles left, right, and control power busses. This is an important safety feature that provides easy debugging/testing access to the vehicles left, right, and control drives while other systems on the vehicle are still energized. More importantly the disconnects allow for safe access to the vehicle batteries. This provides the developer a safer environment when attempting to disconnect, test, or reconnect the batteries to the vehicle. When the batteries are disconnected from the rest of the system there is no draw on the batteries and thus no arcs will be present that can be potentially harmful.

5. Sensor Suite

The MARC sensor suite consists of the following components (See Figure 7)

- 1 - SICK LMS 200
- 1 - Trimble AGGPS 132 GPS Receiver and antenna
- 1 - Corrsys-Datron V3 Sensor
- 2 - IBM Net Camerapro
- 1 – Honeywell HMR3000 Digital Compass Module

The SICK Ladar is used for obstacle detection in both the autonomous challenge and the navigation challenge. The Ladar communicates using RS 232 serial communication and takes up one of the computers 4 communication ports. The Trimble AGGPS Receiver and antenna receives both GPS and DGPS signals that are used in the navigation challenge. The GPS unit also communicates using an RS 232 serial protocol and takes up another of the computer's communication ports. The Corrsys-Datron V3 Sensor is used to measure the velocity and displacement of the vehicle. The sensor outputs an analog signal for linear and angular velocity. Calculations are performed on the output of the sensor to achieve the linear and angular displacement of the vehicle. The two IBM USB net cameras are used in the vision system for lane, barrel, and pothole recognition. The Honeywell Digital Compass is used to determine the vehicles heading during the autonomous and navigation challenges. The compass uses RS 232 serial communication and takes up the third of the computers four serial ports.

Figure 7: MARC sensor suite

6. Control System

6.1 Computer

The Computer for the MARC vehicle consists of a Lian-LI Aluminum PC Case. The Aluminum casing was specially selected to effectively dissipate the heat produced by the processor and the Florida climate. The motherboard was a DFI AM33-EL with an AMD 1.5 GHZ processor. The board has two serial ports, one USB port, and three PCI slots. A 4 port USB hub is connected to computer to support the two USB net Cameras. A two port serial PCI Card was installed in the computer to expand the computers serial port capacity from two to four. An Adlink (16 digital I/O, 16 analog input, 2 analog output) PCI card was installed to the computers second PCI slot. The card is used to send 5V output signals to the two speed controllers and to read the linear and angular analog inputs from the V3 sensor. Windows 98 2nd edition is the operating system that is installed and used during development and operation of the vehicle.

6.2 Control Panels

MARC has three control panels for direct inputs to the vehicle. One panel contains the system and individual subsystem enable buttons plus the E-Stop button. This panel is mounted to the exterior of the shell at the back of the vehicle for easy access. The second panel is mounted to the frame of the vehicle and contains the circuit breakers and fuses for the power distribution system (see Figure 8). The third panel contains the power bus enables.

Figure 8: MARC Circuit Breaker Panel

6.3 Communication

The vehicle communicates with the user through a wireless Ethernet connection. Using a laptop with a PCMCIA card reader the user can gain access to the operating system of the robot to make changes in software, view the events log, or view current activities of the robot. The other subsystems of the vehicle communicate either through the Digital Acquisition Cards or RS 232 Serial Communication.

7 Software

7.1 Ladar (Figure 9)

The Ladar software provides a top down view of the obstacles in front of the vehicle. This image is combined with the output from the neural networks in the mapping system to generate a world map of the course. Shown below is an example of the output of the software with a typical course image superimposed to it.

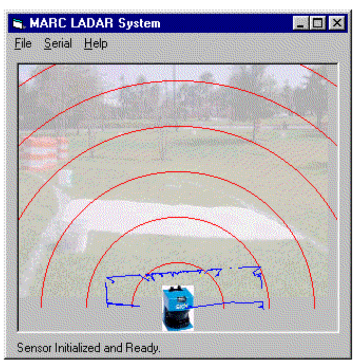

Figure 9: MARC Ladar Software

7.2 Neural Networks

Three separate Neural Networks (NN) are implemented for pattern recognition. One NN identifies barrels, the second white lines, and the third potholes. The output of these NN is sent to the mapping system to combine with the Ladar, Compass, and Optical Sensor outputs to form the world map.

7.3 GPS (Figure 10)

The GPS software is retrieves data from the DGPS receiver and passes the critical information on to the Path Planning software.

