14th Annual Intelligent Ground Vehicle Competition
2006 Design Report

MARVIN III

Mobile Autonomous Robotic Vision-Aided Navigator

Department of Electrical and Computer Engineering
University of Minnesota Duluth

Team members:
Jason Brownlee • Paul Bushey • Ryan Weidemann

Faculty Advisors:
Dr. Rocio Alba-Flores • Dr. Fernando Rios-Gutierrez

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Abstract

The goal of this project is to develop an intelligent vehicle that is able to navigate outdoors autonomously. The vehicle should be able to identify white lines and maintain its course inside these lines, navigating autonomously avoiding any obstacles in its path. The main purpose of designing and implementing this vehicle is to participate in the Intelligent Ground Vehicle Competition (IGVC). This vehicle competition utilizes electrical, computer, and mechanical engineering skills learned in the Electrical and Computer Engineering program at the University of Minnesota-Duluth(UMD). By designing, manufacturing, and troubleshooting this vehicle, the team is able to get hands-on development and test experience that is crucial in the practical engineering field.

1.0 Introduction

This Intelligent Autonomous Vehicle is able to maneuver in an unknown environment using various methods of self-navigation control. A mechanical base, drive-train, and power system have all been designed and built by us. Also, a computer vision component and an obstacle detection component have been integrated to develop the robot's navigation system. All vehicles that participated in the IGVC must meet various safety rules and regulations in order to qualify. MARVIN III (Mobile Autonomous Robotic Vision-Aided Intelligent Navigator) has been designed to meet all IGVC specifications and will be entered into the competition June 10, 2006 in Harrison Township, Michigan. This is an annual event attracting participants from colleges across the country. Last year, UMD's first robot was entered into the competition. MARVIN I was a product of the senior workshop developed by about 17 students. This year, MARVIN III improved upon last year's design and rebuilt the vehicle's base, power supply, and drive system (hardware and software). Our design includes a digital video camera, SICK laser sensor, a desktop computer, remote control, microcontroller, and four 12-volt batteries to operate our vehicle.

2.0 Background

Our team consists of three electrical and computer engineering students. Every portion of this project was designed, implemented, and tested by us. We started the project with some hardware, code, and ideas from last years IGVC project, but ended up redesigning almost everything. The base, power supply, and microcontroller code were all totally redesigned. The only parts that were reused were: video camera, motors w/optical encoders, Power Wheels Batteries, one deep cycle battery, miniDragon microcontroller board, caster wheel, and emergency stop button. The most significant part that we reused from last year was the image processing algorithm and some of the image processing code. We feel that everything has been upgraded or advanced upon and will give future teams more solid components, ideas, and warnings to consider while working on this project/competition

3.0 Vehicle Features

The design of MARVIN III is split up into essentially four groups: base and steering, camera and sensor, vehicle navigation, and power supply/systems.

3.1 Vehicle Base and Steering

In the initial design of MARVIN III's base we had the option to use last year's base (MARVIN II), which was made using a children's Fisher Price Power Wheels Chevy Silverado, or design our own.

We considered using the existing, but ended up creating our own (Figure 3.1). The main drawbacks that we wanted to overcome were: poor traction with plastic wheels, possible slipping with the belt drive system, and the fact that it was harder to mount components to plastic and keep it sturdy (as opposed to wood). We used steel tubing and wood to create our base which proved to be more solid and easier to mount components to. The only drawback was some additional weight, which could also be considered an advantage in that the vehicle will have additional traction. This will help reduce any slipping on loose terrain. Special places were built for mounting the motors and batteries, while everything else was left open because we were not sure what was going to be mounted where on the vehicle. After switching batteries to more compact deep cycle batteries, we decided to position them in the front of the vehicle. This left the original battery spot open for a wooden box to mount the main electrical components to. The other reason for moving the batteries to the front was to increase traction on the wheels.

