AMDV
Autonomous Metal Detecting Vehicle

Group 10

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1.0 Executive Summary

For the common hobbyist or a high grade military application, the AMDV (Automatic Metal Detecting Vehicle) can serve several useful and productive purposes. The technology involved in creating the AMDV is that found in the treasure hunter’s arsenal combing the beach, and devices located in a teenagers cell phone. The AMDV’s main purpose is to automate a metal detector and have it set to search, within a specified parameter, for ferrous metallic materials. For the everyday hobbyist these metals would be those found in coins, rings, and other type of jewelry. In the case of a military application the AMDV would be useful in finding metallic objects such as mines or other types of traps to pave the way for soldiers safely. The AMDV main components are the RC vehicle, the microcontroller unit, sensors, the Bluetooth device, and the metal detector.

The metal detector will be made using IC’s with an internal oscillator. The search coil will oscillate at a frequency close to that of the internal oscillation and when then utilize modern beat frequency oscillation to determine if there is a ferrous material within the detection range. When this ferrous metal is detected a super bright LED will emit with enough luminosity to been easily seen from a distance of thirty feet. Simultaneously, the metal detector will send a signal to the main microcontroller unit to indicate that ferrous metal has been found. The microcontroller unit will record the GPS location of the object and bring the RC vehicle to a halt for a predetermined amount of time. When that time is exceeded, it will continue to search for more metals within the given parameters. The microcontroller controls the movement of the RC car but utilizing an h-bridge design connected to the motor which controls the vehicles acceleration and direction. This is used in conjunction with the sensors in front of the vehicle to act as the eyes.

When the microcontroller unit receives confirmations that ferrous metal has been found, the Bluetooth device will be called and will in effect send a signal to a remote controller held by the user. The current remote controller being considered is the PS3 controller because of its Bluetooth abilities. When the PS3 controller receives the Bluetooth signal that metal has been found, the controller in turn will activate its rumble feature to stimulate the user’s attention that metal has been found. The AMDV will not be purely automatic. Another feature is included in the PS3 controller package that allows the user to directly control the vehicle manually. This feature may be used to bring the vehicle back when it has detected the metal. Upon receipt of the vehicle, the GPS locations recorded will be retrieved from the memory stack of the GPS. This process is then repeated as many times as necessary as seen fit by the user.
2.0 Definition

2.1 Motivations

To design, build, and test a robotic vehicle to locate and mark the location of metallic objects to fulfill the senior design requirement for the Computer and Electrical Engineering BS degrees. The project idea targets both recreational and official use although the primary goals and objectives of this preliminary design and prototype will mainly target the recreational audience. Recreational use of this device would be by treasure hunter enthusiast to find lost metallic objects which may or may not be buried in the ground without having to manually search the area themselves. Future design revisions may be targeted more towards the official use of the device by law enforcement and military personnel to locate possible hazardous metallic objects.

2.2 Qualitative Goals & Objectives

The AMDV has a set of qualitative goals that will be researched and designed. These goals are listed below:

- The AMDV will be low cost, easy to use, and have a light weight, portable design
- The AMDV will go through the following recursive pattern once initiated until the user turns it off:
  1. The vehicle shall move autonomously or manually in areas outdoors or indoors
     - This mode shall be determined by user input wirelessly via a remote
     - When operating autonomously, the vehicle will use a pre-programmed search pattern while performing obstacle avoidance and detecting metallic objects.
     - While operating manually, the vehicle shall communicate to the aforementioned remote for movement and other commands
  2. The vehicle shall sense when it has gone over metal, stop, log the location, and notify the user it has found a metallic object via a feedback mechanism
  3. Upon User-Input, the AMDV will continue on to find the next device

2.3 Quantitative Goals & Objectives

The AMDV will need to reach a specified goal in terms of numbers to have a realistic objective. These realistic objectives will include the following list:

The AMDV must run for a continuous 30 minutes

1. No shutting down due to power loss
2. No shutting down due to out of radius
3. The AMDV must be able to find metal within a depth of 5 inches

1. The AMDV should be able to find metal within these depth through most common mediums
The AMDV must be able to hold at least 20 location points.

2.4 Specifications & Requirements

2.4.1 Project Requirements

2.4.2 RC Vehicle Requirements
This subsection provides a list of the requirements on the R/C vehicle. These requirements are followed throughout the document and provide a basis for the design of the AMDV’s overall structure. The AMDV shall use an R/C vehicle that has:

- Total cost with any motor modification not exceeding $60
- A large frame size to maximize PCB working room
- An off-road frame type; meaning vehicle must be able to travel in sand, rocky, or sandy areas.

2.4.3 Controller Requirements
This subsection provides a list of the requirements on the controller of the AMDV. These requirements are observed throughout the document and provide a basis for the design of the AMDV’s control interface. The controller is how the AMDV will be controlled under manual operation. The AMDV shall use a controller interface that:

- Has low implementation cost; less than $100
- Communicates in part or in all with the vehicle wirelessly
- Can turn the vehicle left or right
- Can accelerate the vehicle forward or in reverse
- Can put the vehicle into/out-of the automatic mode
- Have some kind of feedback device to indicate when the AMDV has sensed a metallic object

2.4.4 Microcontroller Requirements
This subsection provides a list of the requirements on the microcontroller of the AMDV. These requirements are observed through the document. The microcontroller is the processor which acts as the brains of the AMDV. It handles the execution of the code which allows for the vehicle to perform all necessary operations. The AMDV shall use a microcontroller which has:

- Total cost for chip(s) and development board shall not exceed $100
- Low power-consumption and at least one idle power saving mode
- Operational abilities between 32°F and 120°F, or 0°C and 48.9°C respectively; so the AMDV may continue to function out in direct sunlight
- Some type of built-in surge protection to protect chip components
- A programming language that can either be easily learned or already familiar to the team
- Company and 3rd party documentation and tutorials which are free, plentiful, and available online
- Sufficient amounts of memory, I/O ports, processing power to run the AMDV’s GPS, wireless communication, autonomy, and motor functions
- Small dimensions as to be able to fit easily onto the AMDV’s frame.

### 2.4.5 Metal Detector Requirements

The metal detector is to be used to detect any metallic object that the vehicle may come near. The following list of specifications must be met in order for the project to succeed.

- The metal detector should be light weight and consume minimal power
  - < 16 ounces
  - < 10 watts
- It must detect metal at a minimum of 5 inches
- It must be able to fit on the underside of the vehicle
- Must be low cost
  - < $20
- Must be able to connect directly to the microcontroller
- Battery life must last at least 6 hours continuously

### 2.4.6 LED Requirements

The LED will be mounted on the vehicle for vehicle identification purposes. The follow list of requirements must be met:

- Must be bright enough to be seen from 30 feet away
- Must be very efficient in terms of power cost
- Must be less than $1.00

### 2.4.7 GPS Requirements

This subsection provides a list of the requirements of the GPS module of the AMDV. These requirements are observed throughout this document and the design of the AMDV. The AMDV’s GPS module is used to acquire the locations where a metallic object is found. The GPS module shall have the following specifications:

- Fast satellite fix time
- Small, inclusive chipset – GPS module and engine board
- Low cost
- Well documented
- Support WAAS
- High Accuracy (less than 5 meters)

### 2.4.8 Collision Avoidance Requirements
This subsection provides a list of the requirements of the collision avoidance sensors. These requirements are observed in this document and in the design of the AMDV. These sensors are used to allow the AMDV to not run into obstacles in its path under autonomous operation. The collision avoidance sensors shall have the following specifications:

- Works outside
- Works at a wide range of distances
  - Minimal Distance: at least 6 inches
  - Maximum Distance: at least 1 meter
- Small
- Low cost
- Well documented

2.4.9 H-Bridge Requirements
The H-bridge is essential to controlling the direction of the motors using signals sent from the microcontroller. The following list lays out all the specification and requirements needed.

- The H-Bridge must operation within a wide range of voltage inputs.
  - 3V-20V
- The H-Bridge must be power efficient
- The H-Bridge must be low cost
  - <$5.00
- The H-Bridge must be integrated into a chip.
- The H-Bridge must have a high temperature threshold.

2.4.10 Remote Controller Requirements:
The remote controller represents the interface between the vehicle and the user. All commands (except ones related to programming) are sent via the remote controller. Therefore it must be able to communicate in part or in all with the vehicle over the air through the wireless module. This means the Remote controller must be able to send and receive commands and other data to this module. Along with that requirement, the following list of specifications and requirements applies.

- Must cost less than $60 if one is not already on hand.
- Communicate in part or in all with the vehicle wirelessly.
- Turn the vehicle left or right.
- Accelerate the vehicle forward or put it in reverse.
- Put the vehicle into/out of the automatic mode.
- Have some kind of feedback device to indicate when the AMDV has sensed a metal-detecting object.

2.5 Input/Output Solo Block Diagram
This section details a general overview of how the vehicle will be constructed to be able to perform it’s given objectives and requirements set forth in the prior sections. The internals of vehicle operation are not discussed here as different technologies and methods may be used to accomplish the specified tasks and requirements set forth in this project to the vehicle; the internal operation and technologies used are discussed in later sections of this report.

From a top level view, the project will require multiple inputs and outputs to and from the robotic vehicle. These inputs and outputs are the basic minimalistic requirements as seen from an outside observer of the vehicle in operation. The diagram below shows these inputs and outputs. The vehicle will have an antenna to be able to detect radio signals for manual driving operation. The vehicle will have a computer connection port to allow for programming of different parts and operational algorithms. The vehicle will have an antenna to be able to detect its position from GPS satellite broadcasts. The vehicle will have a power port to allow charging of onboard batteries. The vehicle will have an autonomous-manual control switch to allow the user to set which mode of operation to use. The vehicle will detect metal and when metal is found, it will set off a visual or audible alert and log the GPS location.

Figure 2.5-1: Inputs and Outputs Diagram
3.0 Research

3.1 Methods

3.1.1 Research Methods

The project required multiple research techniques to get what we needed to learn and to build the project as a whole. Each of the three members of the group had a particular interest in different parts of the project. In which case, the project was divided up in what was agreed to be equal. The beginning of the project started with how it was going to be built and what the project needed to complete its task. In this process many ideas were thrown around as possible candidates for the project. This method of throwing ideas around as a group helped considerably in finding the perfect compromise that would fit best for the project and keep it at a realistic difficulty.

The multitude of components that needed to be researched were the power supply, the type of RC car to be used, whether or not the RC car is going to be automatically programmed to get a predetermined route or to control it manually through a hand held controller, the GPS unit, LEDs, and types of metal detectors. There are also a handful of other components not mentioned that required as much in-depth research as the main components. With two electrical engineers and one computer engineer, the group will be able to overcome many of the shortfalls that come with lack of knowledge. Each group member has specific knowledge on specific components that need to be implemented.

When doing research, any average and regular person can look up particular components and make a respectable machine or robot. What differentiates the engineers from the common hobbyist is the fact we have in-depth knowledge on the material, and know the inner workings of the components being placed into the circuit. The engineers know where to look and what to look for rather than the average hobbyist just goes to a parts list and regurgitates the schematic or design without putting any of their own imagination and knowledge into the project. With this in mind, the group as a whole is committed to using this design project to fully implement their gather knowledge over the past four years. This will include intuitive and clever manipulations of current technologies to ensure the best performance of the project.

The resources available to the student to be able to research such a complicated project are in healthy supply. The University offers great facilities with available access seven days a week. The main resource the group used was the internet. When using the internet, Google.com was the most popular site visited by far. As a side note, Google used as a verb is actually in Webster’s dictionary, meaning to search for via the web. This just goes to show how popular Google.com has become in any basic search needed. The way Google.com works is that when searching for a particular topic, it finds pages with the highest numbers of web links attached to the topic being search. For instance, the first result after Google-ing, would be at the center of the ‘web’ and be the most relevant site for that page. Of course, other considerations go into how Google.com orders its search results but, the bottom line is that Google.com uses very high tech strategies that help with this ongoing research project.
The other resource available is the famous library. Many students favor the library because of its vast collections that are hard to come by when searching the internet. The older generation may still despise using the internet for any kind of research and rely solely on hardcover books provided by public libraries. Using the library does have its advantages because of how in-depth the books cover its respectable material. They can be a quick and easy reference that can be brought with a person wherever he may go. Text books also provide this luxury. The student may first go to his text book to refresh his memory on the material needed to be researched. No matter what kind of book used to complete and aid in the research process, hard cover books have proven to be invaluable since man knew how to write, in which case should not be overlooked.

Another research method would be to directly consult the professional or guru of the topic being explored. The guru may be a professor at the university or the author of the semiconductor book that was used during sophomore year. In either case, consulting the expert is an excellent way to learn, directly from the source, how the topic works and why it’s useful. One minute with the expert is easily equal to hours of research on the internet or in any book written. The student that approaches a professor will be guided in the right direction as to what needs to be done to satisfy the requirements of his part, or the whole project.

### 3.1.2 Design Methods

One of the major goals of the project was to divide the project into as many sections as possible. Not only would this easily assign each group member a design, it will also help to scope where an error occurred, if it occurred. Making the project as modular as possible, it would be easy to take individual units and upgrade them as necessary without having to redo every component in the project. For example, if the metal detected proved to be useless after running and testing the prototype, then all that would need to be looked at would be the metal detector and everything else could be left alone. The modular system doesn’t have its advantages when failure arises, it has it advantages as to easily dissect the project in which case would make it easier to rebuild if need be.

Another useful tool that helped the project succeed was the use of the program MultiSim. MultiSim help realize many of the circuits and what the expected outputs were to come. But utilizing MultiSim, the team was able to save countless hours that would have been spent in the lab testing circuits and wasting valuable money that could be spent on other areas of the project besides testing. Other tools that will be used in programming the IC chips may include, but are not limited to, MatLab and Bloodshed Dev C++. These two programs offered as open source and through the university will come to be invaluable in the next semester where design, testing and prototyping will be the top priority.

### 3.1.3 Project Management

Management and overall progress of the project is put on the shoulders of each group member. There is not one group member that leads the charge and shows the rest which direction to go next. Each member is burdened with their own task in which case they become their own boss. The motivation without a boss-man would be the fact that they would not get their degree if they don’t proceed at a steady pace. That may be a gloomy way
to say it but, it is the driving force and reason why the project is in existence. The original concept holder laid the foundation, and the group took and ran with it, adding special and unique things to the project that would be unfathomable without multiple sessions of brainstorming and discussing possible ideas and features.

The group would hold weekly meetings to discuss the progress and potential problems that may occur. The meetings are vital to give the rest of the members the status of the project and the progress of each member themselves. If one member seemed to be going slower than planned, the rest of the group would act as that boss-man to coach him to find certain alleyways to continue on.

3.1.4 Implementation

Bringing everything together and watching the work of many weeks of research is the most exciting part of the project. The way this project will be implemented is the way a child builds a rector set. Each member of the group will have assembled his part(s) and bring it to the main hub; which will be the RC car. In the effort mentioned above, keeping the design modular would be vital for this process to work. Once all the parts are gathered, it should be a matter of plug and play. Most all the work will be done by the group members, including etching and design the PCB boards as well as making backup copies of the circuit board in the unfortunate case that one fails.

Having backups for every circuit board is just as important as having done through research. Each backup board must be up to spec as the final product board being presented. As engineers, we know that components fail unexpectedly, and group 10 is not going to fall into the trap where there is no backup contingency. Though it would be nice to have things done right the first time, it is the smartest design to always have a backup plan.

3.2 Architectures

3.2.1 Remote Controllers

3.2.1.1 Intro

There are some really cool ways to manually control an RC vehicle out there. The options include using a PS3 or Wii controller via Bluetooth, a laptop via Wi-Fi connection, or the original RF remote included with the unmodified RC vehicle. However, there are costs issues to using these: Wii Remote $40, PS3 controller $50, or worse, a laptop $400. It’s also important to note that these costs don’t include the cost of the wireless module that is used to communicate between the remote controller and the microcontroller. Figure 3.2-1 below lists the short specifications of each remote controller being considered. Below that is a summary of each of the advantages and disadvantages of using each product as a remote controller for the AMDV.
### Table 3.2-1: Controller Comparison Table

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<td>Bluetooth/XBee via dongle</td>
<td>RF</td>
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<td>6 digital buttons + 8-way direction pad</td>
<td>10 analog buttons + 2 digital buttons + 8-way directional pad + 2 analog sticks</td>
<td>104+</td>
<td>2 2-way sticks</td>
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<td>39.99</td>
<td>42.99</td>
<td>379.95</td>
<td>Included with RC Vehicle</td>
</tr>
<tr>
<td>Units In Hand</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

#### 3.2.1.2 The Original RF remote

The original RF remote that was included with the unmodified RC vehicle has several limitations that pertain to this project. First it has no feedback mechanism for showing when the AMDV has detected a metal object. Second, it is unable to provide a dedicated automation/manual control button. This means that there will have to be some button to do this on the already crowded frame of the vehicle. This is also inconvenient to the user who has to bend over and reach down to press the button when the AMDV remote controller is already in hand. Also, the fact that the included RF remote is already paired and integrated with the vehicle could be seen as an advantage, if it weren’t for the additional microelectronics being installed. To make the existing remote controller work with the new microcontroller would require some reverse engineering, some unprofessional soldering, and potentially complicate things more than it’s worth. If permanent damage to the vehicle’s original PCB occurred during prototyping and/or final building, a whole other RC vehicle would have to be bought versus just the just a new wireless module, potentially increasing costs beyond specifications.

Despite these shortcomings, the original remote does have one strength to it: it’s free. The cost is already included with the purchase of the RC vehicle. This strength, however, does not outweigh the limitations. Also, two of the other remote controller options offer this benefit as they have already been purchased before the project began negating the purchase cost and are readily available.

#### 3.2.1.3 Modern Gaming Controllers

Modern gaming controllers such as the Sony PS3 Dualshock 3, shown below in Figure 3.2-1, or the Nintendo Wii Remote, shown below in Figure 3.2-2, offer the following advantages as remote controller: price, form factor, ergonomics, built-in Bluetooth, advanced controls, and battery life. First their price: the Wii remote comes in at $39.99 while the PS3 Dualshock 3 is
$54.99. There are four Wii remotes on hand while the Dualshock 3 would have to be purchased. This is fine, as the Dualshock 3 price comes in under our remote controller spec budget. Second, both the Wii remote and the Dualshock 3 come in a very handy portable form factor and with that, extremely well designed ergonomics. They can both be carried around for long periods of time without discomfort and don’t have to be put on a table, unlike a laptop. Thirdly, the battery life for the Wii remote and the Dualshock 3 are estimated to be 30 and 14 hours, respectively. This will allow plenty of playtime before the controller has to be replenished with new batteries or recharged. Next, controllers offer advance control. On top of the generous buttons each offer, they both have motion technology. This offers advanced controls for the vehicle as turning the actual controller left or right could do the same for the vehicle. They both offer rumble support which could be useful as when the AMDV finds a metal object, the controller could rumble to notify the user it has found such an object. The rumble response could also vary with the strength of AMDV’s metal detection signal: the closer to the object the AMDV gets, the more the controller rumbles. The Wii remote also has a speaker built-in, so in addition to the rumble, a sound could be played to notify the user of a metal object. Finally, both devices have Bluetooth built-in. This makes wireless connectivity with the AMDV possible without having to dismantle or hack either controller. All that is needed, in theory, is to pair the controller with the Bluetooth module on the AMDV. These advantages make any of the two controllers a good choice for the AMDV remote controller.

The two controllers do offer some disadvantages, namely difficulty pairing and programming, and limited feedback devices. Research has found that pairing the Dualshock 3 will be difficult, if possible. It may require downgrading to the rumble-less Sixaxis PS3
controller, which is much easier to pair with a Bluetooth module. Research has also found adequate documentation for how to program the Sixaxis controller. Presumably once paired the Dualshock 3 would use the same programming as the Sixaxis. However this is not certain. If the case happens to be that the controller doesn’t share the same programming as the Sixaxis, much more research and trial and error would be required. The Sixaxis was considered because of the documentation available but losing the rumble aspect means losing the one feedback mechanism the controller offers for notifying the user that a metal object has been found which makes it no longer suitable to meet the AMDV remote controller specifications. Programming and pairing the Wii remote would also require a lot of research and trial and error due to lack of current documentation with no guarantees of working successfully. The final limitation to using one of the modern controllers is they offer limited forms of feedback: rumble response and in the case of the Wii remote, speaker response. Both would be limited to notifying the user only when it has found something. Neither controller would be able to display current AMDV or metal object GPS coordinates without heavy modification and hacking. Laptops have a big advantage here because they can do just that courtesy of a LCD screen. All in all, the difficulty programming/pairing, combined with the lack of a screen for vehicle feedback make using one of the modern gaming controllers less appealing.