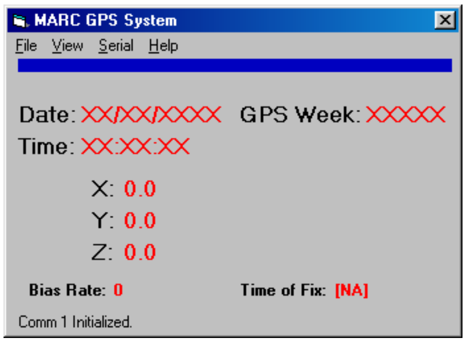

Figure 10: MARC GPS Software

7.4 Digital Compass

The Digital Compass software retrieves the heading of the vehicle and passes the information on to the Mapping software.

7.5 Digital Acquisition Card (DAC)

The DAC software is used for processing of analog and Digital data. The Non-Contact Optical Sensor sends analog signals for the linear and angular velocity, of the vehicle, through two analog ports. Four other ports send the velocity and direction signals to the two speed controllers that drive the 24V motors. The remaining ports are for inputs of the control components such as individual subsystem enables and power switches.

7.6 Manual Drive

The purpose of the manual drive software is to allow the vehicle speed and direction to be controlled by a user from a lab top when not in autonomous mode. This software will be used move the vehicle from place to place when not competing and get the vehicle to the starting line.

7.7 Traffic Cop

The Traffic Cop software monitors the communication between all the separate subsystems to ensure that no problems occur (e.g. buffer overload).

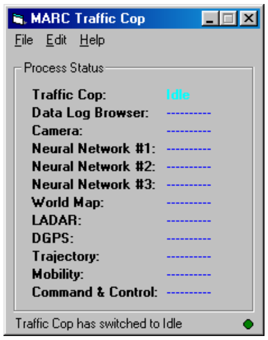

Figure 11: MARC Traffic Cop Software

7.8 Mapping

The mapping system takes the information from the Ladar, Neural Network, and Digital Compass software and overlays the information to generate a world map of the course in front of the vehicle. The bitmaps, generated by this software, are used by the Path Planning software to determine the vehicles optimal path.

7.9 Path Planning

The Path Planning software determines the optimal path the vehicle should transverse based off the information derived from the mapping and GPS software. The Path Planning software operates for both the autonomous and navigational challenges.

7.10 Software Changes

The software was changed from the ground up. This does not mean that the previous software was thrown away. A large portion of last year's code was reused.

<u>Rebuilt the Traffic Cop</u>

The Traffic Cop application is used to manage all intro-program communications. The original design used a shared database where local applications would update unique tables and fields in the database. Remote applications would gain access to the database through shared drives. As applications were added and the communication load increased this proved to be a very shortsighted approach. The new design called for a TCP/IP Client/Server configuration. All applications are built off of a base-client application and therefore have communication protocol handled inherently. Now an application can be on any machine attached to the network. This not only allows for faster communications, but also distributive-processing for applications that are CPU intensive.

Command and Control (C2)

The original C2 software was never fully implemented and with the advent of the Traffic Cop became obsolete. The new C2 software reaching through the Traffic Cop handles Mode and Process management. The vehicle's mode (Automatic, Manual, Null, Follower, and Tele Op) determines what level of intelligence the vehicle will display at any given time. The mode determines what processes are required and what hardware needs to be available. The C2 program than works with all the mode-required processes to perform the task at hand.

All other processes

As implied before, all of last years programs were rebuilt using a Traffic Cop Client as a base. This not only allowed them to be a part of the communications system, but also allowed for fine tuning of the applications themselves.

8 Operators Control Unit (OCU)

As part of fulfilling a separate customer need a large portion of this year's effort was put towards the development of a PDA based controller for MARC. The OCU and reason for its development is described in the following statement.

In an effort to do in-house testing of mobility and sensor algorithms developed by contractors, and to further their own research efforts, MARC team members started developing a lab-robot in October of 2001. The robot was designed to incorporate various sensors such a; laser radar (LADAR), DAY TV, Differential Global Positioning Systems (DGPS), Digital Compass, and Non-Contact Optical. As the robotic platform neared completion, mission needs changed and the original OCU concept of a Laptop and Desktop-emulation software was abandoned. In an effort to parallel the OCU development of the VTI contractor, MARC team members used a commercial PDA as their robots OCU (COMPAQ IPAQ). The new OCU would need to encapsulate the following functions: Mode Control, Complete Manual Functions, Comprehensive Diagnostics, Limited Debugging, and Follower Capability.

9. Design Issues

9.1 Safety

MARC has a large E-Stop button at the rear of the vehicle as well as a wireless remote control E-Stop. The vehicle has a gear ratio that does not allow for it to go surpass a velocity of 5mph. When enabled the vehicle has an active safety system that disables the vehicle drive when communication is lost with the laptop through the wireless Ethernet connection. Four bump guards are located on each side of the vehicle that will kill the drive system of the vehicle if they are triggered at a adjustable load value.