Figure 3.1: Steel and Wooden Base (MARVIN III: 2006)

3.1.1 Chassis

The competition requires the vehicle to be protected from the elements, and be sufficiently stable to carry a 20 pound payload throughout the course. For this reason, the frame was built with three levels

of space to mount components and batteries (see Figure 3.1). The bottom two levels are able to be easily sealed off in case of rain. Plexi-glass will be mounted to the middle level from the top to close to the bottom of the level (leaving a small space for air flow so the desktop and power supply does not overheat). This will completely shield the desktop and power supply from any possible rain. The only part that would get wet is the wooden deck. Also, the power supply is completely sealed in a plastic box and all other major electrical components are mounted with stand-offs in a separate wooden box (see Figure 3.2).
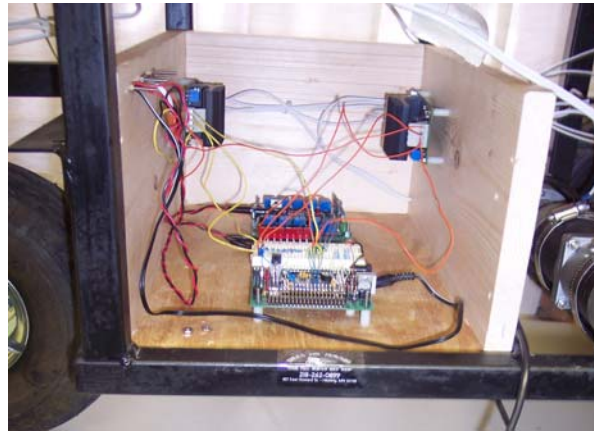

Figure 3.2: Main component box shown with top and side removed

3.1.2 Drive System

The caster wheel functions as the rear wheel of the vehicle, and the other two wheels function as the front wheels of the vehicle. Two DC motors from MCG Inc. drive the vehicle's two front wheels. These motors provide high torque and lower power consumption compared to other similar motors on the market. The large size of the motors requires the wheels to be driven by a system consisting of gears and chains with a gear ratio of approximately 4.5 to 1. This ratio enables for greater torque, which was important for travel on rough terrain and uphill travel with our heavy base. Two 12V deep cycle batteries were able to provide plenty of power to the motors to move the vehicle at least as fast as the competition requirement of 5 MPH maximum for at least ½ hour, which should be longer than we will have to run it in the competition. The steering is a differential drive system where each motor moves independently.

3.1.3 Remote Steering Control

The competition requires the vehicle to be operable through wireless remote control. The remote control device used for this vehicle consists of a set of ten relays and a ten channel UHF hand-held remote control unit purchased from www.Kitsrus.com. Four channels (relays) are used as a four-bit output to navigate the vehicle for straight, straight left, straight right, reverse, reverse left, reverse right, rotate right, rotate left and halt movement (see Table 3.1). All of these movements are done using different

combinations of buttons on the remote control. The four-bit output is sent to the microcontroller and then the correct PWM signal is sent to the H-bridges to power the motors correctly. Another channel is used to remotely switch the vehicles mode of operation from manual remote control to autonomous camera/sensor control.

3.1.4 Safety Features

Having a fully autonomous ground vehicle raises some safety issues. Although our vehicle is probably slow enough that safety is not a huge issue, it is something that we concerned ourselves with. Our vehicle is designed to meet all competition safety requirements. It has a manual and wireless emergency stop features (referred to as E-stop later in the paper). The manual E-stop is a big red button on the top of the vehicle that is easily accessible if the need arises to stop all movement (see Figure 3.3). The button is a simple mechanical switch connected in-line with the main motor power. If the switch is shut off there is no power going to the motors and the vehicle will stop within a few inches. The wireless E-stop is controlled by the remote controller and RF receiver. When the signal is sent, a relay physically cuts logic power to the H-bridges and the vehicle ceases movement within several inches. Because of the slow movement (~5 mph max) and internal resistance of the motors, when the vehicle is stopped it will not roll much, even if it is going downhill. Therefore, we decided that breaks were unnecessary. With two methods of emergency stopping we feel that this autonomous vehicle is perfectly safe for any operator or spectator.

Figure 3.3: Wireless and Manual Emergency Stop

3.2 Camera, Sensors, and Navigation Control

MARVIN III employs a Sony Handycam digital video camera, and a 180 degree SICK LMS 200 laser sensor. The information received from the camera and sensor works together to determine size of an obstacle and the angle at which the vehicle must steer to avoid collision with the obstacle or to avoid crossing a boundary line.