3.2.1.4 MSI Wind U100 Laptop

A laptop as a remote controller offers many advantages; besides offering a whole morsel of buttons, typically 104, it also provides the opportunity to have a GUI that presents GPS and other data to the user. It also offers better scalability, if it were decided in a future project to expand the functions of the AMDV to perhaps include an onboard camera; the laptop could easily display this new data, while the other controllers could not. Laptops offer three major relative disadvantages: high price, lengthy programming, large form factor, and bad ergonomics, the last two affecting portability.

Figure 3.2-3: MSI Wind U100

Permission pending from MSI
The Wind, as shown in figure 3.2-3 above, was chosen because there is one already on hand, and therefore no need to purchase one. This allows the project to use a laptop while still abiding the cost requirement of $60. Getting into specifics, the MSI wind is a 10” netbook with a 6-cell battery life. Netbooks are notoriously small compared to standard 15” notebooks. For instance, the Apple 15” Macbook Pro’s dimensions are 14.35”(L) x 9.82”(D) x 0.95”(H), while the wind’s is 10.23”(L) x 7.08”(D) x 0.748”~1.24”(H). However, this is still relatively large compared to the Wii remote or PS3 controller. Netbooks are also known for their light weight, this one being 2.6lbs with battery as compared to the Macbook’s 5.2lbs. The 6 cell battery gives the netbook an estimated four hour battery life depending on usage. In addition, the Wind has Wi-Fi and Bluetooth modules built-in, so only an XBee dongle would be required if needed. Because of advantages such as the GUI potential, the numerous amounts of buttons, and the built-in wireless modules, the MSI would be a solid choice as a remote controller for the AMDV.

3.2.2 GPS

3.2.2.1 GPS Overview

The Global Positioning System is commonly known as GPS. GPS is a constellation of satellites which provide worldwide coverage broadcasting their current location to GPS receivers which are then able to triangulate their location based on the satellite data. The receivers are also able to determine their current velocity and the current time from the data. At any time there are between 24 and 32 operational GPS satellites in medium earth orbit around the earth and a receiver can typically see at least 6 of them at anytime.

3.2.2.2 WASS Technology

In the recent years, the Wide Area Augmentation System (WAAS) has become a popular addition to GPS receivers. WAAS was developed to provide aircraft with better accuracy/precision and to allow for greater availability of the location data. GPS signals can be loss due to current weather locations at the GPS receiver or the receiver may not have a clear view of the sky, such as being surrounded by buildings in metropolitan areas. The theory behind WAAS is that ground based stations (Wide Area Reference Stations) receive multiple GPS signals from the GPS satellites which are then checked for small deviations and inaccuracies in received data. This information is then sent to WAAS satellites in geosynchronous orbit by the ground earth communication stations (Wide Area Mater Stations) and rebroadcasted by the satellites to the WAAS enabled GPS receivers. These receivers are then able to calculate their position with the GPS data and then increase the accuracy of their position with the WAAS data. Below in Figure 3.2-4, is an illustration of how the Wide Area Augmentation System works in conjunction with the Global Positioning System.
3.2.2.3 Data Received from GPS Satellites

There are many different manufactures of GPS receivers such as Garmin or Magellan. Every manufacture has different hardware and software techniques and technologies that allow for the use of the Global Positioning System but most of these receivers all rely on a GPS chipset which they didn’t manufacture themselves. The GPS chipset is what actually receives the GPS satellite signals and processes it to find the current position, velocity, time; along with receiving other data from the satellites regarding their status and health.

There are a few different producers of GPS chipsets but one of the most prominent on today’s market is SiRF. SiRF GPS chipsets have been proven to have fast GPS satellite acquisition time and are able to acquire the GPS satellite signal in environments where other GPS chipsets fail.

In conjunction with the National Marine Electronics Association (NMEA), SiRF has developed different modes of output messages for use in its products based off of the NMEA 0183 data specification. The table below (Table 3.2.2.1) summarizes the different modes by providing a short description of what each output message includes. The following subsections describe the different modes of messages in detail providing the format of each message. The message modes MSS, VTG, ZDA, 150, 151, 152, and 154 will not be discussed because they are not relevant to the objectives of this project.
### 3.2.2.3.1 GGA Message Format

GGA is the Global Positioning System Fixed Data output message mode. It includes the time and GPS fix data which is used to determine data accuracy. The format of the GGA output message is as follows:

```
$GPGGA,aaaaaa.aaa,bbbb.bbbb,c,ddddd.dddd,e,f,g,h,i,k,m,n,*o<CR><LF>
```

- **$GPGGA** - Header information – Type of message
- **aaaaaa.aa** - UTC Time - hhmmss.sss
- **bbbb.bbbb** - Latitude – dddmm.mmmm
- **c** - N/S indicator, Which hemisphere
- **ddddd.dddd** - Longitude, dddmm.mmmm
- **e** - E/W indicator
- **f** - Position fix indicator{
  - 0=No fix
  - 1=GPS SPS mode
  - 2=DGPS/SPS mode
  - 3-5=Not supported modes
  - 6=Dead reckoning mode
- **g** - Number of satellites used
- **h** - Horizontal dilution of precision
- **i** - Altitude (meters)
- **j** - Units (M=Meters)
- **k** - Geoid separation
- **l** - Units (M=Meters)
- **m** - Age of differential correction – NULL if not using DGPS
- **n** - Differential reference station id number – 0000 if not using DGPS
- ***o** - Checksum
3.2.2.3.2  **GLL Message Format**

GLL is the Geographic Position output message mode. It includes the GPS fix information and geographic latitude and longitude. The format of the GLL output message is as follows:

\[
\$GPGLL,a,aaa.aaaa,b,ccccc.cccc,d,eeeee.eee,e,f,g,*h<CR><LF>
\]

- **$GPGLL**: Header information – Type of message
- **aaaa.aaaa**: Latitude – ddmm.mmmm
- **b**: N/S indicator, Which hemisphere
- **ccccc.cccc**: Longitude, dddmm.mmmm
- **d**: E/W indicator
- **eeeee.eee**: UTC Time - hhmmss.sss
- **f**: Status \{ 
  A=data valid
  V=data not valid \}
- **g**: Mode \{ 
  A=Autonomous
  D=DGPS
  E=DR
  N=Output not valid \}

*\ h: Checksum

3.2.2.3.3  **GSA Message Format**

GSA is the Dilution of Precision and Active Satellites output message mode. It includes the GPS receiver mode and the satellites used to calculate the position. The format of the GSA output message is as follows:

\[
\$GPGSA,a,b,c,…,c,d.d,e.e,f.f,*g<CR><LF>
\]

- **$GPGSA**: Header information – Type of message
- **a**: Mode 1 \{ 
  M=Manual
  A=2D Automatic \}
- **b**: Mode 2 \{ 
  1=No fix
  2=2D fix
  3=3D fix \}
- **c**: Satellite Used – up to the number of channels available
- **d.d**: Position dilution of precision
- **e.e**: Horizontal dilution of precision
- **f.f**: Vertical dilution of precision

*\ g: Checksum

3.2.2.3.4  **GSV Message Format**
GSV is the Satellites in View output message mode. It includes what satellites are currently in view of the receiver and the signal-to-noise ratio between the receiver and satellites. The format of the GSV output message is as follows:

```
$GPGSV,a,b,cc,dd,ee,fff,gg,…,dd,ee,fff,gg,*h<CR><LF>
```

- **$GPGSV**  
  Header information – Type of message
- **a**  
  Number of messages in this group
- **b**  
  Message number
- **cc**  
  Number of satellites in view
- **dd**  
  Satellite ID
- **ee**  
  Elevation (degrees)
- **fff**  
  Azimuth (degrees)
- **gg**  
  SNR
- ***h**  
  Checksum

### 3.2.2.3.5 RMC Message Format

RMC is the Recommended Minimum Specific GNSS Data output message mode. It includes minimal data for the position, velocity, and time. The format of the RMC output message is as follows:

```
$GPRMC, aaaaaa.aaa,b,cccc.cccc,d,eeeee.eeee,f,g,hhh.hh,iiiiii,j,*k<CR><LF>
```

- **$GPRMC**  
  Header information – Type of message
- **aaaaaa.aaa**  
  UTC Time - hhmmss.sss
- **b**  
  Status {  
  A=valid data  
  V=not valid data }
- **cccc.cccc**  
  Latitude – ddmm.mmmm
- **d**  
  N/S indicator, Which hemisphere
- **eeeee.eeee**  
  Longitude, dddmm.mmmm
- **f**  
  E/W indicator
- **g**  
  Speed over ground (knots)
- **hhh.hh**  
  Course over ground (degrees)
- **iiiiii**  
  Date – ddmmyy
- **j**  
  Magnetic variation{  
  E=east  
  W=west }
- ***k**  
  Checksum

### 3.2.3 Metal Detectors

#### 3.2.3.1 Introduction

The metal detector is the heart and soul of the project. If everything else were to fail on the project, the one thing that has to work is the metal detector. There are many things to consider when choosing the best metal detector for the job. The first and most important consideration is the cost of the device. To keep the project under budget, and ideal price
would range from twenty-five dollars to seventy-five dollars. Of course, this budget allocation is only of the metal detector itself. Other costs that may be attached or be used with the metal detector are not included in the estimated budget range. For example, the cost of the power supply and microcontroller is not included. The reason for the omission is because there are many options when considering the final design of the project. When exploring everything needed for the final project, choosing most ideal metal detector technology is the next consideration. There are many different types of metal detector technology all of which will be explored in the following sections.

There are other factors outside the metal detector that need to be considered. For the vehicle to run smoothly, a sleek and small metal detector will be needed. When exploring the technologies of the metal detector, careful consideration comes from the total size of the technology. Another benefit, if made possible, would be the creation of the metal detector technology by hand. In trying to avoid “reinventing the wheel” a benefit of making the device by hand is keeping it at a small and effective size. There are currently three technologies being considered. Further discussion of the metal detector technologies will be covered in the following sections.

### 3.2.3.2 Metal Detector Technology

#### 3.2.3.2.1 VLF – Very Low Frequency

The first technology that will be considered is of the VLF (Very Low Frequency) variety. This technology uses two series of coils, a transmitter and a receiver coil. It’s worth mentioning that this technology may cause a potential problem which is its interference with the vehicle. In the subsequent design section, considerations will be explored using different options on making the various technologies not interfere.

#### 3.2.3.2.1.1 Pioneer VLF Metal Detector by Bounty Hunter

The Pioneer VLF detector is a product of high consideration. It is selected because of its simplistic design, and numerous features. This detector will have to be taken apart, removing its shaft and leaving just the detecting head and the intensity meter.

The following is a list of key features that make the Pioneer appealing:

**Main Features:**

- Sensitivity Meter: Provides visual cue of near target
- Two-Tone Audio Feedback: Audible tool for accurate target identification
- Power Level Control: Reduces electromagnetic interference
- Trash Eliminator: Eliminates unwanted metals from detection
- 7” Closed Waterproof Coil: Detects in damp grass or shallow water
- Lightweight, Ergonomic Design: Provides ease-of-use and comfort for hours of productive detecting

**Modes of Operation:**
• Motion All-Metal Mode: Detects all types of metal with Trash Eliminator off
• Discrimination Mode: Eliminates iron and other unwanted metals with Trash Eliminator on

Two specifications that make the project are the depth detection and the size of the coil system. In both categories, the Pioneer become very appealing and makes it a top choice.

• Depth Detection: 6” for coin-size objects; 2’ for large objects
• Coil System: 7” Closed Waterproof

The only immediate downfall the Pioneer has is its price, currently set at $89.00. This price exceeds the current allocated budget, but doesn’t scratch the Pioneer completely off the list.

3.2.3.2.2  P.I. Metal Detectors (Pulse Induction)

Pulse Induction is not as common as other metal detecting technology, but it has many advantages. Some of the main attributes of Pulse Induction is their ability to ignore small, negligible minerals that occur naturally in the environment. An example of this would be the small amounts of iron in sand along the beaches, or the salt deposits that build up that might interfere as with other technologies. Another appealing advantage is the detection range. The range of Pulse Induction detectors is not affected by the medium it is traveling through.

The Pulse Induction Detector to be considered is the Garret Master Hunter CX Plus. This detector is far beyond what our budget can offer, but it is important to mention because of the advantageous capabilities it has to offer. As with the VLF detector, the shaft will be removed leaving just the detector and the search coil to be attached to the vehicle. Table 3.2.3-1 shows many properties of the pulse induction metal detector. If the project had an application as to where it was searching for metal in the sea or any other body of water, this Pulse Induction detector would fit every specification needed for the job.

<table>
<thead>
<tr>
<th>Features</th>
<th>Main</th>
<th>Search Modes</th>
<th>Settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Metal Deep Seeking Mode</td>
<td>Non-Motion All Metal</td>
<td>Ground Tracking Speed</td>
<td></td>
</tr>
<tr>
<td>Audio Threshold, Adjustable</td>
<td>Adjustable PI discrimination</td>
<td>Discrimination</td>
<td></td>
</tr>
<tr>
<td>Audio Tone ID</td>
<td></td>
<td>Threshold</td>
<td></td>
</tr>
<tr>
<td>Discrimination, Full Range Frequency</td>
<td></td>
<td>Volume Control on</td>
<td></td>
</tr>
<tr>
<td>Ground Balance, Automatic</td>
<td></td>
<td>Detection Frequency</td>
<td></td>
</tr>
<tr>
<td>Ground Tracking</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip Mount Control Box</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microprocessor Controlled</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salt Elimination Mode (PI)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface Mount PC Board</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.2.3.2.3 BFO – Beat-Frequency Oscillator

The Beat-Frequency Oscillator is the top choice for the project at hand. It has a relatively simplistic design and is very cost effective. The schematic for a simple BFO metal detector is shown in Figure 3.2-5.

![Figure 3.2-5: BFO Metal Detector]( Courtesy of bobsdata.com )

In this schematic there are only a handful of components needed, which makes the assembly of the BFO simple and fast. Table 3.2.3-2 shows the parts list for the above schematic. The only component in the schematic that is difficult to find for purchase is the L1 inductor. This shouldn’t cause a problem because the parts list identifies this inductor to only be 22 turns within a 22cm diameter, which is very manageable.
Table 3.2-4: Parts List for a BFO

| Parts List for the 494 KHZ Metal Detector : (resistors are 1/4 watt) |
|--------------------------|-----------------|-----------------|
| R1,2,7,8,12             | 4.7 K           | C1              | 10 pF *(Mica) |
| R3,4,5,6,9              | 12 K            | C2,3,6,7        | 330 pF *(Mica) |
| R10                     | 47 K            | C4,8            | .001 uF *(Mica) |
| R11                     | 470 K           | C5              | 12-24 pF Variable |
| R13,17                  | 5.1K            | C9,10           | 100 pF        |
| R14                     | 560 Ohms        | C11,12,14,17    | .047 uF       |
| R15                     | 10 K Pot.       | C13             | 47 uF / 35V   |
| R16                     | 22K             | C15             | 100 uF / 35V  |
| R18                     | 47 Ohms         | C16,18          | 22 uF / 35V   |

L1 (The search coil) 22 turns of #28 enameled wire on a 6 ¼ inch diameter. This coil also has an aluminum Faraday shield.

L2 (The local osc. coil) 291 turns of #32 enameled wire on a 1/4 inch diameter Ceramic form with an adjustable ferrite core. Coil windings are over a ½ inch length and then covered with epoxy resin.

Q1,2,5                   | 2N5951 JFET Transistors |
Q3,4,6,7                 | 2N2222 BJT Transistors |
D1                       | 1N34 or 1N270 Germanium Diode |
D2                       | 6.8 Volt Zener Diode (1W) |

Other commercial types of the BFO also exist and will be used as a back-up in the unfortunate case that failure incurs on self assembly of the BFO shown above. Commercial BFO are rare because most are not in production anymore. Most BFO metal detectors are built by hobbyists and there are a number of schematics flying around the net.

Mentioned in the parts list above is the CD4011 and the LM78L05. The CD4011 is a CMOS integrated chip and could be substituted for any IC that does AND operations. The specific features of the CD4011, which will be considered, will be discussed in a subsequent chapter of this document. The LM78L05 is a 3 terminal positive voltage regulator, which can also be substituted out for many other regulator types. Voltage regulators will be discussed in subsequent chapters.

Figure 3.2-6 shows the basic principles of how a beat-frequency oscillator works. The concept is that when two sinusoidal waves are added together, the resulting wave is the difference of the two. For example if there was a 100kHz wave and a 99kHz wave that was added together, there would be two resulting waves, one of which that produces a 1000Hz
and another that produces a 199kHz wave. The higher frequency wave would be filtered out only leaving the resulting low frequency wave to be used in the application.

![Figure 3.2-6: BFO Voltage Outputs](Courtesy of vias.org)

3.2.3.2.4 Proximity Detector ICs

3.2.3.2.4.1 Introduction

The proximity detector ICs are virtually a BFO metal detector in a small compact form. Using these proximity detectors, the project will be able to meet its goals in several areas. The first area that will be satisfied is the size restriction. This IC can be put on a very small board with all of its miscellaneous components and still have a sleek design. This will allow minimal interference with the vehicle and even add the possibility of adding more detectors. The second area of high potential value is the cost of the IC chips. In the previous BFO schematic, all the components added together may have exceeded a cost of $20.00. With this IC chip, it’s essential the same circuit at a fraction of the cost that is no more than $3.00.

In the following sections, discussion on specific proximity detectors will be outlined. There are currently two detectors that have great appeal for the purpose of the project. These two chips are the CS209A and the TDA0161 with its manufactured application the STEVAL-IFS005V1.

3.2.3.2.4.2 CS209A Proximity Detector IC

The CS209A is a basic proximity detector whose main application is with metal detection. Inside this small chip, the CS209A sports two current regulators, an oscillator, a peak
detection/demodulation circuit, a comparator and two complementary output stages. The oscillator within the circuit provides a controlled oscillation. The amplitude of the oscillation is very dependent on the quality factor of the inductor capacitor external circuit. If the quality factor is low, a feedback circuit inside the chip provides the main drive to the oscillator. Within the inner workings, the peak demodulator senses the negative side of the oscillating wave and provides a demodulated waveform to the input of the comparator. The comparator then sets the states of the outputs by comparing the input from the demodulator to an internal reference.

Figure 3.2-7: Block Diagram CS209A

Features:
- Separate Current Regulator for Oscillator
- Negative Transient Suppression
- Variable Low-Level Feedback
- Improved Performance over Temperature
- 6mA Supply Current Consumption at Vcc = 12V
- Output Current Sink Capability
  - 20mA at 4Vcc
  - 100mA at 24Vcc

The CS209A’s data sheet shows detailed explanations and examples of typical applications used with this chip. Unlike the TDA0161, the CS209A fully explains the inner workings of its chip and helps the reader understand how to make the most effective metal detector for their project at hand. Though both chips do still look promising, whether they lack specific details or not, the CS209A and the TDA0161 will both have to be tested to determine which
A chip will be used in the final product. Observation just by specs alone is not enough to overrule one for the other.

### 3.2.3.2.4.3 TDA0161 Proximity Detector IC

The TDA0161 is perfect for the project. This chip offers low cost and small, easy to use circuit components that are ideal for the project at hand. One option that may be considered is the use of multiple TDA0161 with similar application to the STEVAL-IFS005V1. More details on the design of the proximity detector will be discussed in the design section.

- **Features:**
  - 10mA Output current
  - Oscillator frequency of 10MHz
  - Supply voltage of +4 to +35V

The block diagram shown in Figure 3.2-8 shows the amount of circuitry that is involved with creating the proximity detector. The BFO’s schematic looks identical to the schematic drawn inside the TDA0161. The difference between the BFO schematic and the TDA schematic is the fact that with the BFO, you can set your oscillating frequency to whatever you application demands. That comes with a drawback of having to design the whole circuit and risk the possibility of errors and flawed components. With the TDA, there is only one component to be concerned about and the main search coil and be designed to an oscillation of your choosing.