9.2 Reliability and Durability

The mechanical design has proven reliable from various mobility and stress tests. The electrical design has safeguards within the design that should prevent any major errors from occurring. The software has been proven reliable as individual components but has yet to encounter the integrated systems testing that would be a prerequisite for a statement of total confidence. The vehicle design should be able to handle any terrain it will encounter during the competition. The shell and vehicle fans should be able to protect the vehicle components from overheating and environmental effects.

9.3 Problems Encountered

Two major problems hampered the design of the MARC vehicle. The first problem would be with the lead-time experienced in the acquisition of critical components such as motors and speed controllers. Almost every major sensor or subcomponent on the vehicle had a longer than anticipated lead-time associated with it. The second major problem was in the commitment of team members after the fall 2001 semester. During the fall 2001 semester all work performed on the robot was connected to a class project in one fashion or another. After the semester many of the team members graduated and/or stopped actively participating in the project. No school projects were associated with the robot after the Fall 2001 semester. Funding was also a common concern during the acquisition and fabrication of the vehicle and its subcomponents. Funding came from various locations including Oakland University, US Army Tacom, and the individual team members.

10. Predicted Performance of the Vehicle

10.1 Speed

The competition guidelines state that the vehicle shall not exceed a speed of 5 mph. MARC has electrical and control software prevention’s enabled that will not allow the vehicle to exceed that speed.

Previous tests have shown that MARC will not exceed a speed o f 4.6 mph even when going down a hill at a greater angle and longer distance than the competitions ramp.

10.2 Ramp Climbing

MARC produces more than enough torque to climb the competition's 15-degree ramp. This is based on design and not test data.

10.3 Reaction Time

It is expected that MARC should have a very good reaction time. The LADAR has a field of view of 180 degrees and the two cameras provide a field of 120 degrees. The output of these two systems provide the vehicle with its obstacle detection capability. The traffic cop maintains efficient communication between the vehicles subsystems thus protecting against data overload.

10.4 Distance at which obstacles are detected

The vehicle has proven through testing to be able to detect the vehicles at distances past 60 ft. This is based on testing the SICK LADAR as a stand-alone entity.

10.5 Battery Life

The vehicle has proven, through endurance testing, to have a battery life up to 4hrs during normal operation. This is calculated based on individual system loads and will need to be verified.

10.6 Dead Ends, Traps, Potholes

The vehicle avoids potholes and obstacles by detecting them with a Neural Network (NN) and sending the NN output to the mapping system. The path planning software then determines the vehicles intended path and sends the appropriate velocity inputs to the mobility system. The efficiency of the pothole and obstacle detection is relative to the effectiveness of the NN. The number of iterations that the NN is trained, the lighting conditions, and number of different images used to train the NN all play a role in the vehicles ability to successfully navigate around these situations. Due to a lack of extensive testing it is difficult to determine the vehicles ability to correctly handle these situations.

10.7 Navigation Challenge

Due to a lack of extensive testing it is difficult to make a prediction on the vehicles ability to perform in this portion of the competition.

MARC Budget

Vender	Line Item	Qty	Unit Cost	Total Cost	Donation
CURTIS	Model 1221 B Speed Controller	2	$1,147.00	$2,294.00	
CURTIS	Model 1310 Vehicle System Controller	2	$620.00	$1,240.00	
InnEVations	ADV DC#140-07-4001 24-36V 2Hp DC Motor	2	$476.00	$952.00	
IBM	USB Web Cam Camera	2	$100.00	$200.00	Yes
Computer Builders Warhouse	Dual Processor PC System with I/O module	1	$2,000.00	$2,000.00	
Trimble	DGPS	1	$3,495.00	$3,495.00	Yes
SICK	LADAR	1	$2,000.00	$2,000.00	Yes
Corsys-Datron	CORREVIT S-CE Non Contact Sensor	1	$5,000.00	$5,000.00	Yes
Bocsh	Vehicle Frame Materials	1	$660.00	$660.00	Yes
IMC	Cooling System(Fans)	2	$50.00	$100.00	
Honeywell	Digital Compass	1	$687.00	$687.00	
Hewlett Packard	User Interface System	1	$500.00	$500.00	
SMC	Wireless LAN System	1	$250.00	$250.00	
	Electrical Components		$760.00	$760.00	
	Mechanical Components		$740.00	$740.00	
	Power Distribution System		$2,600.00	$2,600.00	
	E-STOP System	1	$200.00	$200.00	
	Total Cost			$23,678.00	
	Total Expenses (non-donation)			$12,323.00	