3.2.1 Sony Handycam Digital Video Camera

The Sony Handycam is mounted on a camera tripod high above the body of the vehicle toward the rear part of the vehicle to provide maximum area captured by the camera images. It also has been modified with a wide angle lens to allow for increased vision to the left and right of the vehicle. The camera, along with MATLAB, is able to continuously capture and process still frames of the landscape directly in front of the moving vehicle at an average of approximately one every 0.3 seconds.

The on-board Dell Optiplex desktop computer (3.2 GHz Dual Core Pentium 4 HT and 2GB RAM) processes each separate image coming from the video camera through a USB cable (included with the camera) using MATLAB image acquisition and processing software to detect any obstacles or boundary lines that lie in the immediate path of the vehicle. Image processing is achieved primarily by color detection. Obstacles are detected by searching each image for any orange or white color within a specified color range. Boundary lines are detected by searching for any white color within a specified color range. Also, the background is determined (anything outside of the white lines) and taken out of the image. The image is then processed to show in black and white (Figure 3.4). The detected orange, white, or yellow color shows as white, while the rest of the image appears black. The program then compares the image to the previously stored images, which correspond to the area available for the vehicle to move straight, left, right, etc. If roughly 7% (this is variable and could be changed after further testing) or more of the area that is compared is white then it is assumed that an obstacle or boundary line occupies that space of the landscape. That particular move is then eliminated and the next one is tried. Once a valid move is found, then MATLAB exits the function and outputs a four-bit signal (see Table 3.1) to the desktop's parallel port. This signal is the input to the microcontroller when the vehicle is in Camera/Sensor mode.
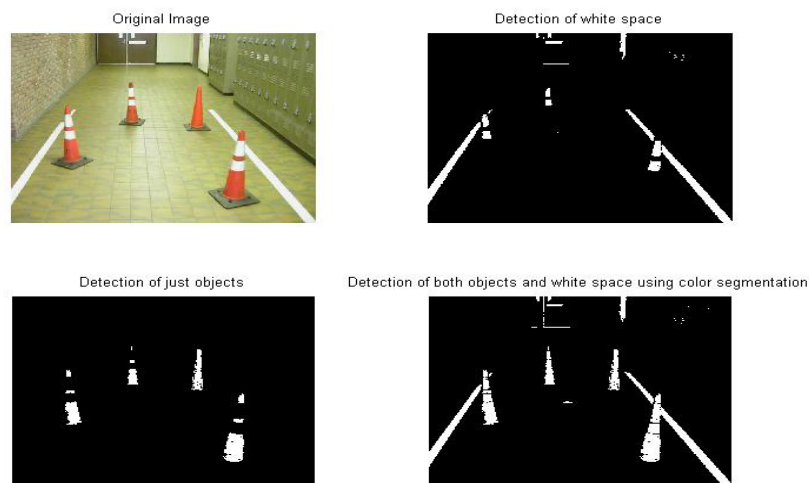

Figure 3.4: Image of obstacles and boundary lines before and after image processing by MATLAB

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3.2.2   SICK LMS 200 Laser Sensor

The SICK LMS 200 laser sensor (figure 3.5) is mounted on the front of the vehicle to detect any obstacles that are directly in the vehicles path.   The sensor outputs, through a serial connection, a continuous hexadecimal string which corresponds to the distance in meters at each degree or half degree, depending on resolution selected.   MATLAB will use this signal as an input, along with the camera images, and make its final decision on how to move.