**Figure 3.2-8: Diagram of the TDA0161**

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*Permission pending from st.com*
3.2.4 Sensors

3.2.4.1 Sensor Overview
There are many different applications for sensors regarding detection of objects or areas. From detecting light to detecting a shape to detecting different terrains; sensors are an important part of all robotic interfaces be that civilian or military. In this application the sensors will be used to sustain the vehicle health and operation. The primary operation of the sensors on this vehicle will be to detect obstructions which are in the path of operation. By being able to detect these obstructions, the vehicle under autonomous operation will be able to take actions to avoid the obstructions and to continue to execute its task safely and effectively. There are many different sensor technologies which could be used for this application which are discussed in the remainder of this section.

3.2.4.2 Light Detection
One type of sensor is based on optical detection of reflected light. Light detection and ranging technology is based off the theory of reflection and refraction. As the light source reaches an object, it is reflected off of an object and the sensor at the origin of the source will pick up this reflected light. The sensor would then process this returned light and perform a designated operation based on the device’s task. A closely related technology is radar. The primary difference between light detection and radar technology is the wavelength of the electromagnetic spectrum which is used. Due to the similarities between these technologies, this section will discuss both of radar and light detection with the primary focus being on the latter. The typical use of these technologies is for mapping such as with radar or medical imaging.

The primary differences in the uses of these technologies are the wavelength of the source used. Different wavelengths from the source will reflect off some objects while going through other objects. The differences in this behavior are what allow for the ability to see only certain objects in mapping; such as only bones in X-Rays or aircraft on radars. For obstacle avoidance along with every other type of mapping technology, a circuit not only needs the source but also a way to detect the reflected waves. Depending on the type of source, there are a number of different detectors available. For light detection, the majority of detectors are a type of solid state photo detectors, with the most common being silicon photodiodes.

Light detecting technology is used with a wide set of wavelengths due to the properties of each set being different. Assorted wavelengths will be absorbed by some substances but not others and they all have different ranges in which they can be used to detect objects effectively. For this reason, the light source and detector both must be tuned to detect the same range of wavelengths otherwise the detector may yield incorrect readings. For effective object detection, the wavelength of the light must reflect off of the majority of all objects.

For light detection, there are a number of different light sources available. The two most prominent are laser and LED. Lasers are typically used for longer distances than LEDs and operate on different ranges of wavelengths. They are often used to actually detect ranges of
objects because of their directionality and ability to travel greater distances while LEDs are used to detect objects in the immediate vicinity of the source and detector.

The following sets of illustrations, in Figure 3.2-9, provide a demonstration of how an object may be seen by a laser scanner. The top set of illustrations show the laser scanning device. The middle set show the path of the laser as it passes through the depicted area. The bottom set of illustrations show a mapping of what has been detected. The black dot represents the origin of the light source and detector (the laser scanner), while the blue crosses represent where an object was detected as seen by the scanner.

![Figure 3.2-9: Demonstration of Optical Object Detection](image)

(Courtesy of Wikipedia user Mike1024)

### 3.2.4.3 Contact Detection

Another type of detection is determining if the vehicle is physically in contact with an object. Detecting an object with this method involves using pressure plates to make an electrical connection when compressed. This connection would signal that the vehicle has run into an object and that an action is needed to get around that object. This method is not normally used alone because it is dangerous to the health and operation of the vehicle to run into objects. Although using this physical pressure method is very reliable in detecting obstructions.

The typical contact sensor is based on a switch. Running into an object would apply pressure to the switch and make an electrical connection. This sensor is typically mounted in the
direction of movement to provide the ability of detecting an object in its path of motion. Also one has to worry with this type of sensor about signal bouncing. Due to the nature of a spring loaded sensor like this, additional care has to be taken when processing the output signal of the sensor. One technique called debouncing is commonly used in switches to reduce/eliminate the ripple effect from the spring on the connection between the electrical contact on the base of the sensor and the contact on the arm of the sensor. Debouncing is often done in software by taking an average of the output signals seen coming from the sensor or by allowing time for the signals to level themselves out. The first option is the more ideal solution for the purpose of the AMDV as the sensor would need to have a very fast debouncing time to successfully detect objects and to avoid damaging the vehicle. The following illustrations, in Figure 3.2-10, demonstrate a switch based pressure sensor. The illustration on the left shows the sensor in the non-triggered state and the illustration on the right shows the sensor in the triggered state with the triggered state referring to being in physical contact with an obstruction.

Figure 3.2-10: Demonstration of Contact Detection

Contact sensor in the open position meaning that it has not been triggered.          Contact sensor in the closed position meaning that it has been triggered.

3.2.4.4 Ultrasonic Detection

Another type of possible sensor that can be used for obstacle detection are ultrasonic sensors. These types of sensors were originally developed by Polaroid as a way to determine range information in cameras. Since that time, they have been widely used in mobile robotics to determine the distance of objects.

Ultrasonic sensors work by producing a sound in the area of 40 kHz (which is considered an ultrasonic frequency) from a transducer. Then a transducer receives an amount of reflected sound energy from objects which are in front of the sensor. This reflected energy is
converted to an electrical signal which is then analysis by a microcontroller to determine the distance an object is away from the device. This distance is calculated by using the speed of sound through air. The overall operation of two types of ultrasonic sensors is illustrated below in Figure 3.2-11. The top sensor is based on the Polaroid sensor which uses a single transducer to both send the sound and receive the reflected sound energy. The bottom sensor is based on a more universal design which is used in by manufactures such as HiTechnic. It uses two separate transducers; one to send the sound and one to receive the reflected sound energy.

Figure 3.2-11: Image of how the transducers send/receive sound energy

There are a few issues that arise from using ultrasonic detectors for obstacle avoidance. The first is that not all objects will reflect sound energy in the same manner or amount. This is dependent on the material/composition of the object and its shape and size as well. A wall will provide better feedback energy than a chair in the room. Another issue is that the sound will not only detect in a line/cone of sight. The sound energy will deviate from the central cone and may produce unexpected reflections. A third issue is that there is a minimum distance that must be between the sensor and the object it is to detect. If the object is within that minimum distance to the detector, the sensor will either not be able to tell that the object is in front of it or the feedback energy will be seen as echoes to the detector and will cause unexpected distance readings by the sensor.

3.2.5 RC Vehicle

There are a number of requirements which must be met by the vehicle chosen to be used as the AMDV. The suspension system must be capable of carry relatively large amounts of mass and provide the capability of traversing different terrains such as sand, gravel, and grass. It must supply large wheels which will help with the traversing of different terrains and allow for high enough ground clearance to mount the AMDV’s metallic detection module. The R/C vehicle must have built in power plants to allow the AMDV to be partially powered by the OEM battery packs which are typically included when purchasing a vehicle. It must also provide a large wheelbase which allows for a mounting area for the AMDV’s electronics and this wheelbase will provide stability when operating. The vehicle must be of
relatively low cost. In addition to the above requirements, these vehicles must also allow for easy motor replacement. The motors in R/C vehicles may not provide the torque that the AMDV will need, so they may be replaced if testing proves this necessary. In addition to motor replacement, H-Bridges may be used to control the new motors. These H-Bridges are discussed in Section 3.3.7.

3.3 Components

3.3.1 Power Supply

3.3.1.1 Introduction

The power supply is a very obvious and mostly overlooked component part that serves a very important role; to supply power to the module. Research on the power supply will look into different aspects of the type of power been sent into all the different component types - whether it is a supply to an IC chip, or to a DC motor. The many different options that will be considered will include renewable power as in solar energy or photovoltaic cells to more common power supplies from various chemical batteries. Choosing the type of power supply is tricky in the sense that a decision is still being processed on having multiple supplies or one central supply. With this said, research on multiple power supplies is not only necessary, but vital to the overall success for a functional module. In the subsections below, the following list of power options will be explored: Solar power, primary batteries, rechargeable batteries, lithium ion batteries, nickel cadmium batteries, and silver-zinc batteries. Discussion on how the batteries will be hooked up and whether or not there will be multiple sources will be covered in the Design chapter.

3.3.1.2 Solar Power

The use of solar power for this project is a very attractive option. The vehicle will be operating outside when it is used for its primary purpose, which is to search for metal objects. Solar power can be used to recharge batteries placed in the vehicle for a virtually unlimited source of energy. A realistic scenario for a typical application of our project is that this vehicle will be set on a beach combing the sand for coins or other various metallic objects. When the user is relaxing and enjoying his or her lemonade, the last thing they would want to worry about would be whether or not the vehicle is stranded somewhere because they forgot to charge the battery. Solar power will ease this worry and supply the vehicle with enough energy to storm the beach just so long as that is it daylight. A company called Power Film sells small and light weight and cost effective. One of their products advertises a solar film that specifically charges AA batteries. This can be a very useful product, given that the battery chosen is a AA.

3.3.1.3 Primary Batteries

There are many different battery types to be considered for the project. Batteries can be separated into two distinct categories, primary and secondary. Primary batteries can only be used once due to their chemical reactions are limited and once empty, they have to be disposed. Table 3.3.1-1 shows the many different primary battery types with their maximum voltage rating, along with other important details about each of the batteries. Before moving
on to discuss the different primary batteries, if a good battery is found but has low voltage, or if it has low capacity, figure 3.3-1 shows there are different ways to connect the battery to compensate for those loses.

Table 3.3-1: Primary Battery Types

<table>
<thead>
<tr>
<th>Cell Type</th>
<th>Anode</th>
<th>Cathode</th>
<th>Maximum Voltage</th>
<th>Maximum Capacity</th>
<th>Working Voltage</th>
<th>Energy Density</th>
<th>Shelf Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon-Zinc</td>
<td>Zn</td>
<td>MnO2</td>
<td>1.6</td>
<td>230</td>
<td>1.2</td>
<td>65</td>
<td>18</td>
</tr>
<tr>
<td>Alkaline-MnO2</td>
<td>Zn</td>
<td>MnO2</td>
<td>1.5</td>
<td>230</td>
<td>1.15</td>
<td>65</td>
<td>30</td>
</tr>
<tr>
<td>Mercury</td>
<td>Zn</td>
<td>HgO</td>
<td>1.34</td>
<td>185</td>
<td>1.2</td>
<td>80</td>
<td>36</td>
</tr>
<tr>
<td>Silver Oxide</td>
<td>Zn</td>
<td>AgO</td>
<td>1.85</td>
<td>285</td>
<td>1.2</td>
<td>80</td>
<td>36</td>
</tr>
<tr>
<td>Zinc-Air</td>
<td>Zn</td>
<td>O2</td>
<td>1.6</td>
<td>815</td>
<td>1.1</td>
<td>200</td>
<td>18</td>
</tr>
<tr>
<td>Lithium</td>
<td>Li</td>
<td>(CF)</td>
<td>3.6</td>
<td>2200</td>
<td>3.0</td>
<td>650</td>
<td>120</td>
</tr>
<tr>
<td>Lithium</td>
<td>Li</td>
<td>CrO2</td>
<td>3.8</td>
<td>750</td>
<td>3.0</td>
<td>350</td>
<td>108</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg</td>
<td>MnO2</td>
<td>2.0</td>
<td>270</td>
<td>1.5</td>
<td>100</td>
<td>40</td>
</tr>
</tbody>
</table>

This section will delve deep into the details on most of these battery types. It will start by researching the most common ones, their uses and their disadvantages. Primary batteries can be used in conjunction with solar power arrays and also the rechargeable batteries. When considering which battery to use, for this research section, it is best to assume that the main battery type will be a primary battery.

**Figure 3.3-1: Battery Connections: Series and Parallel**

Connecting in Series (double voltage, same capacity [ah])

Connecting in Parallel (same voltage, double capacity [ah])

(Permission Granted: http://www.zbattery.com)

With that said, the most realistic scenario when selecting the batteries is to which is most readily available to the group. Of course, this will not limit our selection because when the research is complete, the ideal battery may not be easily found in a near-by hobby store and in which case it would be beneficial to the group to seek the battery in question either online or at a not so common retailer.
3.3.1.3.1 Carbon-Zinc Primary Battery

The Carbon-Zinc batteries are mostly used with low power consuming devices. If the circuit device board ended up consuming a low amount of energy then the carbon-zinc based batteries may be very ideal for the module. Some other downsides to the carbon-zinc battery is that they do not withstand heat and cold very well. The Carbon-zinc battery does have its major advantages though: lost cost, a nice variety of different sizes and they are easily accessible from almost any hardware or component store like RadioShack or Sky craft. Alkaline batteries have almost replaced the use of carbon-zinc batteries because of advances in technology which lowered the cost of the alkaline battery.

3.3.1.3.2 Alkaline Primary Battery

Alkaline batteries have cells of 1.5V. Like the carbon-zinc, most of the alkaline battery types are general purpose. The alkaline battery has many advantages which is why it is a popular choice. When comparing the alkaline battery and the carbon-zinc battery, the alkaline has nearly double the energy density of the carbon-zinc. The capacity of the alkaline as compared to the Nickel Cadmium is four times greater. It also provides a constant capacity over a wide range of current drains, which is nice because the motor will be drawing in variable amounts of current at random times. Other advantages are that the alkaline battery has a relatively good shelf life and, it comes in a wide range of sizes including AA, AAA, C, D and 9V. Some of the disadvantages of the alkaline battery are that it can be sometimes more expensive than the carbon-zinc battery. Other disadvantages are that the weight is about 25% more than a carbon-zinc battery.

3.3.1.3.3 Silver Oxide Primary Battery

The next battery type to be considered is the silver oxide battery. Figure 3.3-2 shows what a typical silver oxide battery would look like. There are two kinds of silver oxide batteries that are commonly available at electronic stores like RadioShack. The first of which is made with a sodium hydroxide and the other with a potassium hydroxide. The sodium hydroxide typically last between two to three years which make them highly desirable for low power consumption applications. The life span of this battery is not a requirement for the project because in this project, it is assumed that the battery would be drained relatively fast due to the motor. This battery may be excellent for the scenario where it would be useful for multiple power supplies, and the sodium hydroxide battery could power the IC chips when tied with a voltage regulator. More discussion on the implementation of the battery with the rest of the components is in the design section of this report.
The other type of silver oxide battery is the potassium hydroxide. These battery types generally provide short bursts of high current drains that are required from applications like LCD watches with a backlight feature. Other electronics that use the potassium hydroxide include hearing aids, and electronic measuring equipment. As mentioned above, the silver oxide seems to be only good for small electronics that need minimal power requirements. It might be best to use the silver oxide when in need of multiple power supplies.

### 3.3.1.3.4 Lithium Primary Batteries

Lithium batteries are very common in almost all electronic stores and for good reason also. Lithium batteries provide the highest capacity of ampere-hours of all metals. Lithium batteries also offer many advantages over other common batteries like a longer life span, it being more reliable and the generally larger capacity. Below is a list of specifications given by [http://www.steatite.co.uk/batteries/battery_why_lithium.htm](http://www.steatite.co.uk/batteries/battery_why_lithium.htm) telling you to get choose a lithium battery if:

- A high voltage is needed (i.e. 3.0 to 3.9 volts per cell)
- A recharging circuit is not available or too costly
- The power source has to be as light weight as possible
- Long shelf life is required
- A wide temperature range is required
- Reliability is crucial
- Extremely high energy density is needed
- Environmental concerns such as temperature, vibration or shock are especially severe
- Your application demands a continuous source of power for extensive periods of time

### 3.3.1.4 Secondary Batteries (Rechargeable)

Secondary batteries offer many advantages just like the primary batteries. One of the more obvious advantages is the ability to recharge the battery to be able to use it multiple times. This ability is very useful because it will envitably lower the cost of the project over time by not having to replace the batteries so often, and it can also be used in conjunction with the
solar panel. The solar panel will only be used if and only if there is a rechargeable battery in the module. This does not mean that if a rechargeable battery is used, a solar panel must be used. The solar panel would be a luxury. Table 3.3.1-2 shows a series of different secondary battery specifications. In this section, the rechargeable batteries that will be considered are Lithium-ion batteries, and the Nickel Cadmium batteries.

Table 3.3-2: Secondary Battery Types

<table>
<thead>
<tr>
<th>Battery Type</th>
<th>Anode</th>
<th>Cathode</th>
<th>Maximum Voltage</th>
<th>Maximum Capacity</th>
<th>Working Voltage</th>
<th>Energy Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead-Acid</td>
<td>Pb</td>
<td>PbO2</td>
<td>2.1</td>
<td>55</td>
<td>2.0</td>
<td>37</td>
</tr>
<tr>
<td>Edison(Ni-Fe)</td>
<td>Fe</td>
<td>NiO</td>
<td>1.5</td>
<td>195</td>
<td>1.2</td>
<td>29</td>
</tr>
<tr>
<td>NiCad</td>
<td>Cd</td>
<td>NiO2</td>
<td>1.35</td>
<td>165</td>
<td>1.2</td>
<td>33</td>
</tr>
<tr>
<td>Silver-cadmium</td>
<td>Cd</td>
<td>AgO</td>
<td>1.4</td>
<td>230</td>
<td>1.05</td>
<td>55</td>
</tr>
<tr>
<td>Cadmium-air</td>
<td>Cd</td>
<td>Air(O2)</td>
<td>1.2</td>
<td>475</td>
<td>0.8</td>
<td>90</td>
</tr>
<tr>
<td>Silver-Zinc</td>
<td>Zn</td>
<td>AgO</td>
<td>1.85</td>
<td>285</td>
<td>1.5</td>
<td>100</td>
</tr>
<tr>
<td>Zinc-air</td>
<td>Zn</td>
<td>Air(O2)</td>
<td>1.6</td>
<td>815</td>
<td>1.1</td>
<td>150</td>
</tr>
</tbody>
</table>

3.3.1.4.1 Lithium-Ion Batteries

Lithium-ion batteries are a very common and well respected rechargeable battery type. This rechargeable battery would work well with the solar panel array to help recharge it. The lithium battery by itself could serve as the primary battery also. The energy density of the lithium-ion battery is twice as much as a nickel-cadmium battery type. The cell voltage is 3.6V which allows greater battery designs with the use of only one cell. Lithium batteries are also low maintenance, which eases the worry when completing the project and having to check the battery and figure out if it is in good shape or not. Table 3.3.1-3 shows different chemistries of the lithium ion battery and also what each associated nominal voltage is rated. This table will help in choosing which type of lithium-ion chemistry is needed for the module. The range of the voltages are from 3.2V which is the phosphate, to the highest being 3.8V which is the manganese. When choosing the right lithium-ion battery, considerations will be made from the cost of the battery.

Table 3.3-3: Lithium-Ion Chemistry Table

<table>
<thead>
<tr>
<th>Chemistry</th>
<th>Nominal V</th>
<th>Charge &amp; discharge C-rates</th>
<th>Energy density Wh/Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobalt</td>
<td>3.6 V</td>
<td>1C limit</td>
<td>110-190</td>
</tr>
<tr>
<td>Manganese</td>
<td>3.7-3.8 V</td>
<td>10C cont. 40C pulse</td>
<td>110-120</td>
</tr>
<tr>
<td>NCM (nickel-cobalt manganese)</td>
<td>3.7 V</td>
<td>5C cont. 30C pulse</td>
<td>95-130</td>
</tr>
<tr>
<td>Phosphate</td>
<td>3.2-3.3 V</td>
<td>35C cont.</td>
<td>95-140</td>
</tr>
</tbody>
</table>
Though the lithium-ion battery has many favorable features, it does have a few drawbacks that need to be taken into consideration. The battery is relatively fragile and requires a protection circuit to have it in a safe operation. This protection circuit also limits the peak voltage of the cells inside the battery. The web resource batteryuniversity.com gives these two lists of advantages and limitations for the lithium-ion battery:

**Advantages**

- High energy density - potential for yet higher capacities.
- Does not need prolonged priming when new. One regular charge is all that’s needed.
- Relatively low self-discharge - self-discharge is less than half that of nickel-based batteries.
- Low Maintenance - no periodic discharge is needed; there is no memory.
- Specialty cells can provide very high current to applications such as power tools.