Figure 3.5: SICK laser sensor mounted on MARVIN III

3.2.3   Dell Optiplex Desktop Computer

In order to process data, we needed a powerful processor to perform data calculations fast enough so the vehicle can continuously navigate through the unknown course obstacle.   Originally, a 1GHz Pentium 3 based laptop with 512MB of RAM was to be used.   The advantages of this computer were: small size, low weight, and self-powered.   The disadvantages are: slow processing speed, average memory size, and hard to mount.   Because processing speed was by far our main concern, we decided that it would be in our best interest to upgrade to a faster computer.   Our faculty advisors were able to secure funding for a new computer.   A compact desktop was decided as the best choice.   An ultra-fast 3.2 GHz Pentium 4 with Hyper Threading CPU, 2GB RAM, and wireless card could be obtained in this type of computer with our budget.   Dell's Ultra Small Form Factor Optiplex was chosen because it is small, lightweight, and uses some laptop components (which generally use less power and are more shock resistant).   By using a desktop computer, we are able to eliminate the need for a monitor, keyboard, and mouse by accessing the computer remotely with a wireless router and a laptop computer (which we already had). This leads to lower power consumption and easier programming and troubleshooting since we do not have to touch the vehicle at all to alter any code or software at any time.   Also, the case has mounting holes built in, which made it very convenient to mount anywhere (see Figure 3.6).   The only downfall is that it would require external power.   This is accomplished by using a 12V deep cycle battery along with a DC to AC power inverter.   There will be some power efficiency loss using an inverter, but we did not want to risk damaging the computer by altering or bypassing any portion of its built in power system.

Figure 3.6: Dell Optiplex GX 620 Desktop Mounted

3.3   Vehicle Navigation Control

The vehicle navigation works with the information obtained from the camera and sensor to determine how MARVIN III will navigate through the course. The miniDragon microcontroller board receives input from MATLAB through the desktop's parallel port or from the RF remote control receiver. In order to avoid confusion the microcontroller can take in signal from either MATLAB or the remote controller but not both. This mode is controlled by a signal (combination of buttons pushed) on the remote controller which controls a tri-state buffer to allow the correct signals to be inputted to the microcontroller (figure 3.7).
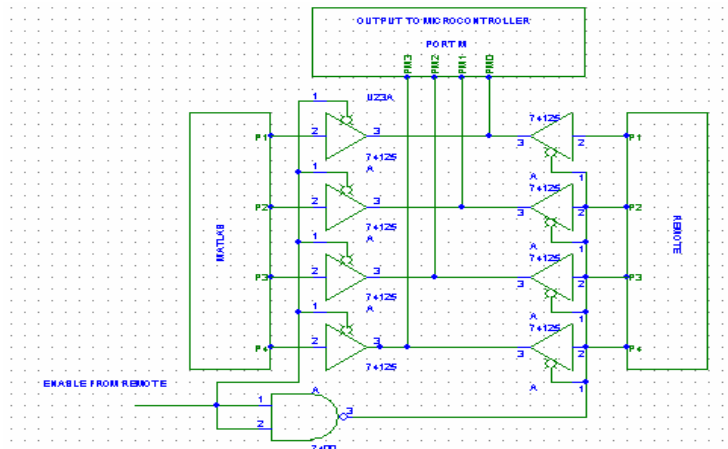

Figure 3.7: Circuit diagram of MATLAB/Remote switching circuit

3.3.1   Parallel Port Communication

MATLAB communicates with the miniDragon microcontroller through a form of parallel port communication. Such a communication method is necessary in order to process an image and send the resulting "move" to the microcontroller for further vehicle control. MATLAB does not require a parallel port protocol to be implemented, but uses the parallel port as a simple communication register. Data that is sent to the parallel port through MATLAB is made available on the parallel port data lines immediately

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as they are sent out. In order to simplify the design and minimize problems, we choose this communication to be one-way (from MATLAB to the microcontroller).

General purpose input/output port M on the miniDragon is used as a 4-bit parallel port data register to receive data from the desktop. The same port is also used for the remote control signal. One or the other is used from the output of a tri-state buffer (see Figure 3.7). Assembly language code is used for the parallel port communication. The MATLAB design requirements are that the Data Acquisition toolbox and a parallel cable connection are made available. The Data Acquisition toolbox commands are used to send data to the miniDragon through the parallel port. Data to be sent is stored in MATLAB as a binary vector.

At the desktop end, a standard parallel port connection is used. The cable then inputs the signals to the microcontroller through five wires (4-bit signal and ground) connected to the appropriate 4-bit input register. MATLAB has full control over data residing on the parallel port data lines. Therefore, the data can easily be changed continuously (as fast as the desktop can process the images and sensor data) as the vehicle navigates through the course.

3.3.2 Pulse Width Modulation

Two DC motors, manufactured by MCG Inc., are used to control the left and right wheels. These motors are controlled by Devantech MD03 - 50Volt 20Amp H-bridges motor drive circuits. One H-bridge controls each drive wheel. The H-bridges (in analog/PWM mode) require a square wave signal with a frequency of 20 kHz or greater. The microcontroller outputs a PWM (pulse width modulation) signal of approximately 50 kHz. In order to vary the speed of the motors, a percent duty cycle system is used. In our system, the duty cycle values are 0, 50, 66, or 100 percent in both directions. The Motorola 68HC12 microcontroller (figure 3.8) has a PWM module that can be programmed to generate up to eight different PWM waveforms. For the purpose of controlling the robot, two PWM channels are needed. We are using PWM3 to control the right H-bridge and PWM2 to control the left H-bridge. Also, the program will make a decision based on what the vision program in MATLAB tells it to. Depending on what 4-bit binary signal the microcontroller's navigation program receives from MATLAB, the robot will move straight, right, left, etc.
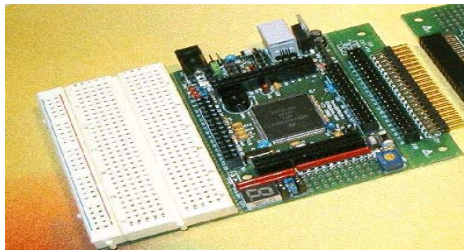

Figure 3.8: MiniDragon Microcontroller Development Board (Motorola HC12)

3.3.3 Obstacle Course Algorithm

The obstacle course algorithm combines the image processing power of MATLAB, the parallel port, camera, sensor, optical encoders and pulse width modulation. The information from these devices allows for the detection of white lines and orange/white objects in order to guide the robot around the obstacle course. A simple parallel port communication protocol was between MATLAB and the microcontroller. The protocol codes are summarized in Table 3.1 below.

Move Codes			
Protocol Code	Description	Left Motor PWM	Right Motor PWM
0100	Go Straight	100%	100%
0110	Turn Right	100%	66%
0010	Rotate Right	50%	-50%
1100	Turn left	66%	100%
1000	Rotate left	-50%	50%
0000	Halt	0%	0%
0001	Reverse	-100%	-100%
0011	Reverse Right	-100%	-66%
1001	Reverse Left	-66%	-100%

Table 3.1: Protocol codes indicating a robotic move
(note: codes are given in binary and percentages are given relative to full motor speed that would cause the vehicle to travel approximately 5mph on level ground)

4.0 Power Supply Design

Power supplies are a critical component when it comes to designing electronic devices, especially automatic vehicles. Therefore, it was very important not only to be able to build a power supply that could supply sufficient energy to run the components of the vehicle efficiently, but also to prevent dangerous power surges. The design process for the power supply consisted of building the power supply circuit board and the power supply box (together known as Power Supply Module). The power supply needed to provide 24 volts (to power the motor and laser sensor), 12 volts (to power RF receiver), 9 volts (to power microcontroller), 5 volts (for TTL logic), and 3.3 volts (to power GPS unit). Current requirements were fairly low for all specific voltages (around 100mA or less) except for the 24 volt (which requires around 10-20A). Given these specifications, all voltages were able to be obtained using voltage regulators except the 24 volts which was obtained using two 12V batteries in series. All voltage outputs are fused with reasonable fuse values after the regulators. The circuit board consisted of the