**Limitations**

- Requires protection circuit to maintain voltage and current within safe limits.
- Subject to aging, even if not in use - storage in a cool place at 40% charge reduces the aging effect.
- Transportation restrictions - shipment of larger quantities may be subject to regulatory control. This restriction does not apply to personal carry-on batteries. (See last section)
- Expensive to manufacture - about 40 percent higher in cost than nickel-cadmium.
- Not fully mature - metals and chemicals are changing on a continuing basis.

3.3.1.4.2 **Nickel Cadmium Batteries**

Nickel cadmium batteries are good for big bursts of energy. It generally performs better when it is under high stress. This defining characteristic makes the nickel cadmium battery ideal for powering components such as the motor which require higher amounts of energy then the other low power components like the microcontroller or the metal detector. Some advantages of the Nickel cadmium is its high number of charge cycles, which makes it reliable up to 1000 charges if maintained properly. The battery is a strong and durable battery, and still performs well in unforgiving conditions. This could prove to be helpful if the vehicle hit a wall, or if another unfortunate event hit the battery, it would still give its rated performance. Nickel cadmium is also reasonably prices and comes in a wide range of sizes which makes it good when it comes to versatility. Limitations concerning the nickel cadmium is its low energy density, and its high self-discharge. The battery will be needed to be recharged after it has been stored.
3.3.2 Microcontrollers

3.3.2.1 Overview

A lot depends on the microcontroller (shortened MCU from now) inside the AMDV. It will connect to all the microelectronics and process all the incoming data from them. That’s why it’s crucial to pick the right one. Ideally, performance would be the number priority when picking an MCU however since the project is not being sponsored, cost is number one. MCU ICs don’t cost very much, usually not beyond $10. Their development boards, however, can range drastically in price. The following two MCUs were researched because both had development boards for under $30 and met the requirements outlined in the microcontroller specifications. These two MCUs are the MSP430 series and the Atmel ATMega328. A comparison between the two appears below in table 3.3.2-1 while each MCU is talked in detail in the following section. In the final microcontroller research section, the two’s development boards are compared and discussed.

Table 3.3-4: Microcontrollers Comparison Table

<table>
<thead>
<tr>
<th>Table 3.3-4: Microcontrollers Comparison Table</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MCU</strong></td>
</tr>
<tr>
<td>Company</td>
</tr>
<tr>
<td>Price</td>
</tr>
<tr>
<td>CPU Architecture</td>
</tr>
<tr>
<td>Flash Memory</td>
</tr>
<tr>
<td>EEPROM Memory</td>
</tr>
<tr>
<td>RAM</td>
</tr>
<tr>
<td>I/O Lines</td>
</tr>
<tr>
<td>Temperature Range</td>
</tr>
<tr>
<td>Operating Voltage</td>
</tr>
<tr>
<td>Power Consumption - Active</td>
</tr>
<tr>
<td>Power Consumption - Standby</td>
</tr>
<tr>
<td>Power Consumption - Off (RAM Retention)</td>
</tr>
<tr>
<td>Theoretical Max Power Consumption</td>
</tr>
<tr>
<td>Performance</td>
</tr>
<tr>
<td>Package</td>
</tr>
<tr>
<td>Dimensions</td>
</tr>
</tbody>
</table>
3.3.2.2 Texas Instruments 16-bit MSP430F2013 Microcontroller

The TI MSP430 microcontroller, picture below in figure 3.3-3, is meant to be a small, low cost, ultra-low power consuming MCU. This MCU came under consideration because of its extremely low implementation cost. $20 dollars pays for three chips and a USB thumb-like development board. Also, as the title suggests, it uses very little power, namely 2.2V and 220 µA both at 1 MHz. It also features numerous power-saving modes. These two power features will give our product a much longer battery life. The chip’s operating temperature range is very good. And since all the driving the AMDV is going to do is in the sun, it’s good to know the MCU can take the heat. Size wise, this chip will make very efficient use of the very limited mounting space in the vehicle frame, as it is incredibly tiny. It’s smaller than a thumbnail. Unfortunately, it will need this extra space as performance is not this chip’s middle name.

![Figure 3.3-3: Pinout of the MSP430 in a PDIP Package](image)

The use of additional memory chips and/or TI MSP430 chips may be required as a result of some of the underwhelming tech specs given. Firstly, 16-bit CPU @ 16MHz means it should be sufficient for one or two tasks in the AMDV, maybe just not everything at once. Secondly, the 2KB flash and 128B of RAM will not be a sufficient amount of memory alone to handle all of AMDV tasks. Finally, the 10 I/O ports, while able to be independently programmable, is just not a lot of total I/O ports. This is especially noticeable when compared to the ATmega328 and its 23 I/O ports. The low performance, small memory, and small amount of I/O ports really bring down the usefulness of this chip. The small price tag may not be enough to justify its use in the AMDV.

3.3.2.3 Atmel 8-bit AVR® ATMega328 Microcontroller with Arduino Bootloader

This MCU came under consideration due to the fact that the very similar ATMega168 was selected for the GNAC project. The ATMega328, pictured below in figure 3.3-4, is just like the ATMega168; only it has double the memory of the ATMega168. GNAC picked the
ATMega168 for its plentiful features, excellent documentation, and its relatively low implementation cost.

Figure 3.3-4: The ATMega328 in a DIP package

The ATMega328 offers several advantages over the MSP430 including more I/O pins, more memory, more performance, higher operating voltage, and far better 3rd party documentation. The ATMega328 has 23 I/O pins, 13 more than the TI MSP430. This will allow us to connect more devices to an individual microcontroller, decreasing the total number of MCUs needed. Next, this MCU has at least twice as much memory and as much as four more MIPS than the TI MCU. This will allow more complex programs to be run. The Atmel MCU also has a better operating voltage range and will allow DC power supply to keep its single line at 5V versus adding a second for 3.3V which would be necessary for the TI MCU. Finally the ATMega328 has a huge online following where it is used in multiple Do-It-Yourself projects. The popularity of the Atmel chip will make it far easier to program in the long run, since there is way more documentation available than the MSP430. The programming itself is done in the Arduino development environment which is based on C/C++, just like the MSP430, which was the preferred programming language set in the specifications section. These advantages give the Atmel ATMega328 a distinct edge over the TI MSP430.

3.3.2.4 Microcontroller Development Board Overview

As stated earlier, the development boards were considered more important than the IC when considering MCUs due to development board’s typical higher costs. Below in table 3.3.2-2 lists the development boards for the MCUs discussed above, after which will be two sections discussing each of the boards.
Table 3.3-5: Development Board Comparison

<table>
<thead>
<tr>
<th>Features/Name</th>
<th>eZ430-F2013</th>
<th>Arduino Dueilanove</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCU</td>
<td>TI MSP430</td>
<td>Atmel ATmega328</td>
</tr>
<tr>
<td>Cost</td>
<td>$20.00</td>
<td>$29.95</td>
</tr>
<tr>
<td>PC Connection</td>
<td>RS232/USB</td>
<td>USB</td>
</tr>
<tr>
<td>Power</td>
<td>USB</td>
<td>USB/DC Power Supply</td>
</tr>
<tr>
<td>Dimensions</td>
<td>~65(L) x 20(W) mm</td>
<td>68.6(L) x 53.3(W) mm</td>
</tr>
<tr>
<td>Site</td>
<td>ti-estore.com</td>
<td>SparkFun</td>
</tr>
</tbody>
</table>

3.3.2.5 MSP430 USB Stick Development Tool (eZ430-F2013)

The benefits of the MSP430 USB stick development kit shown above are fivefold: price, interface, documentation, popularity, and programming language. First, it comes at the low, low price of $20 as mentioned above. Second, it comes in a handy dandy USB interface disguised as in a thumb drive form factor. Next, a quick Google search of “MSP430 guide” yielded numerous and useful 3rd party tutorials and forums, showing the popularity of this MCU. The manufacturer also provides great documentation in a CD-ROM included with the kit (which is also available as a PDF on TI’s website). Finally, the ability to code in C is a major plus since the AMDV team is already familiar with the language. This will allow more time to be spent on polishing the software. This cheap development kit is really the strongest selling point for the underpowered MSP430.
3.3.2.6 Arduino Duemilanove USB Development Board

Figure 3.3-6: Arduino Duemilanove

The Arduino platform, of which the Duemilanove is the latest family member of, is a lot of what makes the ATMega328 so special. It can be argued that much of the popularity of the ATMega168/328 is due to the platform. Straight from their website, the “Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It's intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments.” The open source nature produces mounds of immediate, free information and a low price tag for the development board, as it is meant for people with not a lot of money. This website is full of tutorials, downloads, links, and FAQs for the platform. SparkFun, the website where the development board and the MCU would be purchased for a low price of $29.95 and $5.50 respectively, also hosts plenty of useful information regarding the platform. This will all make programming and acquiring the parts much easier and painless. This latest board, pictured above in figure 3.3-6, adds the capability to automatically detect whether power is hooked through the USB or the DC power cable and switch to appropriate one.

3.3.3 GPS

Many different GPS boards and receivers exist on the market that may be suitable for use with this project. After researching different products from different manufactures, a concern arose that some GPS boards did not include the actual GPS receiver. This has been addressed by implementing an additional requirement that the GPS board must have an on-board GPS receiver. Out of the many GPS boards available that meet this requirement, a few have been selected as possible candidates for use in this project. Additional research was
done to determine these boards overall compatibility in regards to their specifications and conformity to the projects specifications. The GPS receivers listed in Table 3.3.3 have been evaluated as meeting the basic criteria set forth in the project definition sections of this report. They also all support state-of-the-art GPS technology such as WAAS and 3 of the below use top-of-the-line chipsets. These boards were manufactured by USGlobalSat Incorporated or by Locosys Technology.

Table 3.3-6: Comparison of GPS Modules

<table>
<thead>
<tr>
<th></th>
<th>EM-406a</th>
<th>EM-408</th>
<th>ET-112</th>
<th>LS20031</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chipset</strong></td>
<td>SiRF StarIII/LP Single</td>
<td>SiRF StarIII/LP Single</td>
<td>SiRF GSC2X Single</td>
<td>MediaTek MT3318</td>
</tr>
<tr>
<td><strong>Number of Channels</strong></td>
<td>20</td>
<td>20</td>
<td>12</td>
<td>32</td>
</tr>
<tr>
<td><strong>SBAS Used</strong></td>
<td>WAAS, EGNOS, MSAS</td>
<td>WAAS, EGNOS, MSAS</td>
<td>WAAS, EGNOS, MSAS</td>
<td>WAAS, EGNOS, MSAS</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td>5 meters (WAAS)</td>
<td>5 meters (WAAS)</td>
<td>5 meters (WAAS)</td>
<td>3 meters (WAAS)</td>
</tr>
<tr>
<td><strong>Cold Start Acquisition Time (seconds)</strong></td>
<td>42</td>
<td>42</td>
<td>48</td>
<td>36</td>
</tr>
<tr>
<td><strong>Hot Start Acquisition Time (seconds)</strong></td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td><strong>Operating Voltage (DC)</strong></td>
<td>4.5 – 6.5</td>
<td>3.3 + - 5%</td>
<td>3.8 – 6.5</td>
<td>3.3</td>
</tr>
<tr>
<td><strong>Voltage Ripple Tolerance</strong></td>
<td>0.1V</td>
<td>0.1V</td>
<td>0.1V</td>
<td>---</td>
</tr>
<tr>
<td><strong>Power Consumption (mA)</strong></td>
<td>44</td>
<td>44</td>
<td>42</td>
<td>---</td>
</tr>
<tr>
<td><strong>Battery Backup</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Interface Type</strong></td>
<td>6-pin connector</td>
<td>5-pin connector</td>
<td>20-pin connector</td>
<td>5 solder pads</td>
</tr>
<tr>
<td><strong>Data Type</strong></td>
<td>TTL</td>
<td>TTL</td>
<td>TTL</td>
<td>TTL</td>
</tr>
<tr>
<td><strong>External Antenna Port</strong></td>
<td>No</td>
<td>Yes, MMCX</td>
<td>Yes, MCX</td>
<td>No</td>
</tr>
<tr>
<td><strong>Dimensions (mm)</strong></td>
<td>30 x 30 x 10.5</td>
<td>36.4 x 35.4 x 8.3</td>
<td>71 x 40.5 x 10</td>
<td>30 x 30</td>
</tr>
<tr>
<td><strong>Supported Output Messages</strong></td>
<td>GGA, GGL, GSA, GSV, VTG, RMC</td>
<td>GGA, GSA, GSV, RMC, VTG, GLL</td>
<td>GGA, GSA, GSV, RMC, VTG, GLL</td>
<td>GGA, GLL, GSA, GSV, RMC, VTG</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>$46.99</td>
<td>$47.99</td>
<td>$43.99</td>
<td>$59.95</td>
</tr>
</tbody>
</table>
3.3.4 Sensors

There are a number of different sensors which would have been suitable for use in this project in regards to obstacle detection. After researching many different technologies for obstacle detection, the two primary technologies which appear to be most suited for our application are infrared (IR) and ultrasonic. An issue relating to this project that arose between the different technologies was their use outdoors. For this reason, most light detecting technologies cannot be used. An exception to this is a Sharp IR detector; it has been proven to have some success outdoors in limited sunlight. The obstacle detection/ranging sensors listed in the table below (Table 3.3.4 – 1) have been evaluated as meeting the basic criteria set forth in the project definition sections of this report. These sensors appear to be the most widely used for obstacle avoidance and range detection in small scale robotic projects.

<table>
<thead>
<tr>
<th>Technology</th>
<th>PARALLAX PING))</th>
<th>Maxbotix LV-EZ1</th>
<th>Devantech SRF04</th>
<th>Sharp GP2Y0A21YK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can Use in Sunlight?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Limited</td>
</tr>
<tr>
<td>Supply Voltage</td>
<td>5 +/- 10%</td>
<td>2.5 – 5.5</td>
<td>5</td>
<td>4.5 – 5.5</td>
</tr>
<tr>
<td>Minimum Distance</td>
<td>2 cm</td>
<td>6 in</td>
<td>3 cm</td>
<td>10 cm</td>
</tr>
<tr>
<td>Maximum Distance</td>
<td>3 m</td>
<td>254 in</td>
<td>3 m</td>
<td>80 cm</td>
</tr>
<tr>
<td>Connections</td>
<td>Vdd, Vss, 1 I/O pin</td>
<td>RS232, Analog, PWM</td>
<td>Pulse TTL, Echo Output, Vcc, GND</td>
<td>Vo, Vcc, GND (JST)</td>
</tr>
<tr>
<td>Dimensions</td>
<td>22 x 46 x 16 (mm)</td>
<td>19.9 x 22.1 x 16.4 (mm)</td>
<td>0.78 x 1.70 x 0.54 (in)</td>
<td>---</td>
</tr>
<tr>
<td>Cost</td>
<td>$29.99</td>
<td>$24.95</td>
<td>$29.50</td>
<td>$9.95</td>
</tr>
</tbody>
</table>

3.3.5 Voltage Regulators

3.3.5.1 Introduction

The voltage regulator will be needed in most of the components that have a power supply. The DC voltage regulator ensures that the circuit will have a constant voltage source even when the supply voltage may be varying. These can prove to be very useful because it will reduce our erroneous readings and measurements due to variable voltage inputs.

In most applications, linear regulators are the most popular choice when maintaining a voltage is needed. The IC versions of the linear regulator are cheap and very easy to use. Also, the linear regulator is available at most electronic stores.
Research on each of the specifications needs to be explained to fully utilize max efficiency of the circuit. The maximum load current will ensure that the circuit will have sufficient current flowing throughout when at its worst operating conditions.

Depending on whether a DC or an AC is chosen, there are two ideal regulators that need to be considered. First, if a DC source is used a typical Low Dropout (LDO) regulator is needed. LDO regulators are able to fully utilize the input voltage and it is also able to operate longer when the battery goes into its discharge cycle. However, if the input voltage is AC, the LDO regulator is not as useful. In most cases, a standard regulator would suffice for the application but there has been new LDO regulator technology that will make the LDO still effective even in an AC situation.

The output voltage tolerance usually is not a big factor in the overall design of the circuit, but it is worth mentioning because it still needs to be considered to be as accurate as possible for the project overall. Normal tolerances are 5% or below, which is acceptable for the project at hand. There are, however, better regulators that can give tighter tolerances from below 2% which are sometimes common in the new regulators.

The quiescent current (idling current) draws from the source when in the ‘off’ mode. This idling current needs to be as low as possible to ensure longevity of the power supply. A grim foreshadowing example would be when testing the project multiple times before the final presentation; the quiescent current was slowing draining the battery. The obvious result is when it was time to face the colors, the machine didn’t turn on, and due to a small quiescent current that was slowly draining the battery life within the two weeks of testing. Luckily, many of the new LDO regulators are optimized for low idling currents from the range of 75-120uA. The specific regulators that will be researched are the LM7805, DE-SW050, and the LM317.

### 3.3.5.2 LM7805 3-Terminal 5 Volt 1A Regulators

Given the specifications above, the LM7805 qualifies for most of the considerations needed. First, the output voltage is 5 voltages. These regulators are designed as fixed regulators making them very ideal for the project. Below is a brief list of features offered in the LM 7805 Voltage Regulator:

- Output Current up to 1A
- Output Voltage of 5V
- Thermal Overload Protection
- Short Circuit Protection
- Output Transistor Safe Operating Area Protection

Other specifications are it only contains three pins which makes it small enough to not have to worry about space restrictions. Its voltage tolerance is 4%, which is lower than that maximum tolerance given in our project requirements. The one downfall of this regulator is the quiescent current, which is typically 5.0mA with the max quiescent current being as high as 8mA. This may or may not present a problem when it comes to testing each specification.
The worst case would be to just have extra batteries on hand. Figure 3.3-7 shows a typical application for the LM7805 voltage regulator.

**Figure 3.3-7: LM78MXX Voltage Regulator**

![LM78MXX Voltage Regulator Diagram](image)

*Permission pending from national semiconductors*

### 3.3.5.3 DE-SW050 Switching Voltage Regulator

The DE-SW050 is pretty much like the LM9805 but on steroids. This voltage regulator offers a plethora of features that are very appealing, but also come at a steep cost. Below is a list of features provided by the regulator:

- Drop-in replacement for LM78XX
- Up to 30V input voltage
- 1.3V dropout voltage
- 3.3V and 5V output voltages available
- 1A continuous output current
- Efficiency up to 87%
- Integrated bypass capacitors
- Integrated heat spreader
- Weighs only 3.8g
- Can drive inductive loads

To provide an in-depth view of what the DE-SW050 can offer, Table 3.3.5-1 shows a detailed characteristic chart which includes everything needed to running the qualification test for the project at hand.
### Table 3.3-8: Characteristics of the DE-SW050

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Min</th>
<th>Typical</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>Vout+1.3V</td>
<td>--</td>
<td>30V</td>
</tr>
<tr>
<td>Output Current (RMS)</td>
<td>0A</td>
<td>--</td>
<td>1A</td>
</tr>
<tr>
<td>Pulsed Output Current (5 sec)</td>
<td>--</td>
<td>--</td>
<td>1.5A</td>
</tr>
<tr>
<td>Output Ripple</td>
<td>30mV</td>
<td>70mV</td>
<td>100mV</td>
</tr>
<tr>
<td>Efficiency (See Figure 2 and Figure 3)</td>
<td>65%</td>
<td>83%</td>
<td>87%</td>
</tr>
<tr>
<td>Transient response in load regulation (0-1A pulses, 1ms, Vp-p)</td>
<td>--</td>
<td>4%</td>
<td>--</td>
</tr>
<tr>
<td>Power dissipation</td>
<td>100mW</td>
<td>800mW</td>
<td>1.2W</td>
</tr>
<tr>
<td>Power output in still air</td>
<td>0W</td>
<td>--</td>
<td>5W</td>
</tr>
<tr>
<td>Quiescent current draw (Vin = 12V)</td>
<td>--</td>
<td>16mA</td>
<td>--</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>230kHz</td>
<td>270kHz</td>
<td>290kHz</td>
</tr>
</tbody>
</table>

Conclusions from the above are first, the quiescent current is twice that of the LM9850, and the efficiency is only 83%. This product would be useful if that project needed variable voltage regulators without placing multi fixed regulators on the circuit board.

#### 3.3.5.4 LM317T Variable Voltage Regulator

The LM317T regulator is a commonly used variable regulator. They are able to supply a wide range of voltage, from 1.2V to 37V. Additionally, both line and load regulations are better than standard fixed regulators. The LM317 comes in a standard transistor package and are easily mounted. Other features that make the LM317 more attractive as compared to even standard fixed regulators, is its higher performance and a series of full overload protection. This regulator can take up to several hundred voltages by keeping the input-to-output differential below the maximum threshold. Below is a list of features provided with the LM317:

- Guaranteed 1% output voltage tolerance
- Guaranteed max. 0.01%/V line regulation
- Guaranteed 1.5A output current
- Adjustable output down to 1.2V
- Current limit constant with temperature
- 80dB ripple rejection
- Output is short-circuit protected
3.3.6 LED

3.3.6.1 Introduction

The LED is a small component but is needed to identification purposes for the project. The current conventional LED colors are Red, Yellow, Orange, Green, Blue, Violet, Purple, Ultraviolet, and White. The LED will need to be bright enough to be able to be seen from a distance. A normal LED that you would commonly see from a stud finder or a home stereo set will not be bright enough to be seen from a distance. The specifications spelled out for the LED are in section 2.0. This section of the research process will consider these three colors: Red, Green, and White. For the White LED, two types of be considered. For the white LED, the RL5-W8045 and the RL5-W18030 will be considered. For the red LED the RL5-R8030, and the RL5-3545. For the Green LED, the RL5-G7532 and the RL5-G8045. All the LEDs mentioned have a greater luminosity then normal LEDs which should hopefully be seen from the 30 feet away given in the Specs. The reason why the color green, white, and red were chosen is because the group feels as if these colors will be best seen in the daylight without too much trouble. When the LED is being powered on, we must protect the LED from

\[ V_{\text{OUT}} = 1.25 V \left( 1 + \frac{R_2}{R_1} \right) + I_{\text{ADJ}}(R_2) \]

Permission pending from National Semiconductor
damage by placing a resistor in series with the LED. The resistor value can be easily chosen by using the simple equation $R = (V_{Source} - V_{LED})/I_{LED}$.

### 3.3.6.2 RL5-W8045

The RL5-W8045 is a super white LED with a luminosity of 8000 mcd with the forward current is greater than 20mA. The typical voltage needed to power the LED is 3.5V. The number 45 in the W8045 serial number represents the viewing angle of the LED. 45 degrees is a very acceptable viewing angle and will be highly appealing when choosing the final LED. Table 3.3.6-1 shown below shows the parameters of the RL5-W8045. Using the equation given in the introduction, we can determine the resistor needed to protect this LED from high voltage damage.

$$R = (V_{Source} - V_{LED})/I_{LED}$$

Let $V_{source} = 5V$, $V_{LED}=3.5V$, and $I_{LED}=20ma$

From the equation above, if you plug in all the values given, the resistor value needed will be equal to 75ohms.

### Table 3.3-9: -W8045 - Super-White LED

<table>
<thead>
<tr>
<th>Part Number: RL5-W8045 - Super-White LED (InGaN on GaN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>absolute maximum ratings: (TA=25°C)</td>
</tr>
<tr>
<td>PARAMETER</td>
</tr>
<tr>
<td>Power Dissipation</td>
</tr>
<tr>
<td>Continuous Forward Current</td>
</tr>
<tr>
<td>Peak Forward Current (1/10th duty cycle, 0.1ms pulse width)</td>
</tr>
<tr>
<td>Reverse Voltage</td>
</tr>
<tr>
<td>Operating Temperature</td>
</tr>
<tr>
<td>Storage Temperature</td>
</tr>
<tr>
<td>Reverse Current (VR=5V)</td>
</tr>
</tbody>
</table>

### 3.3.6.3 RL5-W18030

The RL5-W18030 is a super white LED with a luminosity of 18000 mcd with the forward current is greater than 20mA. The typical voltage needed to power the LED is 3.4V. The RL5-W18030 has a viewing angle of only 30, which is a little but less than the 45 degree viewing angle, but it is still in tolerable levels for the project at hand. Table 3.3.6-2 shown below shows the parameters of the RL5-W18030. Using the equation given in the introduction, we can determine the resistor needed to protect this LED from high voltage damage.

$$R = (V_{Source} - V_{LED})/I_{LED}$$

Let $V_{source} = 5V$, $V_{LED}=3.4V$, and $I_{LED}=20ma$
From the equation above, if you plug in all the values given, the resistor value needed will be equal to 80ohms.

Table 3.3-10: RL5-W18030 - Super-White LED

| Part Number: RL5-W18030 - Super-White LED (GaN/InGaN) |
|-------------------------------|-------------------|------------------|
| PARAMETER                     | SYMBOL | RATING | UNIT |
| Power Dissipation             | PD     | 120    | mW   |
| Continuous Forward Current    | IF     | 30     | mA   |
| Peak Forward Current (1/10th duty cycle, 0.1ms pulse width) | IFM | 70 | mA |
| Reverse Voltage               | VR     | 5      | V    |
| Operating Temperature         | TA     | -25~+80 | °C |
| Storage Temperature           | TSTG   | -30~+100 | °C |
| Reverse Current (VR=5V)       | IR     | 100    | µa   |

3.3.6.4 RL5-R8030

The RL5-R8030 is a super red LED with a luminosity of 8000 mcd when the forward current is greater than 20mA. The typical voltage needed to power the LED is 2.2V. The voltage is significantly lower than the white LEDs which make it more desirable. The RL5-R8030 has a viewing angle of only 30, which like the RL5-W18030 is still in tolerable levels for the project at hand. Table 3.3.6-3 shown below shows the parameters of the RL5-R8030. Using the equation given in the introduction, we can determine the resistor needed to protect this LED from high voltage damage.

\[
R = \frac{(V_{\text{source}} - V_{\text{LED}})}{I_{\text{LED}}} ; \quad \text{Let } V_{\text{source}} = 5V, \quad V_{\text{LED}}=2.2V, \quad \text{and} \quad I_{\text{LED}}=20\text{mA}
\]

From the equation above, if you plug in all the values given, the resistor value needed will be equal to 140ohms.

Table 3.3-11: RL5-R8030 - Super-Red LED

| Part Number: RL5-R8030 - Super-Red LED (AlGaNp) |
|-------------------------------|-------------------|------------------|
| PARAMETER                     | SYMBOL | RATING | UNIT |
| Power Dissipation             | PD     | 80     | mW   |
| Continuous Forward Current    | IF     | 20     | mA   |
| Peak Forward Current (1/10th duty cycle, 0.1ms pulse width) | IFM | 50 | mA |
| Reverse Voltage               | VR     | 5.0    | V    |
### 3.3.6.5 RL5-R3545

The RL5-R3545 is a super red LED with a luminosity of only 3500 mcd when the forward current is greater than 20mA. The typical voltage needed to power the LED is 2.2V. The voltage is again significantly lower than the white LEDs. From looking at these two Red LEDs alone, the specification require of low power consumption is currently being won by the super light emitting red LED. The RL5-R3545 has a viewing angle of 45, which makes it a very valuable player in the decision process. Its only downfall as of right now is the 3500 mcd which may or may not be able to be seen from a distance of 30 feet. Table 3.3.6-4 shown below shows the parameters of the RL5-R8030. Using the equation given in the introduction, we can determine the resistor needed to protect this LED from high voltage damage.

\[
R = \frac{(V_{source} - V_{LED})}{I_{LED}}; \quad \text{Let } V_{source} = 5V, \quad V_{LED}=2.2V, \text{ and } I_{LED}=20mA
\]

From the equation above, if you plug in all the values given, the resistor value needed will be equal to 140ohms.

#### Table 3.3-12: RL5-R3545 - Super-Red LED

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>RATING</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Dissipation</td>
<td>PD</td>
<td>80</td>
<td>mW</td>
</tr>
<tr>
<td>Continuous Forward Current</td>
<td>IF</td>
<td>20</td>
<td>mA</td>
</tr>
<tr>
<td>Peak Forward Current (1/10th duty cycle, 0.1ms pulse width)</td>
<td>IFM</td>
<td>50</td>
<td>mA</td>
</tr>
<tr>
<td>Reverse Voltage</td>
<td>VR</td>
<td>5.0</td>
<td>V</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>TA</td>
<td>-40~+85</td>
<td>°C</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>TSTG</td>
<td>-40~+85</td>
<td>°C</td>
</tr>
<tr>
<td>Reverse Current (VR=5V)</td>
<td>IR</td>
<td>10</td>
<td>μa</td>
</tr>
</tbody>
</table>

### 3.3.6.6 RL5-G7532

The RL5-G7532 is a super green LED with a luminosity of 7500 mcd with the forward current is greater than 20mA. The typical voltage needed to power the LED is 3.6V. This voltage is higher than both the red and the white LED, making it fall on the wayside in desirability. The number 45 in the W8045 serial number represents the viewing angle of the LED. The RL5-G7532 has a viewing angle of 32 degrees which is an odd angle considering the above viewing angles were only 45 and 30. With the case of it being 32 degrees, this is still an acceptable range given that the mcd level is 7500. Table 3.3.6-5 shown below shows
the parameters of the RL5-G7532. Using the equation given in the introduction, we can determine the resistor needed to protect this LED from high voltage damage.

\[ R = \frac{(V_{\text{Source}} - V_{\text{LED}})}{I_{\text{LED}}} \]

Let \( V_{\text{source}} = 5\text{V} \), \( V_{\text{LED}}=3.6\text{V} \), and \( I_{\text{LED}}=20\text{mA} \)

From the equation above, if you plug in all the values given, the resistor value needed will be equal to 70ohms.

### Table 3.3-13: RL5-G7532 - Super-Green LED

<table>
<thead>
<tr>
<th>Part Number: RL5-G7532 - Super-Green LED (GaN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>absolute maximum ratings: (TA=25°C)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>RATING</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Dissipation</td>
<td>PD</td>
<td>100</td>
<td>mW</td>
</tr>
<tr>
<td>Continuous Forward Current</td>
<td>IF</td>
<td>20</td>
<td>mA</td>
</tr>
<tr>
<td>Peak Forward Current (1/10th duty cycle, 0.1ms pulse width)</td>
<td>IFM</td>
<td>50</td>
<td>mA</td>
</tr>
<tr>
<td>Reverse Voltage</td>
<td>VR</td>
<td>5</td>
<td>V</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>TA</td>
<td>-40~+85</td>
<td>°C</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>TSTG</td>
<td>-40~+85</td>
<td>°C</td>
</tr>
<tr>
<td>Reverse Current (VR=5V)</td>
<td>IR</td>
<td>10</td>
<td>µa</td>
</tr>
</tbody>
</table>

#### 3.3.6.7 RL5-G8045

The RL5-G8045 is a super white LED with a luminosity of 8000 mcd with the forward current is greater than 20mA. The typical voltage needed to power the LED is 3.5V. The number 45 in the G8045 serial number represents the viewing angle of the LED. 45 degrees is a very acceptable viewing angle and will be highly appealing when choosing the final LED. In terms of voltage rating and viewing angle, the RL5-G8045 is exactly the same as the RL5-W8045 given the color difference. In the introduction, the ideal LED will have to be seen outside in daylight, making the green LED more preferable over the white LED. Table 3.3.6-6 shown below shows the parameters of the RL5-G8045. Using the equation given in the introduction, we can determine the resistor needed to protect this LED from high voltage damage.

\[ R = \frac{(V_{\text{Source}} - V_{\text{LED}})}{I_{\text{LED}}} \]

Let \( V_{\text{source}} = 5\text{V} \), \( V_{\text{LED}}=3.5\text{V} \), and \( I_{\text{LED}}=20\text{mA} \)

From the equation above, if you plug in all the values given, the resistor value needed will be equal to 75ohms.
### Table 3.3-14: RL5-G8045 - Super-Green LED

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>RATING</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Dissipation</td>
<td>PD</td>
<td>80</td>
<td>mW</td>
</tr>
<tr>
<td>Continuous Forward Current</td>
<td>IF</td>
<td>30</td>
<td>mA</td>
</tr>
<tr>
<td>Peak Forward Current (1/10th duty cycle, 0.1ms pulse width)</td>
<td>IFM</td>
<td>100</td>
<td>mA</td>
</tr>
<tr>
<td>Reverse Voltage</td>
<td>VR</td>
<td>5</td>
<td>V</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>TA</td>
<td>-20~+85</td>
<td>°C</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>TSTG</td>
<td>-30~+85</td>
<td>°C</td>
</tr>
<tr>
<td>Reverse Current (VR=5V)</td>
<td>IR</td>
<td>10</td>
<td>µa</td>
</tr>
</tbody>
</table>

| absolute maximum ratings: (TA=25°C) |

3.3.7 H-Bridge

#### 3.3.7.1 Introduction

Research of the H-bridge is needed to be able to control the direction of the motor through specifically designed circuitry. The microcontroller will be connected directly to the selected H-Bridge to give directly control to the reverse mode and the forward mode of the motor. Using the H-Bridge is one of the most common ways to control different polarities of a voltage, and will be especially useful for the project at hand. H-Bridges are commonly used on DC motors, which is exactly the type of application we have to be considered. Figure 3.3-9 shows a basic example of how the polarity of the motor would be switched using an H-Bridge.

![Figure 3.3-9: H-Bridge Configuration](image)

*(Courtesy of Cyril BUTTAY)*

In Figure 3.3-9 the H-Bridge shows the steps to reverse the polarity of the motor. The picture on the left shows the switches to be closed to have the motor operate in the positive, or forward, direction while the picture on the right shows how the motor would be operated in the negative, or reverse, direction. H-bridges can be implemented in many different ways. They can be made using discrete components such as transistors, field effect transistors, or any kind of solid state device. Another way these bridges can be made is by using multiple...
3.3.7.2 H-Bridge Using Relays

In Figure 3.3-10, a sketch of an H-bridge being implemented by using only relays is shown. In Figure 3.3-10, they use an example of implementing a logical one by using 12 volts. When the motor is to be in the forward position, the A relay and the D relay needs to be a closed switch. This would provide a completed circuit for which the current to flow in the respective forward direction. For the motor to operate in the reverse direction, the relay B and relay C need to be a closed switch. With both of these relays activated, the motor will operate in the reverse direction, respectively.

![Figure 3.3-10: H-Bridge using Relays](image)

The use of relays is very simple in design and can be easily controlled by a common MCU processor. One of the disadvantages observed is the size of the relay and how much space it may take on the circuit board. Because of the limited size given on the circuit board, the H-bridge configuration needs to be as small and compact as possible to fit other components that are apart of the project.

3.3.7.3 H-Bridge Using Solid State Devices

Other ways to implement the H-Bridge is by using semiconductor or a type of solid state device. Semiconductors can better implement the design of the H-bridge when compared to...
the H-Bridge. Figure 3.3-11 shows a simple schematic of how the H-Bridge would be connected using transistors. Neglected from the research report on the relays was the need of diodes across from the inductors to reduce the back EMF. With the transistors, the diodes will need to be put across the PNP and NPN, one on each side. The PNP in this design will act as the high side or the “source” while the NPN will act as the low side or the “sink”. As with the relays, the transistor model of the H-Bridge can also be directly controlled by a MCU processor. In Figure 3.3-11, dprg.org uses the source to be 12V which isn’t realistic in what the project at hand calls for. It would be more realistic that the supply side or the high course will be in between 5 and 9 volts. Moving on with the operation of the transistor model, when both of the high side terminals, A-PNP and the B-PNP are in the high mode, the motor will resist turning effectively acting as a brake. The same is true when both the low side terminals, C-NPN and the D-NPN, are activated. For the motor to operate in the forward direction, the A-PNP and the D-NPN will have to be activated. Similarly, for the motor to operate in the reverse or backward direction, the B-PNP and the C-NPN will have to be activated.

**Figure 3.3-11: H-Bridge Implemented using transistors**

A couple issues arise when considering a transistor model for the H-Bridge. The first issue is that the transistor has some resistance to it so it will get hot after a given time. A way to counter this is to use N mosfets and P mosfets. The counter itself presents a problem because of cost. N mosfets itself are relatively cheap to purchase but the P mosfets can get expensive.  

---

A B C D Function
---
---
1 0 0 1 Forward
0 1 1 0 Reverse
1 1 0 0 Brake
0 0 1 1 Brake
1 1 0 0 Fuse test :)  
0 1 0 1 Fuse test :)  
Don’t do the fuse tests

**Pending permission request from dprg.org**
Research involving the H-Bridge will be centered on the list of specifications laid out in Section 2.4.

3.3.7.4 H-Bridge Using Integrated Circuit Chips

Using transistors and relays both cause the same foundation problem of taking up too much space on the circuit board. Though transistors are considerably smaller, the use of IC chips will be the most beneficial and cost efficient way for controlling the H-Bridge. The IC chips will be able to handle a wide range of supply voltage, well within the limits without having to worry about it overheating. Also, the IC chip provides versatility given one could easily change the design on the H-Bridge without having to move multiple components around and raising the chance of causing human error. The IC chips for the H-Bridges they will be considered are the L293B, FAN8200, and the LMD18201.

3.3.7.4.1 L293B H-Bridge

The L293B is a quadruple push-pull driver that is able to output 1A per channel. Each of the channels is able to be controlled by a TTL compatible logic input. Also, there is a separate voltage supply input to provide the logic so it can run off of a lower voltage. The L293 B will be able to control four dc motors in one direction or, it has the ability to control two dc motors in forward and reverse direction.