various voltage regulators, capacitors, resistors, and diodes. Other parts required for the power supply module are: fuses and holders, switches, stand-offs, LED's, plugs, different gauge wire, ring connectors, and wire nuts. The electrical system layout, and how the power supply module is used to distribute the necessary voltage for operating the required devices, is shown in Figure 4.1
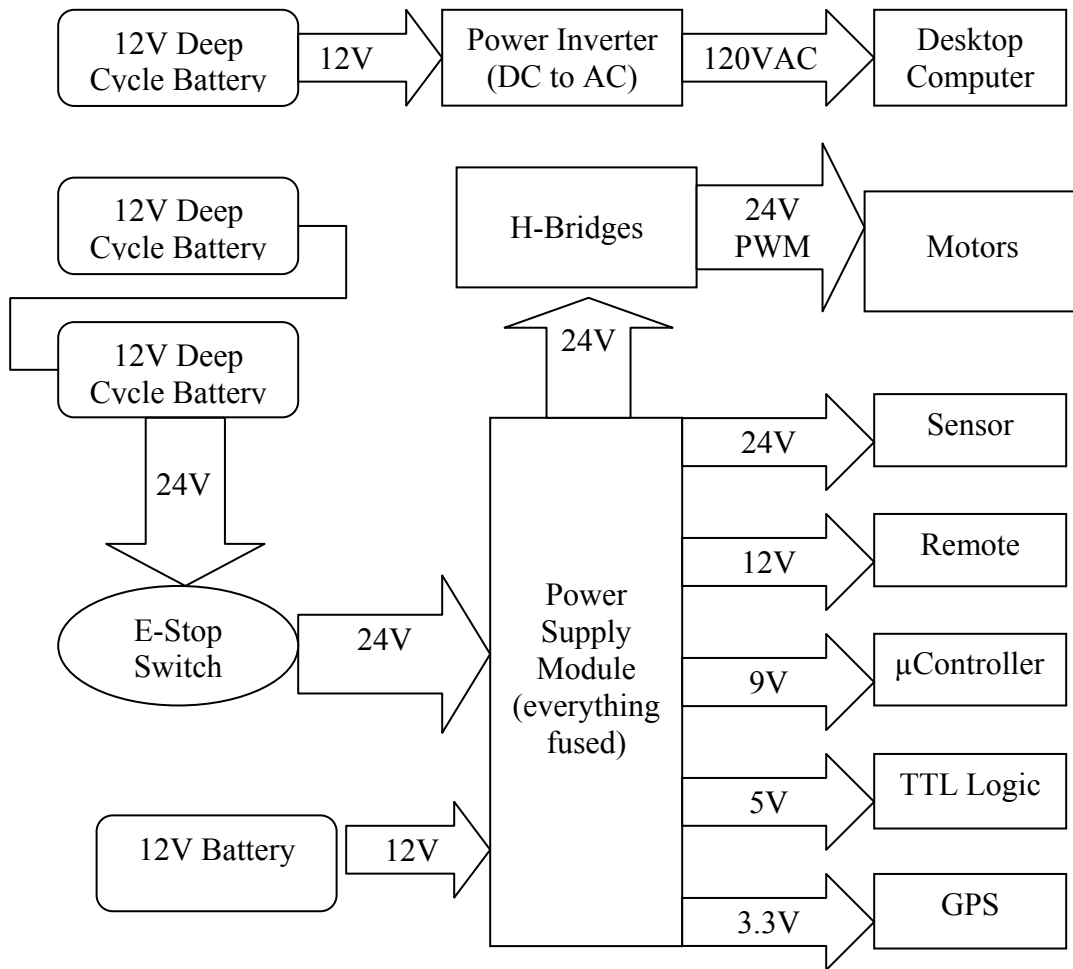

Figure 4.1: Functional block diagram of the MARVIN III electrical system

4.1 The Power Supply Module

Since the electrical components of the vehicle all require specific amounts of voltage and current, a power supply module (power supply circuit board and the power supply box combined) was constructed to provide these power requirements. The input to the module comes from a 12-volt battery. As shown in Figure 4.1, the voltage must be divided up to satisfy the voltage requirements of each component. The H-Bridge that drives the DC motors board requires 24 volts for the motor side and 5 volts for the data side, the laser sensor requires 24 volts, the remote requires 12 volts, the miniDragon microcontroller