![Figure 3.3-12: L293B Common Motor Hook Up](Permission pending from ST.com)

The features of the H-Bridge are all highly needed for the operation of our project. But unfortunately comes at a price. The L293B is currently running at around $6.27. The downfall about this is that there would only be one shot to test it and if a mistake happened in the lab, the price of getting a replacement may add-up. With the quad ability of this H-Bridge, since the project is projected to have only one motor, use of ‘one’ H-Bridge can be the tester while the other could act as the backup in the case that the first should fail.
A feature list given on the datasheet of the L293B is as follows:

- Output Current 1A per channel
- Peak output current at 2A per channel
- Inhibit facility
- High noise immunity
- Separate logic supply
- Overtemperature supply

**Table 3.3-15: Absolute Maximum Ratings for the L293B**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vs</td>
<td>Supply Voltage</td>
<td>36</td>
<td>V</td>
</tr>
<tr>
<td>Vss</td>
<td>Logic Supply Voltage</td>
<td>36</td>
<td>V</td>
</tr>
<tr>
<td>Vi</td>
<td>Input Voltage</td>
<td>7</td>
<td>V</td>
</tr>
<tr>
<td>Vinh</td>
<td>Inhibit Voltage</td>
<td>7</td>
<td>V</td>
</tr>
<tr>
<td>Iout</td>
<td>Peak Output Current</td>
<td>2</td>
<td>A</td>
</tr>
<tr>
<td>Ptot</td>
<td>Total Power Dissipation</td>
<td>5</td>
<td>W</td>
</tr>
<tr>
<td>Tstg</td>
<td>Storage and Junction Temperature</td>
<td>-40 to +150</td>
<td>C</td>
</tr>
</tbody>
</table>

**3.3.7.4.2 FAN8200 H-Bridge**

The FAN8200 is a little more versatile than the L293B. They are very similar in the way that they both have a dual H-Bridge configuration. The FAN8200 mentions that the H-Bridges are built inside the chip using two vertical PNP power transistors which will lower the power consumption of the H-Bridge. This H-bridge is versatile because it can be used for a multitude of applications besides the application of the stepping motor. Figure 3.3-13 shows a typical set-up of how the FAN8200 can be used to control two different motors.
As Figure 3.3.7-5 shows, the set-up is rather simple to implement and operate the H-Bridge. There is a huge appeal of choosing the FAN8200 over the L293 because of the price listed. Currently on jameco.com, the price for the FAN8200 is set at $0.63. This is a far better price than the $6.00 L293B. At that price, the testing could afford to lose multiple H-Bridges due to overheating or just bad connections. The feature set on the FAN8200 is as follows:

- 3.3V and 5V MPU interface
- Dual H-Bridge drivers for bipolar stepping motor drivers
- Built-in vertical-PNP power transistors
- Wide supply voltage range (Vcc=2.5V~7.0V)
- Low saturation voltage (0.4V@0.4A)
- Built-in chip enable function for each bridge
- Built-in shoot-through current protection
- Built-in thermal shutdown(TSD) function
Table 3.3-16: Maximum Ratings for the FAN8200 (Ta = 25°C)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage</td>
<td>$V_{CC,(MAX)}$</td>
<td>9.0</td>
<td>V</td>
</tr>
<tr>
<td>Power supply voltage</td>
<td>$V_{S,(MAX)}$</td>
<td>9.0</td>
<td>V</td>
</tr>
<tr>
<td>Output voltage</td>
<td>$V_{OUT,(MAX)}$</td>
<td>$V_{S} + V_{CF}$</td>
<td>V</td>
</tr>
<tr>
<td>Input voltage</td>
<td>$V_{IN,(MAX)}$</td>
<td>7.0</td>
<td>V</td>
</tr>
<tr>
<td>Peak output current per channel</td>
<td>$I_{O,(PEAK)}$</td>
<td>1</td>
<td>A</td>
</tr>
<tr>
<td>Continuous output current per channel</td>
<td>$I_{O}$</td>
<td>0.65 (FAN8200)</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.4 (FAN8200D)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.55 (FAN8200MTC)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.35 (FAN8200MP)</td>
<td></td>
</tr>
<tr>
<td>Power dissipation</td>
<td>$P_{D,(NEW)}$</td>
<td>1.0 (FAN8200)</td>
<td>W</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.6 (FAN8200D)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.87 (FAN8200MTC)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.8 (FAN8200MP)</td>
<td></td>
</tr>
<tr>
<td>Junction temperature</td>
<td>$T_{J}$</td>
<td>150</td>
<td>°C</td>
</tr>
<tr>
<td>Storage temperature</td>
<td>$T_{STG}$</td>
<td>-40 ~ 125</td>
<td>°C</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>$T_{A}$</td>
<td>-20 ~ 75 (FAN8200)</td>
<td>°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-20 ~ 75 (FAN8200D)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-20 ~ 75 (FAN8200MTC)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-30 ~ 80 (FAN8200MP)</td>
<td></td>
</tr>
</tbody>
</table>

3.3.7.4.3 LMD18201 H-Bridge

The LMD18201 H-Bridge is National Semiconductors version of the H-Bridge IC chip. The application type given on the National Semiconductor datasheet site tells use of this chip for motion control cameras, hence the high amperes outputted. Nevertheless, this h-bridge can still be used for a simple DC motor design. A main apparent advantage of the LMD18201 is that the high amperes will provide a lot of power to the motor having it create more torque. Figure 3.3.7-5 shows a simple schematic of how the LMD18201 would be implemented with a DC motor.
The LMD18201 doesn’t come cheap. Current listings put the LMD at around $9.00. The performance is why you’re paying the increase price. As compared to the L293B, it is $3.00 more but it comes with more thresholds. It’s obvious that the LMD18201 is designed for bigger motors than ones used for a typical RC car, but it still could be implemented. The feature list for the LMD18201 is listed below:

- Delivers up to 3A continuous output
- Operates at supply voltages up to 55V
- Low Rds(on)
- TTL and CMOS compatible inputs
- No “shoot-through” current
- Thermal warning flag output at 145C
- Thermal shutdown at 170C
- Internal clamp diodes
- Shorted load protection
- Internal charge pump with external bootstrap capability

### 3.3.8 Wireless Communications

Being able to send and receive instructions wirelessly from the vehicle is an important aspect of the AMDV since the main device is a vehicle and will constantly be on the go. The wireless module is the middle man between the remote controller and the microcontroller and must be able to interface successfully to both of them as well as provide a means of communication between them. This means the wireless module must be able to send and receive commands and other data to the remote controller as well as the microcontroller and between the two as necessary. The rest of the specifications and requirements for the wireless module are listed below.
- Shall be able to communicate without being in the line of the sight of the remote controller
- Shall be able to communicate with the remote controller from at least 20 Feet away
- Shall have low power consumption, under 500 mA
- Module implantation, consisting of the module, development board, and other costs associated with the module, shall cost under $100.
- Shall have integrated antenna or easily attachable external antenna for easy hardware integration
- Shall have an operating temperature range of at least 0°C to 60°C

3.4 Similar Projects

3.4.1 GNAC

3.4.1.1 About GNAC

GNAC, or GPS Navigated Autonomous Convoy, was a senior design project finished in summer 2008. Its Executive Summary states that it’s “a fully functional autonomous convoy consisting of two vehicles; a Master and a Slave vehicle.” The master vehicle navigates “through a path of predetermined waypoints” automatically, avoiding and navigating around any obstacles along its way. It uses GPS for finding the predetermined waypoints and multiple sensors and algorithms to sense obstacles. Two microcontrollers process each device’s info and tells the motors when to take appropriate action. The Slave vehicle has no “object avoidance algorithms”. Instead, its job is to follow the Master vehicle at a safe distance through “a triangulation method and measurements obtained by the ultrasonic and infrared sensors”. The Slave’s microcontroller then processes the data from the sensors and tells the motors what action, if any, needs to be taken.

3.4-1: GNAC’s Master and Slave Vehicles

Permission Granted: GNAC team
3.4.1.2 Project Differences

Its Executive Summary ends with the following: “The GNAC offers a low cost alternative for autonomous convoy navigation.” The GNAC and AMDV’s differences start at the price tag. On page 101 of their final design documentation it lists the GNAC Budget total: $1,158.27. This in large is because they had two vehicles, and each had its own sensors and a microcontroller or two. This is where AMDV and GNAC start to diverge. The GNAC’s budget is estimated to be under $500, less than half of GNACs budget. It’s important to note GNAC had four team members to split the bill, while AMDV has three. Also, AMDV team members have much less discretionary money to fund the project. These two issues contributed strongly to AMDVs smaller budget.

GNAC’s number one goal was to have a master vehicle navigate autonomously while a slave car followed from a safe distance using various sensors for each task. AMDV also navigates autonomously but its secondary goal is to find metal. As a result, while AMDV lacks a slave car, the project gains a new technology to integrate: electrical metal detection.

3.4.1.3 AMDV and GNAC

Since the AMDV and the GNAC Master Vehicle are both autonomous vehicles, GNAC was used a reference constantly and influenced many design aspects of the AMDV including the GPS, the object avoidance sensors, the microcontroller, and the electrical schematics. Picking similar technologies or parts in the AMDV also brought some self-assurance to the project, as the components were used together successfully in the GNAC. Self-assurance also came from knowing these components and the designs using them were well documented in the final design documentation. That’s why in the design selection many of the same parts used in GNAC appear including the EZ1 sensor for object avoidance, the EM-406A Module for GPS navigation, the ATmega168 microcontroller, and the Arduino USB Board.

GNAC’s use as a reference extended beyond the hardware and design aspects, as its project documentation was very well designed. Many times when a team member was unsure of a section, in its format or content, a quick look at GNAC’s documentation was all it took to remedy the situation.

3.4.2 Digitags

Digitags was chosen as a similar project because of the common use of Bluetooth devices and its power supply. Both the AMDV and Digitags rely on wireless communication so by studying the Digitags research, the group was able to easily find what hardware to use for the Bluetooth and which power supply to use. Without Digitags, not much consideration would be put into the use of rechargeable batteries, or even the idea of having a solar panel to supply power to the module. Digitags and AMDV differ in many different ways and have completely different functions in the end, but the technology used to provide that given function is essentially the same. Also, another thing similar in the design of Digitags and the AMDV is the microcontroller. Though used for two completely different functions, the same technology is used to process information coming in wirelessly, and outputting information to other circuit components. Figure 3.4-2 shows a rough image of the Digitags with identical components like the LED, possibly the solar panel, and the antenna.
Figure 3.4-2: DigiTags Rough Sketch

Permission Pending: DigiTags
4.0 Design

4.1 Metal Detecting Design

Through the research on the metal detector, it seems that the TDA0161 is perfect for the project. The TDA0161 can be hooked up to look like the STEVAL-IFS005V1 application version which implements multiple detectors on the device. An issue with the design process is the detection range. The detection range will be to be tested through trial and error due to the fact the data sheet does not give what the inductor values should be set to. Also, the data sheet does not shows how the inductor value relates to the oscillation frequency or the resistance value for the external circuit. The metal detector being design will be acting like a beat-frequency oscillator when searching for metal. The equation below is how much the frequency will decrease when coming across the metal. The inductance of the coil can also be determined from the equation below.

\[ L = \frac{\mu N^2 A}{l} \quad f_0 = \frac{1}{2\pi \sqrt{LC}} \]

Taking these two equations into consideration, it is important to remember that the frequency of the designed search coil has to be the same as the frequency of the reference coil. The set up using the TDA0161 will be as seen in Figure 4.1-1. This figure will be modified by replacing the cs209A with the TDA0161, and removing the buzzer. Also, the power supply will still be variable. 9 volts still would seem like a good choice. The amount powered to the circuit will be discussed in the power supply design section.

Figure 4.1-1: Basic Metal Detector Schematic

(Courtesy of Andy Collinson)
4.2 Manual Control Interface

The controller shall be of the following design selection: Sony PS3 Bluetooth Dual Shock 3 controller. The controller shall be able to do the following in order to meet the requirements:

- Communicate with the AMDV via Bluetooth.
- Turn the vehicle left or right. This shall be controlled with the left analog stick by tilting left or right respectively or by pressing left or right again respectively on the 8-way directional pad.
- Accelerate the vehicle forward or put it in reverse. This shall be controlled with the right analog stick or the X and O button, respectively. Tilting the analog stick up or holding the X button will move/accelerate the vehicle forward and tilting down or holding the O button will put the vehicle in reverse/move it back.
- Put the vehicle into/out of the automatic mode. This shall be done by pressing the Triangle button once to put the vehicle into automation mode and by pressing it again to put the vehicle back into manual control. This process shall be ongoing.
- Rumble when the vehicle detects a metal object. The rumble shall vary with the strength of the metal detecting signal.

4.2.1 Manual Control Design

The manual control for the AMDV will require designs on both the hardware and software sides. The following section will detail the hardware design used to interface with the AMDV. The final section will detail the software design used.

4.2.2 Manual Control Hardware

The remote controller for the AMDV shall be of the following design selection: MSI Wind U100. Despite its relatively poor portability (the fact that it must be laid on a flat surface or held awkwardly in one hand unlike modern video game controllers), the Wind was primarily picked above the Wii remote or the PS3 Dualshock 3 because of its primo feedback device, its 10” screen. While the Wind makes a great wireless controller for the AMDV, it also can program it wirelessly, further adding to its advantages. The specifications of the Wind U100 netbook used for the AMDV are listed below followed by figure 4.2-1 which displays the Wind in its full glory. The specific advantages of the specs will be discussed after the figure.

- 10-inch LCD Screen
- Intel Atom N270 @ 1.6 GHz Processor
- 2GB DDR2 667MHz RAM, 800 GB SATA Hard Drive (upgraded from 1GB)
- Built-in Bluetooth 2.0 + EDR
- Windows Vista Home Premium OS (upgraded from Windows XP Home Edition)
- 3 USB 2.0 Ports
The advantages go further in the MSI Wind. First, the 1.6GHz Atom processor is designed for maximum power savings and will be more than sufficient for the CPU tasks of the remote controlling software written. Second, this version of the Wind comes with a six cell lithium ion battery. This combined with the aforementioned processor produces outstanding battery life averaging four to five hours. This will allow the AMDV to be controlled for hours on end when not near a power outlet. On top of this, the 10” LCD screen, the two internal speakers, the ergonomic keyboard, and the remote controlling software (please see 4.2-2 below) will provide an excellent and easy way for the user to interface with the AMDV and will act in unison to serve as the controller’s required feedback device.

Another benefit the Wind provides is its built-in Bluetooth. As section 4.4 describes, Bluetooth is being integrated on the AMDV. This will provide a hassle free way of communication with the AMDV, as no additional inconvenient USB dongle or hacking is required which saves cost and time.
In addition to being used as a manual controller for the AMDV, the Wind also has the advantage to perform the initial programming for the microprocessor. This will be done using one of the Wind’s type “A” USB ports which will connect to the microcontroller development board’s type “B” USB port. Later programming will be done wirelessly through the Bluetooth once the AMDV and the Wind are properly paired with each other using this technology. On the software side of programming, the Wind has Windows Vista installed. This will provide an easy and familiar programming environment for the group.

4.2.3 Manual Control Software

User interaction will be presented via a graphical user interface (GUI) in the Java programming language. It is run on a client computer to which the AMDV is connected to via Bluetooth. This controlling software is designed in a three tier architecture. The first tier is the onboard software of the AMDV and the onboard Bluetooth module. This is how information is passed to and from the AMDV. The AMDV will use a provided manufacture’s software package or an open-source software package to handle the passing of information using standard Bluetooth protocols. The second tier involves the Bluetooth module of the client’s computer and the software to act as a direct communication interface between the GUI and the AMDV. It handles the actual communication of data on the client computer. This tier uses the built-in Bluetooth software of the computer to communicate with the AMDV and uses a scripting language program to communicate between the Bluetooth software and the Java GUI via http protocols. The third tier is the actual GUI. This is how the user interacts with the AMDV. It provides the autonomous/manual operational switch which is used to determine which mode of operation the AMDV is to operate in. This also allows for the safety protocol to be implemented as discussed in Section 4.9.2. The GUI also includes the GPS data logging capability of the AMDV. This means that the GUI is responsible for keeping a record of the location where metallic objects are found. In addition to these controls and data monitoring capabilities, the GUI also needs to implement the actual controller interface. The AMDV has six functional control directions; forward, forward left, forward right, reverse, reverse left, and reverse right. An initial layout of the GUI is shown below in Figure 4.2-2. Note: See Section 4.9 for more information on the AMDV’s software design.
4.3 Automation

4.3.1 Automation, Code Control, and Execution

Autonomous vehicles are very common in today’s society; from military drones to the Rumba floor cleaner. They all operate basically in the same way with the primary difference being in the tasks that they are designed to perform. The AMDV’s primary function is to perform metal detection in both manual user control and under self-autonomous control. For successful autonomous operation, all of the AMDV’s components will need to be utilized effectively and perform at a minimum of the required specifications at all autonomous operational times. This “Automation” subsection is written with the understanding that the other subsections of the design portion of this report are focus on how signals are created from their respective components of the AMDV and how they are given to the vehicle’s automation control interface.

The vehicle’s automation control interface is a microcontroller which acts as the AMDV’s brain. It controls the automation of the AMDV. The microcontroller contains code written by the programmer which the microcontroller utilizes to mimic ‘artificial intelligence’. The microcontroller does not really have artificial intelligence because artificial intelligence is exhibited by a machine that learns and makes decisions on its own while what the microcontroller onboard the AMDV really is doing is that it is following an elaborate set of instructions and making decisions based on programmed choices. The AMDV will only perform operations that have instituted by the programmer and its performance is limited by the abilities of the programmer, by the resources available, and by the performance of the AMDV’s internal components.
The AMDV’s primary microcontroller contains a set of instructions (the code) which it will sequentially execute. This means that it will only be able to perform one instruction at a time. The code will utilize the different components of the AMDV by either sending or receiving a signal to/from the components via the microcontroller’s input and output pins. When a signal is on a pin, it will appear to the microcontroller as a 1 versus when a signal is not on a pin, it will appear that to the microcontroller as a 0. In reality, on the lines that lead to and from the pins, there is a voltage which is turned into a binary signal microcontroller by using threshold voltages. Also note that the microcontroller that is being used also is able to read and write to digital I/O pins which will be utilized with the GPS output and sensor output.

The code is written into the microcontroller’s non-volatile memory which means that if power is lost or shut off to it, the program code will still be available once power is restored. Variables and constants may also be stored in the non-volatile memory of the microcontroller which allows for the AMDV to remember data regarding its mission and operation. The microcontroller also contains volatile memory which can be used for temporary storage of non-critical data that is not required to be saved in the event of a power loss. This memory is useful for storage of data structures that will not be used in any future time or for data which needs to be reset in the event of a power loss.

The microcontroller executes the code in its memory with the respect to the current state of the AMDV. The current state of the vehicle is how decisions are made in regards to which path of a control loop to take. The current state will be recognized by reading different values of pins on the microcontroller as discussed earlier. The microcontroller may also be used to parse data streams from the components and perform actions based on the success of the parse and the information acquired from the parsed data. The following subsections will discuss how the different components of the AMDV will be used in autonomous operation. Note that the following subsections are written in-conjunction with Section 4.8 which discusses the overall software specifications and design.

### 4.3.2 Automatic Controlled Interface

The AMDV’s automation algorithms are designed to be used with minimal user interaction. A two way software switch is incorporated into the graphical user interface (GUI) on the client computer. One position represents operation under manual user control, while the other position represents autonomous operation. When the autonomous operational mode position is selected, the AMDV starts autonomous operation. It will perform continuously in this mode for some designated time (which is set in code.) Once that time period has elapsed it will pause operation and wait for input from the user. The AMDV will require the switch be set to manual mode and at that point, it can once again be set to autonomous mode and the process will be repeated. This protocol is implemented for safe operation so that the AMDV will not run rampant and out of control under autonomous operation. The AMDV may also be brought out of autonomous mode by the user at any time by changing the switch to the manual operation mode position.
4.3.3 GPS Location

The GPS receiver onboard of the AMDV will always be active when powered on. Although it would be possible to record the track of the AMDV, that is not the operational goal of the GPS module onboard of the vehicle. It will send the GPS location of the AMDV to the client computer at all times, but the single goal of the GPS module is to provide the position of the AMDV when the AMDV detects a metallic object so that it can be recorded. The data lines from the GPS will be read by the AMDV’s microcontroller, parsed, and sent to the client computer. Whenever the microcontroller receives a signal from the metal detection module that metal has been detected, it will in turn send a signal to the client computer which will record the GPS location. The parsed data will be stored on the client computer via the GUI. Once the GUI receives good data from the parsing operation and stores that data, the AMDV will continue the autonomous metal detection operation.

4.3.4 Metal Detection

The metal detection module will be operational whenever the AMDV is powered on. Whenever this module detects a metallic object, it will alert the AMDV’s primary microcontroller by setting the line between the module and microcontroller high. Whenever the metal detection module does not detect a metallic object, it will set the line to low. By having the microcontroller read the pin connected to metal detection module, the AMDV will be able to take appropriate actions based on the current state of that module. If the module has detected metal (the line is set high), the AMDV will enter a control loop in the code which will perform a set of procedures. Within this loop, the microcontroller will stop the AMDV, turn on an LED, have the onboard buzzer make noise, and will signal the client computer to store the AMDV’s current GPS location. Once the GPS location has been acquired, the AMDV will continue autonomous operation. If the module has not detected metal (the line is set low), the AMDV’s microcontroller will set the control lines of the LED and buzzer to off/low and continue the autonomous search operation.

4.3.5 Collision Prevention

Collision prevention is a very important part of an autonomous vehicle. Without collision prevention, the AMDV would run into objects which may cause catastrophic failure of components of the vehicle or of the entire vehicle. The collision prevention measures of the AMDV will only be operational when the vehicle is in autonomous operation mode. If in manual mode, it is left to the user not to run into objects. The AMDV employs a front mounted ultrasonic sensor which will determine how far away an object is away from it. The returned value will be processed by the microcontroller and check it against a threshold value stored in the code which is the closet an object is allowed to come to the AMDV before taking evasive action. When the returned value of the sensor is less than that threshold value, the AMDV will initiate an evasive action control loop. This control loop will consist of the AMDV stopping the current motion, backing up, stopping, turning approximately 30 degrees to the right (starboard), stopping, moving forward, stopping, turning 60 degrees to the left (port), stopping, and checking the ultrasonic sensor. If the sensor does not find an object within the threshold range, then the vehicle will continue on that trajectory. If the sensor does find an object within the threshold range, then the vehicle will stop, backup, stop, turn 90 degrees to the right (starboard), and then the vehicle will continue on that trajectory. In
either case the AMDV will then return to the primary control loop and continue normal autonomous operations.