requires 9 volts, TTL logic (used with the microcontroller logic, remote control logic, and the tristate circuit requires) 5 volts, and the Garmin Global Positioning System (GPS) requires 3.3 volts. All voltage requirements are direct current voltages. The Sony video camera has its own battery for power. The main motor voltage of 24 volts (which is provided by two 12 volt deep cycle batteries in series) is ran through the manual emergency stop switch/button (E-stop) so that when that switch is off the vehicle stops moving no matter what. The wireless E-stop is controlled by the remote controller and cuts off logical power to the H-bridges. These are two of the main requirements for the competition. The power supply box is a black, plastic casing on which the main power supply circuit board, fuses, switches, and plugs are mounted. The Power Supply Module's size and dimensions are 8x6x3 inches. It is fully enclosed and also has a small CPU fan powered by 12 volts to reduce heat. The three switches control main motor voltage, all regulated voltage (12, 9, 5, and 3.3 volts), and the fan. LED's indicate if any fuses have been blown and only turn on when a button is pushed. This was done so that they would not be constantly drawing current from the battery and we could still check the status of the fuses at any time. The main LED for the supply input voltage (which is fused by a 15A fuse) is always on when the power supply is switched on. Figure 4.2 shows the power supply module without its cover lid.

Figure 4.2: The complete Power Supply Module without its cover

4.1.1 Fuses and Switches

As much as it is necessary for a power supply to successfully accommodate the functionality of various components connected to it (microcontroller, remote sensor, etc), it is also necessary to protect it against any undesired electrical surges that might arise in the whole electrical system. This is where the fuses come into play. A fuse is a safety device with a metal wire or strip that melts when the current gets too strong, cutting off the flow of the electrical current. For every component in our system, fuses are used to protect against current spikes and short circuits. Regular fuse holders are used to easily plug the fuses in and out of the power supply box without physical contact with the main circuit board.

The remote control circuit and TTL logic are protected using 1-amp fuses, while the miniDragon microcontroller board is protected using a 2-amp fuse. The motors and H-bridges are protected by one 25A fuse each. The power supply circuit (mainly the regulators) is protected with a 15A fuse. Three

small switches are mounted on the power supply box one of which turns on the whole main circuit board, another controls the power to the motors, and the last one turns the cooling fan on and off.

The power supply module shown in Figure 4.2 has the main circuit mounted in the power supply box but excludes the H-bridges and the motors which are separate components.

4.1.2 The H-Bridge Circuit and Motor Control

Motors tend to generate a back electromotive force into the control lines when the motor direction or speed is changed. This is where the H-Bridges come into play. The H-Bridge is a classic method of controlling DC motors. It allows control with a minimum number of components. The name "H-Bridge" comes from the letter "H" which is resembled by the switch connections that govern the direction in which the motor spins. When you only switch S1 and S4 on, the motor rotates in a forward direction; while if you only switch on S2 and S3, the motor rotates in a reverse direction (Figure 4.3). Not only do H-Bridges provide power to the DC motors of the vehicle, but also isolate other components from electrical problems.
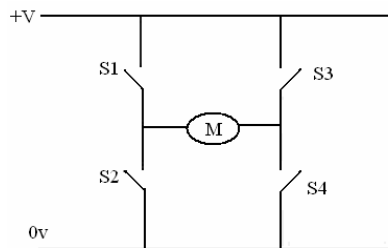