4.3.6 Automation Software

The AMDV relies on software in both manual user controlled operation and autonomous controlled operation modes. The overall software and manual control software designs are located in Section 4.8 of this report. This section primarily focuses on the software design of methods and algorithms that are used while under the autonomous operational mode. Some notations that will be used are that a rounded-corner rectangle means that it is a function/method call and that a diamond means that a decision will be made by the connected function which control path to take. Another notation is when the figure says “Set Motor Control”; the AMDV checks the interrupts and communication ports from the Bluetooth module which is connected to the client computer and sets corresponding variables accordingly. The following figure (Figure 4.3-1) shows the outside state of the AMDV software algorithm from the top most level view. It shows the entrance and exit points of the AMDV’s autonomous algorithm. Note that this diagram uses a method called “Which_Mode()” that is discussed in detail in Section 4.8. “Which_Mode()” will read the value of a two-way switch to determine which operation mode the AMDV is set to and will either initiate a call to “Autonomous_Mode()” or “Manual_Mode()”. When control is returned to the “Which_Mode()” function, it then returns control back to the “main()” function.

![Figure 4.3-1: Top Level Software Architecture View](image)

When the “Which_Mode()” determines that the mode on the switch is set to the autonomous operational mode position, then it calls “Autonomous_Mode()”. This function is responsible for the overall control loop of autonomous operation. The figure below shows the overall structure of the autonomous control loop. This function will first check the value of the “requireManual” flag variable which is part of the safety protocol to not allow the AMDV to run in autonomous mode forever without user interaction. If the flag is set, then the AMDV will return back to the “Which_Mode()” function. If the flag is not set, the function will then call “Auto_Timer()” which will either update or reset the timer for the autonomous control...
condition time and if the maximum time has been reached set the “requireManual” flag variable to signal that. Control is then given back to the “Autonomous_Mode()” function and the “DoMetal()” function is called which will perform the metal detection and perform actions based on if metal was found or not. When those actions are completed, control is returned to the “Autonomous_Mode()” function, then the “DoObstruction()” function will be called. This function will check for an obstruction and perform actions based on if an obstruction was found or not. If no obstruction was found or after evasive action was performed, control is returned to the “Autonomous_Mode()” function. At this point, the AMDV will set/reset its motors and steering to movement in a straight line to allow the AMDV to continue its mission. Control is then returned to the “Which_Mode()” function.

Figure 4.3-2: Autonomous_Mode() Control Flow Diagram

When control is given to the “Auto_Timer()” function by the “Autonomous_Mode” function, that means that the “requireManual” flag variable has not been set. The “Auto_Timer()” function is used to update the amount of time the AMDV has been under autonomous operation by incrementing the global variable “timeInAuto”. This function compares the “timeInAuto” variable with a constant value, “MAXTIMEINAUTO”, which represents the maximum time (maximum loop iterations) that the AMDV is allowed to be in autonomous operation. If “timeInAuto” is incremented to greater than “MAXTIMEINAUTO”, then the “requireManual” flag variable is set. Once these increments and checks are performed, control is then returned to the “Autonomous_Mode()” function. The above statements are represented pictorially in the following figure 4.3-3.
When the “doMetal()” function is called by the “Autonomous_Mode()” function, the AMDV checks for metal and will perform actions based on whether metal was found or not. The flow of control is shown below in the figure “doMetal() Control Flow Diagram.” This function will check the status of pins on the microcontroller that are connected to the metal detection module. This module will default the pins to low when metal is not detected and will set them to high when metal is detected. If the pins are low, then the lines leading to an LED are set to off and control is returned to the “Autonomous_Mode()” function. If the pins are high representing that the device has detected a metallic object, the AMDV will determine if this metallic object has already been detected. It will do this by checking if the lines leading to an LED is set to on. If they are set, then control is returned to the “Autonomous_Mode()” function. If the pins are high representing that the device has detected a metallic object, the AMDV will determine if this metallic object has already been detected. It will do this by checking if the lines leading to an LED is set to on. If they are set, then control is returned to the “Autonomous_Mode()” function. If they are set to off, then this is the first time the AMDV has detected this particular metallic object. At this point, the AMDV will perform a series of actions pertaining to acknowledging the find. It will first stop the AMDV (set motor controls to off). It will then turn on an LED. It will then call the “getGPS()” function which will determine the location of the AMDV and record this location. When control is returned from “getGPS()” to “doMetal()”, it will also be returned to “Autonomous_Mode()”.

Figure 4.3-3: Auto_Timer() Control Flow Diagram
The “getGPS()” function is responsible for acquiring and recording the AMDV’s location according to the onboard GPS module. This function’s control flow is shown in the below figure. When the “getGPS()” function is called from the “doMetal()” function, the AMDV will start to listen to the output from the GPS. This output will be coded NMEA messages which were discussed in section 3.2.2. This function will parse the output messages and will compare the outputted data with the expected data format. If the format is incorrect, then the function will continue to try to parse the output messages until the format is correct. Once the correct format is detected, then the location data in this output message will be recorded in the microcontroller’s non-volatile memory for later use. At this point, control will be returned to the “doMetal()” function.

Figure 4.3-4: doMetal() Control Flow Diagram

Figure 4.3-5: getGPS() Control Flow Diagram
When the “doObstruction()” function is called by the “Autonomous_Mode()” function, the AMDV checks for obstructions based on the reading of an ultrasonic sensor and performs actions based on if this reading is within a threshold distance value meaning that there is an object too close to the AMDV. The control flow of the “doObstruction()” function is pictorially represented in the below figure. When this function is called, the AMDV will initiate a call to the sensor module which will return the distance of the closest object in its field of view. This returned distance value is then compared with the threshold distance, “THRESH_DIST”; the minimum distance an object is allowed to come to the AMDV without taking actions. If the returned distance is greater than “THRESH_DIST”, then the AMDV will return control back to the “Autonomous_Mode()” function. This means that there was no obstruction detected. If the returned distance is less than “THRESH_DIST”, then evasive actions are taken to avoid the detected obstruction. These evasive actions will be handled by a motor control loop.

This control loop will consist of the AMDV stopping the current motion, backing up, stopping, turning approximately 30 degrees to the right (starboard), stopping, moving forward, stopping, turning 60 degrees to the left (port), stopping, and checking the ultrasonic sensor again for an object within “THRESH_DIST”. If the sensor does not find an object within “THRESH_DIST” (the threshold range), then control is returned to the “Autonomous_Mode()” function. If the sensor does find an object within the threshold range, then the vehicle will backup, stop, turn 90 degrees to the right (starboard), and stop. At this point the vehicle will be facing 90 degrees to the right of the original direction and the AMDV’s evasive actions for this loop iteration would be complete. Control is then returned to the originating “Autonomous_Mode()” function.
4.4 Wireless Module

4.5 Power Supply

The design of the power supply is very variable early in the project. As of right now, it seems as if it would be best to have two separate power supplies, one to power the motor and one to power all the small electrical components. The batteries that are being considered are both the lithium primary battery and the lithium-ion secondary battery. The lithium primary battery offers a lot of advantages spelled out in the research chapter, and it is also easily available at an affordable cost. The lithium-ion battery would be set aside specifically for the motor due to the fact the motor draws the most energy and it would be convenient that when the battery dies, it can be recharged. The primary lithium battery would be used to power the
small electrical components. For the lithium-ion, a 9V version would suffice to the motor. For the electrical components, thoughts about connecting AAs in series or providing a 9V to the circuit are practical. Figure 4.5-1 shows how the power supply would be hooked up to the different components. Both of the supplies are hooked up in parallel to each component to ensure equal voltage on each component. The two lithium AA batteries are hooked up in series to provide an added voltage potential to the circuit components.

Figure 4.5-1: Power Supply hookups

4.6 GPS

The AMDV utilizes the USGlobalSat’s EM-406a GPS engine board. The EM-406a was chosen as the GPS module for the AMDV because it is well documented and widely used, has relatively cheap cost, and meets all of the requirements and specifications set forth in the beginning of this report. This receiver supports WAAS technology. It is an all inclusive chipset; has the GPS receiver hardware and antenna on a single chip. It has a small footprint which allows for the module to be mounted in a small area on the AMDV. The EM-406a has high accuracy; while using WAAS, it has an accuracy of less than 5 meters. It also has fast satellite fix time. From a cold start, it only takes 42 seconds for the GPS to have a good fix on satellites and be ready for use. The following table gives some of the manufacture’s specifications of the EM-406a GPS engine board. Other specifications of this module are given in Section 3.3.3 of this report.
**Table 4.6-1: EM-406a Manufacture Specifications**

<table>
<thead>
<tr>
<th>GPS MODULE PART NO.</th>
<th>EM-406A</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chipset</strong></td>
<td>SiRF StarIII/LP Single</td>
</tr>
<tr>
<td><strong>Channels</strong></td>
<td>20</td>
</tr>
<tr>
<td><strong>SBAS</strong></td>
<td>WAAS EGNOS MSAS</td>
</tr>
<tr>
<td><strong>RoHS Compliant</strong></td>
<td>Y</td>
</tr>
<tr>
<td><strong>Operation Voltage (DC)</strong></td>
<td>4.5 ~ 6.5</td>
</tr>
<tr>
<td><strong>Voltage Ripple Tolerance</strong></td>
<td>0.1V</td>
</tr>
<tr>
<td><strong>Data Output Voltage</strong></td>
<td>0 ~ 2.85V</td>
</tr>
<tr>
<td><strong>Power Consumption (mA)</strong></td>
<td>44</td>
</tr>
<tr>
<td><strong>Power Consumption (Trickle Mode)</strong></td>
<td>25</td>
</tr>
<tr>
<td><strong>Power Consumption (Receiving Mode)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Serial Port / Data</strong></td>
<td>1 / TTL</td>
</tr>
<tr>
<td><strong>Interface Type</strong></td>
<td>6-PIN Connector</td>
</tr>
<tr>
<td><strong>Male Connector Digikey Part No. (on PCB)</strong></td>
<td>455-1806-1-ND</td>
</tr>
<tr>
<td><strong>Female Connector Digikey Part No. (for cable)</strong></td>
<td>455-1381-ND</td>
</tr>
<tr>
<td><strong>PPS Output Available</strong></td>
<td>Y</td>
</tr>
<tr>
<td><strong>Built-in LNA</strong></td>
<td>Y</td>
</tr>
<tr>
<td><strong>Built-in Regulator</strong></td>
<td>Y</td>
</tr>
<tr>
<td><strong>Gold Capacitor Back-Up (Hours)</strong></td>
<td>12</td>
</tr>
<tr>
<td><strong>Antenna Bias Voltage</strong></td>
<td>N</td>
</tr>
<tr>
<td><strong>External Antenna Port</strong></td>
<td>N</td>
</tr>
<tr>
<td><strong>Patch Antenna</strong></td>
<td>Y</td>
</tr>
<tr>
<td><strong>Dimensions (inches)</strong></td>
<td>1.2x1.2x0.4</td>
</tr>
<tr>
<td><strong>Dimensions (mm)</strong></td>
<td>30x30x10.5</td>
</tr>
<tr>
<td><strong>Mounting Holes</strong></td>
<td>N</td>
</tr>
<tr>
<td><strong>History</strong></td>
<td>EM-406</td>
</tr>
</tbody>
</table>

The EM-406a module has four input pins. There are two ground pins and one Vcc pin which takes a DC power supply voltage of 4.5 to 6.5 Volts. The forth input pin is the RX receiving pin. This pin communicates with the microcontroller to handle updating the output information type and receiving modes of the GPS. The EM-406a also has two output pins. The first pin is the PPS pin which allows the microcontroller to synchronize with GPS time by pulsing the PPS pin at a rate of one pulse per second. The other pin is the TX pin. This
pin is responsible for transmitting the GPS NMEA messages to the microcontroller. The following figure shows the pin inputs and outputs of the EM-406a.

**Figure 4.6-1: EM-406a Pin Input and Output**

- RX (From Microcontroller) → EM-406a → TX (To Microcontroller)
- GND (From Power Plant) → EM-406a → PPS (Not Connected)
- GND (From Power Plant)
- Vcc (From Power Plant)

4.7 Vehicle

There are a number of radio control vehicles which would be sufficient for this project. They all meet the requirements set forth in Section 2.0 of this report. These vehicles have suspension systems capable of carrying relatively large amounts of mass and provide the capability of traversing different terrains such as sand, gravel, and grass. They supply large wheels which also help with the traversing of different terrains and allows for high enough ground clearance to mount the AMDV’s metallic detection module. These R/C vehicles have built-in power plants which will allow for the AMDV to be partially powered by the OEM battery packs which are included when purchasing a vehicle. These vehicles also provide a large wheelbase which allows for a mounting area for the AMDV’s electronics and this wheelbase provides greater stability when operating. These vehicles are all of relatively low cost which is one of the major design constraints and reasoning behind using a toy R/C vehicle. The motors in these R/C vehicles may not provide the torque that the AMDV will need, so they may be replaced if testing proves this necessary. In addition to motor replacement, H-Bridges may be used to control the new motors. These H-Bridges are discussed in Section 3.3.7. The vehicle that was chosen to be used unfortunately does not have a model number. This vehicle in particular has been chosen to be the base of the AMDV because it does meet all the specified requirements and is to be donated by a team member. The following photos in Figures 4.7-1 and Figure 4.7-2 are of the vehicle which will be used as the AMDV’s base. Figure 4.7-1 is the top view of the vehicle. This figure shows the overall body of the vehicle and the frame.
Figure 4.7-1: R/C Vehicle Top View

Figure 4.7 – 2 is the side view of the vehicle. This figure shows the large wheels and high ground clearance of the vehicle. It also shows the suspension system of the vehicle and the multiple possible mounting locations for the AMDV’s electronics. This vehicle comes stock with a 49 Mhz RF unit which will not be used in the final AMDV design. The antenna to this RF unit is the green tube coming from the top of the vehicle.

Figure 4.7-2: R/C Vehicle Side View
4.8 Sensors

The AMDV utilizes the Maxbotix LV-EZ1 ultrasonic sensor. The LV-EZ1 was chosen as the collision avoidance sensor for the AMDV because it is well documented and widely used, has relatively cheap cost, and meets all of the requirements and specifications set forth in the beginning of this report. This sensor performs well in sunlight. The LV-EZ1 also has a good range; a minimal distance of 6in and a maximum distance of 254in. The following list gives some of the manufacture’s specifications of the LV-EZ1 ultrasonic sensor. Other specifications of this module are given in Section 3.3.5 of this report.

- Continuously variable gain for beam control and side lobe suppression
- Object detection includes zero range objects
- 2.5V to 5.5V supply with 2mA typical current draw
- Readings can occur up to every 50mS, (20-Hz rate)
- Free run operation can continually measure and output range information
- Triggered operation provides the range reading as desired
- All interfaces are active simultaneously
- Serial, 0 to Vcc
- 9600Baud, 81N
- Analog, (Vcc/512) / inch
- Pulse width, (147uS/inch)
- Learns ringdown pattern when commanded to start ranging
- Sensor operates at 42KHz
- High output square wave

The LV-EZ1 sensor has 4 input pins. There is one ground pin and one Vcc pin which takes a DC power supply voltage of 5 Volts. It has one RX pin which is connected to the microcontroller to signal the sensor when to get the ranging data. The sensor also has a BW pin which tells the sensor which output mode to use, pulse or serial. LV-EZ1 also has three output pins. The TX pin outputs the ranging data to the microcontroller in RS232 format. The AN pin varies the voltage to signify the ranging data. The PW pin varies the timing of a pulse to signify the ranging data. The following figure (Figure 4.8-1) shows the pin inputs and outputs of the Maxbotix LV-EZ1.

![Figure 4.8-1: LV-EZ1 Pin Input and Output](image-url)
4.9 Software

4.9.1 General Software Information

The AMDV is designed to be operated autonomously or with user interaction. The software for automation has already been discussed in section 4.3 of this report. This section is primarily focused on the user interaction aspects of the software although there is overlap between the two sections. Even though this section is considered the “manual” or “user-controlled” section of the vehicle’s operation, software involvement is still required for the AMDV to complete its objectives successfully. The AMDV is programmed using the standard C programming language. This allows access too many programming libraries that will allow for more advance programming concepts to be used onboard the AMDV. As the automation section stated, the program code is written into the microcontroller’s non-volatile memory which means that if power is lost or shut off to it, the program code will still be available once power is restored. Variables and constants may also be stored in the non-volatile memory of the microcontroller which allows for the AMDV to remember data regarding its mission and operation. The microcontroller also contains volatile memory which can be used for temporary storage of non-critical data that is not required to be saved in the event of a power loss. This memory is useful for storage of data structures that will not be used in any future time or for data which needs to be reset in the event of a power loss.

The microcontroller executes the code in its memory with the respect to the current state of the AMDV. The current state of the vehicle is how decisions are made in regards to which path of a control loop to take. The current state will be recognized by reading different values of pins on the microcontroller. The microcontroller may also be used to parse data streams from the components and perform actions based on the success of the parse and the information acquired from the parsed data. In manual operation, the ultrasonic sensor used for collision avoidance and the GPS used to find the location of the AMDV are not being used. The following subsections will discuss how the other components of the AMDV will be utilized.

4.9.2 Automation Safety Protocol

Due to the AMDV being able to operate in manual and autonomous modes, a two way switch is on the top of the vehicle. One position represents operation under manual user control, while the other position represents autonomous operation. When the autonomous operational mode position is selected, the AMDV starts autonomous operation. It will perform continuously in this mode for some designated time (which is set in code.) Once that time period has elapsed it will pause autonomous operation and wait for input from the user. The AMDV requires the switch be set to manual mode and at that point, it can once again be set to autonomous mode and the process will be repeated or optionally, it could be operated under manual user control. This protocol is implemented for safe operation so that the AMDV will not run rampant and out of control under autonomous operation. The AMDV may also be brought out of autonomous mode by the user at any time by changing the switch to the manual operation mode position.
4.9.3 Metal Detection

The metal detection module is operational whenever the AMDV is powered on. Whenever this module detects a metallic object, it will alert the AMDV’s primary microcontroller by setting the line between the module and microcontroller high. Whenever the metal detection module does not detect a metallic object, it will set the line to low. By having the microcontroller read the pin connected to metal detection module, the AMDV will be able to take appropriate actions based on the current state of that module. While the AMDV is under manual user control, if this module has detected metal (the line is set high), the AMDV will set a LED to on and buzzer to make noise. If the module has not detected metal (the line is set low), the AMDV will set a LED to off and buzzer to not make noise. Note that if the AMDV is under autonomous operation, other appropriate actions would have taken place.

4.9.4 User Interaction Software

The AMDV relies on software in both manual user controlled operation and autonomous controlled operation modes. The autonomous software designs are located in Section 4.3 of this report. This section primarily focuses on the software design of methods and algorithms that are used while under the manual operational mode. Some notations that will be used are that a rounded-corner rectangle means that it is a function/method call and that a diamond means that a decision will be made by the connected function which control path to take. The following figure shows the outside state of the AMDV software algorithm from the top most level view. It shows the entrance and exit points of the AMDV’s autonomous algorithm. The “Which_Mode()” function will read the value of a two-way switch to determine which operation mode the AMDV is set to and will either initiate a call to “Autonomous_Mode()” or “Manual_Mode().” When control is returned to the “Which_Mode()” function, it then returns control back to the “main()” function.

Figure 4.9-1: Top Level Software Architecture View

When the “Manual_Mode()” function is called by the “Which_Mode()” function, that means that the AMDV mode switch is set to the manual operation position. The following figure shows the control flow of the “Manual_Mode()” function. When this function is called, it will first reset the flag variable “requireManual” to false and the “timeInAuto” variable to 0.
Both of these variables are used when the AMDV is under autonomous operation and are part of the safety protocol discussed in section 4.8.2. “requireManual” is used to determine if the AMDV has been operating in autonomous mode too long and “timeInAuto” is a variable holding how long the AMDV has been operating in autonomous mode. Once these variables are reset, the “Manual_Mode()” function will pass control to the function “doMetalManual()”. This function will perform actions based on if a metallic object has been detected by the metal detection module of the AMDV. When control is returned back to the “Manual_Mode()” function, the motors and steering are set according to the Radio Controller. Control is then returned back to the “Which_Mode()” function.