Figure 4.3: Simple H-bridge diagram where M represents the motor

The MD03 is a single motor 20A H-Bridge designed for motor control applications. The device is built using a multi-technology process which combines bipolar and CMOS control circuitry with other power devices on the same monolithic structure. This circuit is ideal for driving DC and stepper motors. Another reason for using MD03 is the fact that they facilitate low-loss sensing of the output current. The H-Bridges receive the forward and/or reverse signal for the direction from the microcontroller and even accommodate pulse width modulation. The layout of the H-Bridge power side pin-outs is illustrated in Figures 4.4 and 4.5. Each of the motors receives 0-24 volts from the H-Bridges for direction control and operation. The chip is equipped with a large heat-sink to prevent overheating. The MD03 chip can handle up to 20 amps. Some testing of the H-Bridges showed that the motors were drawing less than 20 amps therefore the circuit is robust enough to handle our setup. The power supply module uses a switch to turn the delivery of power to the motors on or off.
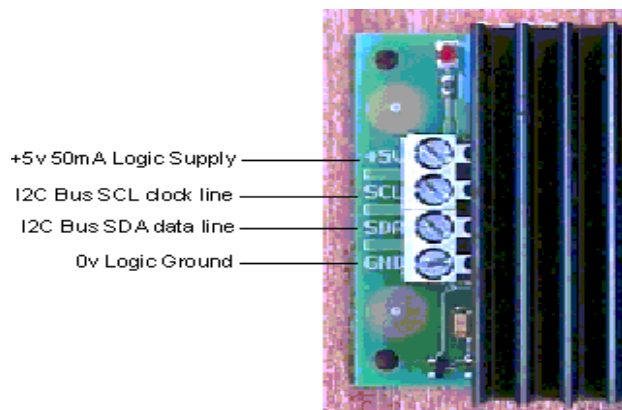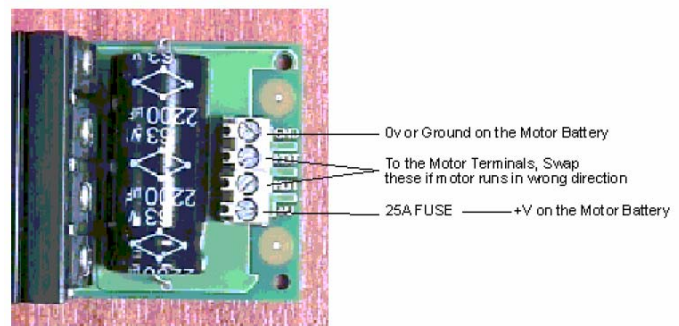
Figure 4.4: Logic side of H-bridge **Figure 4.5:** Main power side of H-bridge

5.0   Parts and Price List

Part Name	Qty	Price	Total
SICK LMS 200 Laser Sensor	1	$4,500	$4,500
Dell Optiplex GX620 (desktop)	1	$2,000	$2,000
Sony Handycam Digital Video Camera	1	$800	$800
Devantech MD03 H-Bridge Circuit	2	$100	$200
MCG Brushless Motors	2	$100	$200
Wide Angle Camera Lens	1	$160	$160
12V Deep Cycle Batteries	3	$50	$150
Plugs, Switches, Brackets, Fuses, etc.	1	$100	$100
miniDragon Microcontroller Board	1	$75	$75
DC to AC Inverter	1	$70	$70
Go-Cart Wheel w/gear	2	$30	$60
Wireless Remote Control Kit	1	$60	$60
Devantech CMPS03 Digital Compass	1	$47	$47
Steel Tubing	1	$40	$40
Camera Tripod	1	$40	$40
Wire and Cables	1	$40	$40
Regulators, Resistors, and Capacitors	1	$30	$30
Caster Wheel	1	$29	$29
Emergency Stop Button	1	$26	$26
Chain (for Go-Cart gears)	2	$10	$20
Estimated Total Cost:			**$8,647**

Table 5.0 Prices for Parts and Supplies

6.0 Conclusion

MARVIN III was designed by 3 students from the University of Minnesota in Duluth for the Intelligent Ground Vehicle Competition. The vehicle is designed to navigate through an obstacle course consisting of obstacles, boundary lines, and other specified impediments. The idea of autonomous vehicles such as this is an important area of research for military, transportation, and various other fields. Each individual design (camera, sensors, GPS, navigation, base design, power supply design, etc.) performs on its own and also as a portion of the full vehicle project.

We feel confident that we will be able to compete against some teams that have been involved with IGVC for many years. Also, it is felt that this is an excellent project for future ECE to research and improve upon and that combining the initial work done and future research on MARVIN III, it could one day win the Intelligent Ground Vehicle Competition.

7.0 References

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       http://www.mathworks.com/products/image/description4.html

[5]   Digikey: Regulator Datasheet
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[6]   MCG motors: ID23000 Series Brush Motors
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[7]   Optical Encoders   http://www.quantumdev.com/pdf/qd200.pdf

[8]   HC12 Minidragon Web Site http://www.evbplus.com/

[9]   MD03 H-bridge Motor Controller http://www.robot-electronics.co.uk/htm/md03tech.htm