**Figure 4.9-2: Manual_Mode() Control Flow Diagram**

The “doMetalManual()” function is responsible for determining if the metal detection module has found metal and performing different actions based on whether a metallic object has been found or not. When this function is called by the “Manual_Mode()” function, it first reads a pin on the microcontroller which is connected to the metal detection module. If the pin is low, then the metal detection module has not detected metal. If this is the case, then a LED is set to off and a buzzer is set to not make noise. If the pin is high, then the metal detection module has detected metal. If this is the case, then a LED is set to on and a buzzer is set to make noise. Control is then returned to the “Manual_Mode()” function. The following figure pictorially represents the flow of control through the “doMetalManual()” function.
The microcontroller and its development board for the AMDV shall be of the following design selections: the Atmel ATMega328 and the Arduino Duemilanove, respectively. Both can be bought through SparkFun Electronics for $5.50 and $29.95 respectively. The pinout for the MCU is shown above in figure 4.10-1 and is worth noting it shares same pinout as the ATmega168. The top and bottom of the Arduino is shown below in figure 4.10-2. There shall be two ATMega328s in the AMDV. The first, hereby known as MCU1, will serve the object avoidance sensor, H-bridges, and metal detector. The second, hereby known as MCU2, will serve both the Bluetooth and GPS modules. MCU1 and MCU2 will communicate with each
other. Please see figure 4.11-1 for a hardware block diagram. The relevant specifications for the ATMega328 and its development board are outlined below.

- 8-bit RISC Architecture
- 32 KB Flash / 512B EEPROM / 1 KB RAM
- 23 I/O Pins
- -40°C to 85°C
- MCU Operating Voltages: 1.8V-5.5V (MCU),
- Arduino Operating Voltages: 5V
- MCU power consumption: 300µA @ 1Mhz, 1.8V (Active), 0.8µA @ 1Mhz, 1.8V (Standby), 0.1µA @ 1Mhz, 1.8V, 10.8 mW (theoretical maximum)
- Up to 20 MIPS @ 20 MHz
- MCU IC: 28 pin DIP
- MCU Dimensions: 37.5(L) x 9.5(W) mm
- Arduino Dimensions: 68.6(L) x 53.3(W) mm
- USB Interface
- C/C++ based programming language

The ATMega328 was chosen because its plentiful I/O pins, large memory, high performance, and 5V operating voltage. The ATMega328 has 23 I/O pins which will be plenty considering there will be two MCUs. The 32KB flash, 1KB RAM and 20 MIPS will ensure there’s plenty of space and computing power for the programs being designed for the AMDV. The operating voltage range will allow the DC circuits to remain simple, as it will only have to supply 5V to all the microelectronics. The ATMega328 microcontroller is only half the package. The other part, its development board, pictured below in figure 4.10-2, is what really makes the ATMega328 shine.

Figure 4.10-2: The Top of the Arduino Duemilanove

Permission Pending: SparkFun Electronics
The Arduino Duemilanove was chosen because of its open-source developing environment, and its low cost. It’s the latest in the Arduino development boards and this version adds the capability to automatically detect whether power is hooked through the USB or the DC power cable and switch to appropriate one. The open source nature produces fantastic amounts from free 3rd party resources. Websites like Arduino.cc and sparkfun.com that are full of tutorials, forums, and other information for the ATMega328 in its Arduino form. This will make help make the MCU programming a breeze. The programming itself is done in the Arduino development environment which is based on C/C++, which was the preferred programming language set in the specifications section. Finally, two microcontrollers and one development board costs $40.95 total, well below the microcontroller’s cost limit specification of $100. These advantages made the ATMega328 and its development board, the superior choice for the AMDV’s microcontroller.
4.11 Electrical Schematics

This section shows how everything is connected on the microelectronics level. First in figure 4.11-1 is a simple hardware block showing basic links between devices. Then in Figure 4.11-2, the vastly more specific electrical schematic is presented detailing the exact connections. Please note that the Atmega168 is presented in place of the Atmega328 in the electrical schematic because only the Atmega168 was available in the Eagle schematic library. The two share the same pinout and differ only in memory sizes.

Figure 4.11-1 Top Level Hardware Block Diagram
5.0 Prototype

5.1 Build & Implementation Strategy

The parts from the research section all need to come together. The steps the group will take to put the project together will be as follows in that order:

- Order all parts necessary
  - GPS
    - GPS development board
  - Sensors
  - Circuit components
    - Resistor
    - Capacitors
    - Inductors
  - Metal detecting Parts
  - RC car
Microcontroller

- H-Bridge

- Divide amongst the group on which part to work on
  - Highest Priority
    - Metal Detector
    - Sensors
    - Microcontroller
  - Medium Priority
    - H-Bridge
    - GPS
  - Low Priority
    - RC Car

- Test each part
- Piece all the parts together for a working prototype
- Polish up the prototype to be ready for the final presentation.

5.2 Acquiring Parts: Vendors & PCB Building

GPS Engine Board:
- Part: EM-406a
- Manufacturer: USGlobalSat
- Cost: $46.99
- Site to Purchase From: USGlobalSat

Collision Avoidance Sensor:
- Part: LV-EZ1
- Manufacturer: Maxbotix
- Cost: $24.95
- Site to Purchase From: SparkFun

Proximity Detector
- Part: TDA0161
- Manufacturer: ST
- Cost: $3.77
- Site to Purchase From: DigiKey

Voltage Regulator
- Part: LM317T
- Manufacturer: National
- Cost: $0.49
- Site to Purchase From: DigiKey
LED
Part: RL5-W18030
Manufacturer: superbrightleds.com
Cost: $0.59
Site to Purchase From: DigiKey
URL: http://www.superbrightleds.com/cgi-bin/store/commerce.cgi?product=LEDS#RL5-R8030

H-Bridge
Part: FAN8200 H-Bridge
Manufacturer: superbrightleds.com
Cost: $0.83
Site to Purchase From: JameCo
URL: http://www.jameco.com/webapp/wcs/stores/servlet/ProductDisplay?langId=-1&storeId=10001&catalogId=10001&productId=241867

5.3 Coding

The AMDV’s software will be programmed using Microsoft’s Visual Studio with a license granted through the University of Central Florida’s MSDN program and with a freeware program called Bloodshed’s Dev-C++. Both of these programs are considered Integrated Development Environments (IDEs) which provides the programmer with various tools for helping with the programming of the AMDV’s software. One of the most important tools these include is a run-time debugger which will help locate errors within the code which may be fatal to the AMDV’s operation. These programs also include the C libraries and compilers, which will be used to convert the high-level C to a lower level language which the onboard microcontroller understands. The software will be designed as stated in sections 4.9 and 4.3 in regards to the flow of control. The program will first be put together as an empty shell. This will allow for the software to run with prototype functions available as the software is developed. Writing the software in this manner allows for sections of the code to be tested without having a fully functional software package. Progressively as code sections and functions are completed, the software will start to take shape and these portions will be able to be tested and debugged together. It is expected that a new software package will be released bi weekly which is ready to be ran onboard of the AMDV. Each of these code releases will allow for implementation testing of different parts along with fixing any bugs which have been fixed from the previous code release. By the fifth code release, it is expected that the majority of the AMDV’s software will be operational and bug-free. The periodic remaining code releases will fix any additional bugs which may arise and implement additional software features which are not considered a necessity to the AMDV’s successful operation.

6.0 Testing

6.1 Testing for Success: Meeting Our Specifications and Requirements
The AMDV shall undergo multiple testing procedures determining the success in accordance to its operational goals and objectives. These operational goals and objectives are stated in Section 2.0. The first of these tests will be determining the accuracy of the GPS module. GPS accuracy was stated to be at a minimum of 5 meters. If accuracy is determined to be greater than this value by the test procedures described in Section 6.2, this part of the AMDV will be considered a failure. The next of these tests will be determining the functionality of the collision avoidance system. The success of this system requires that the AMDV not collide with objects when undergoing forward motion. This will be tested as described in Section 6.3 and if the AMDV does strike an object, the collision avoidance system will be considered a failure. The third test will determine the success of one of the primary modules of the AMDV, the metal detection module. This module will be tested as described in Section 6.4 and is considered a failure if metal is not detected at the specified minimum distance.

The success of the AMDV also depends on the autonomous and manual operational modes. These modes also include testing of the individual modules described previously to test the combined AMDV. The autonomous operational mode testing is discussed in Section 6.6 and the manual operational mode testing is discussed in Section 6.5. If either of these testing operations is considered a failure as described in their respective sections, then the control of the AMDV is a failure. If any of the individual testing procedures is a failure, then the AMDV as a whole will be considered a failure otherwise the AMDV will be considered a success.

### 6.2 GPS Accuracy

GPS accuracy shall be tested by comparing the AMDV’s GPS position as given by its onboard GPS module to a consumer handheld GPS receiver. The AMDV will be positioned to run over a metallic object while in autonomous mode and once it has recorded the GPS position, the AMDV will be stopped. The GPS location recorded to the AMDV’s microcontroller will be read and inputted into the consumer GPS receiver. The consumer GPS will be used to find the location which the AMDV has marked as the location of the metallic object. That location will be physically marked. If the distance between that location and the real location of the metallic object is less than five meters plus the accuracy of the consumer GPS, then the AMDV’s onboard GPS is accurate to within specified requirements. Below is a figure of the distance requirements between the consumer GPS marked location and the real location.
6.3 Collision Prevention

The AMDV’s collision prevention system shall be tested in two phases. In the first phase, the AMDV will be placed on a trajectory which would cause it to run into a singular object. If the AMDV is able to go around this object by following a set of software protocols, then the AMDV has successfully completed the first phase of collision prevention system testing. These protocols were described in Section 4.3.5 but are listed below for completeness:

This control loop will consist of the AMDV stopping the current motion, backing up, stopping, turning approximately 30 degrees to the right (starboard), stopping, moving forward, stopping, turning 60 degrees to the left (port), stopping, and checking the ultrasonic sensor. If the sensor does not find an object within the threshold range, then the vehicle will continue on that trajectory.

The second phase of collision prevention testing involves a boundary such as a wall. If the AMDV is able to realize that there is an object in front of it and if the above set of software protocols returns that there is still an object in front of the AMDV, then another set of protocols are enacted. These protocols have the AMDV turn 90 degrees to the right, putting the AMDV on a right angle trajectory with respect to its original path. Once again, these protocols were described in Section 4.3.5 but are listed below for completeness:
If the sensor does find an object within the threshold range, then the vehicle will stop, backup, stop, turn 90 degrees to the right (starboard), and then the vehicle will continue on that trajectory.

If both of these phases cause the AMDV to behave as expected without running into objects, then the AMDV’s collision prevention system performs successfully.

### 6.4 Metal Detection

Testing of the metal detector is while take many tools to complete. The obvious goal is to detect metal when within a certain distance. The way the testing is to run, is to find test the inductor value made and see if the output current of the proximity IC detector is above the 8ma to be sent to the microcontroller. The detector will be hooked up to the oscilloscope and to various meters to test whether or not there is an output current, voltage, and when these currents and voltages are made relative to the distance of the metal being detected. Testing on simple metallic coins will be the primary conductive material. When it comes to the need of the project and when asked for the demonstration, metallic coins will be used again. This will keep the testing consistent without having to change the medium or variable with it is time to do the demonstration.

### 6.5 Manual Control

The AMDV’s manual operation mode will be tested by performing a series of actions on the client computer’s GUI. These actions are discussed in the following list. If any of these actions are not completed successfully, the AMDV will be considered a failure.

1) Turn on the AMDV and client computer.
2) Sync the client computer to the vehicle.
3) Using the remote:
   a) Move the vehicle forward.
   b) Move the vehicle backward.
   c) Have the vehicle make a right turn.
   d) Have the vehicle make a left turn.
   e) Move the vehicle over a metal object. Test to see if metal-detecting feedback mechanism is working correctly.
   f) Put the vehicle into automation mode.
   g) Bring the vehicle back into manual mode

In addition to the above testing requirements, the AMDV must also comply with the GUI interface requirements. While the AMDV is powered on, the GPS location will be determined by the onboard GPS module and sent to the client computer via Bluetooth. This GPS location will be displayed on the client’s GUI. If this location is not successfully displayed, the AMDV will be considered a failure. Also while operating, the AMDV is searching for metal. When a metallic object is found, the GPS location will be recorded in the GUI. To confirm operational success of the metal detection system, a metallic object will
be placed in the path of the AMDV. If this location is not successfully recorded in the GUI, the AMDV will be considered a failure.

6.6 Autonomy
The AMDV’s autonomous operation mode will be tested by purely monitoring the operation of the AMDV while in autonomous operation. The AMDV will follow pre-programmed search routines and will modify those search routines on the fly if the collision avoidance system detects an obstacle. To confirm operational success of the collision avoidance system, an obstruction will be placed in the path of the AMDV. If the system does not avoid the obstacle, the AMDV will be considered a failure. While the AMDV is operating, the GPS location will be determined by the onboard GPS module and sent to the client computer via Bluetooth. This GPS location will be displayed on the client’s GUI. If this location is not successfully displayed, the AMDV will be considered a failure. Also while operating, the AMDV is searching for metal. When a metallic object is found, the GPS location will be recorded in the GUI. To confirm operational success of the metal detection system, a metallic object will be placed in the path of the AMDV. If this location is not successfully recorded in the GUI, the AMDV will be considered a failure.

6.7 Remote Controller Testing
The following procedure shall be used to test the controller to make sure all requirements and elements of design have been implemented successfully.

1. Turn on the remote controller.
2. Pair the remote controller to the wireless module on the vehicle, if necessary.
3. Using the remote:
   a. Move the vehicle forward.
   b. Move the vehicle backward.
   c. Have the vehicle make a right turn.
   d. Have the vehicle make a left turn.
   e. Move the vehicle over a metal object. Test to see if metal-detecting feedback mechanism is working correctly.
   f. Put the vehicle into automation mode.
   g. Bring the vehicle back into manual mode.

6.8 Microcontroller
The microcontroller shall be tested using the following procedure twice; once in the Arduino development board and then again once it’s in the final PCB connected properly to 5V and ground (pins 7 and 8 respectively). This procedure tests all I/O ports verifying input and output signals are working correctly using software designed in the Arduino programming language and then transferred to the ATMega328. There will be three I/O ports used for this process. The software will tell the first one to turn on. This output will go to the 2nd one, which is used as the input. The software will tell the MCU if there is an “on” signal from this port, turn on the third I/O pin, which in theory should turn the LED light on.
1. Via a wire, connect the first two I/O ports to each other.

2. Insert a 330 Ohm resistor in series with an LED at the third I/O port. The LED will then connect to ground.

3. Run the software telling the MCU to turn “on” the first I/O port. This will send a signal to the second I/O telling the MCU to turn “on” the third I/O port. The LED in the third I/O port should turn on. Verify the LED is lit.

4. Repeat this process until all I/O ports have been tested for input and output signals.

7.0 Administrative Aspects

7.1 Budget & Financing

Currently, there are not any sponsors or significant contributors. The project team is currently asking for community support from various companies and groups. Any costs which are not covered by financial contributions will be split evenly between team members at the conclusion of this project. Our estimated budget is described in Table 7.1-1 below.

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Development Cost</th>
<th>Cost of Project</th>
<th>Cost to Reproduce</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAN8200</td>
<td>$0.00</td>
<td>$0.83</td>
<td>$0.83</td>
</tr>
<tr>
<td>LV-EZ1</td>
<td>$0.00</td>
<td>$24.95</td>
<td>$24.95</td>
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<tr>
<td>EM-406a</td>
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<td>$46.99</td>
<td>$46.99</td>
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<td>TDA0161</td>
<td>$0.00</td>
<td>$3.77</td>
<td>$3.77</td>
</tr>
<tr>
<td>en22 9 Volt</td>
<td>$0.00</td>
<td>$1.00</td>
<td>$1.00</td>
</tr>
<tr>
<td>RLS-R8030</td>
<td>$0.00</td>
<td>$1.77</td>
<td>$1.77</td>
</tr>
<tr>
<td>LM317</td>
<td>$0.00</td>
<td>$2.88</td>
<td>$2.88</td>
</tr>
<tr>
<td>MSI Wind U100</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$379.95</td>
</tr>
<tr>
<td>ATmega328 with Arduino Bootloader</td>
<td>$0.00</td>
<td>$11.00</td>
<td>$11.00</td>
</tr>
<tr>
<td>Arduino Duemilanove USB Board</td>
<td>$29.95</td>
<td>$29.95</td>
<td>$29.95</td>
</tr>
<tr>
<td>Bluetooth® Modem - BlueSMiRF Gold</td>
<td>$0.00</td>
<td>$64.95</td>
<td>$64.95</td>
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<tr>
<td>Unknown</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$40.00</td>
</tr>
<tr>
<td>PCB Building</td>
<td>$0.00</td>
<td>$60.00</td>
<td>$60.00</td>
</tr>
</tbody>
</table>

Total Costs: $44.95 $248.09 $668.04

7.2 Project Schedule

7.2.1 Spring 2009 Schedule

The project team followed the schedule in Table 7.2.1-2 for the Spring 2009 semester. The objectives for this semester were to complete the initial design review and to create documents describing project requirements and the design. The table lists a week by week schedule of what was accomplished and associated meetings. Additional project meetings were added but are not reflected in this table. Text prefaced with an “A:” are general notes.
and the objectives for the week. Text prefaced with a “B:” are items that were to be completed individually. Text prefaced with a “C:” are critical dates throughout the semester in regards to project completion.

### 7.2-1: Spring 2009 Schedule

<table>
<thead>
<tr>
<th>Week of</th>
<th>Objectives for the week</th>
<th>Meetings</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/22 – 2/28</td>
<td>A: Complete Table of Contents</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B: 2/24: Table of Contents Due at 7:30am!</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A: Divide parts of research section among group</td>
<td>2/26 – 8:30am – 10:15am</td>
</tr>
<tr>
<td></td>
<td>A: Discuss project ideas, specifications, requirements, schedule</td>
<td>2/26 – 8:30am – 10:15am</td>
</tr>
<tr>
<td></td>
<td>C: Research projects similar to ours and think about ideas for project</td>
<td></td>
</tr>
<tr>
<td>3/1 – 3/7</td>
<td>A: Discuss additional ideas relating to project design and specifications for parts and methods</td>
<td>3/3 – 8:30am – 10:15am</td>
</tr>
<tr>
<td></td>
<td>C: Research parts and methods for assigned sections (including part specs, cost, development)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C: Write research sections of paper for assigned sections</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A: Discuss initial project/vehicle designs</td>
<td>3/5 – 8:30am – 10:15am</td>
</tr>
<tr>
<td></td>
<td>What will be needed for project</td>
<td></td>
</tr>
<tr>
<td>3/8 – 3/14</td>
<td>C: Research parts and methods for assigned sections (including part specs, cost, development)</td>
<td>Spring break – Out of Town (Use email to communicate)</td>
</tr>
<tr>
<td></td>
<td>C: Write research sections of paper for assigned sections</td>
<td></td>
</tr>
<tr>
<td>3/15 – 3/21</td>
<td>B: 3/16: Have majority of research sections written for group discussion</td>
<td>3/17 – 8:30am – 10:15am</td>
</tr>
<tr>
<td></td>
<td>A: Discuss information obtained from research</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A: Create preliminary design plans with part specification and integration into overall design</td>
<td>3/17 – 8:30am – 10:15am</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3/19 – 8:30am – 10:15am</td>
</tr>
<tr>
<td></td>
<td>C: Perform additional research on parts and how to integrate (all)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A: Divide parts of design section among group</td>
<td>3/26 – 8:30am – 10:15am</td>
</tr>
<tr>
<td></td>
<td>C: Revise sections on research you wrote</td>
<td>3/26 – 8:30am – 10:15am</td>
</tr>
<tr>
<td>Date Range</td>
<td>Task Description</td>
<td>Time Schedule</td>
</tr>
<tr>
<td>------------</td>
<td>------------------</td>
<td>---------------</td>
</tr>
</tbody>
</table>
| 3/29 – 4/4 | A: Open discussion on project and possible design problems | 3/31 – 8:30am – 10:15am
|            |                  | 4/2 – 8:30am – 10:15am |
|            | C: Write design sections of paper for assigned sections |               |
| 4/5 – 4/11 | A: Open discussion on project and possible design problems | 4/7 – 8:30am – 10:15am
|            |                  | 4/9 – 8:30am – 10:15am |
|            | C: Write design sections of paper for assigned sections |               |
| 4/12 – 4/18| B: 4/20: Have majority of design sections written for group discussion | 4/14 – 8:30am – 10:15am
|            |                  | 4/16 – 8:30am – 10:15am |
|            | A: Open discussion on project and possible design problems | 4/14 – 8:30am – 10:15am
|            |                  | 4/16 – 8:30am – 10:15am |
|            | A: Divide remaining sections among group or write sections as a group | 4/14 – 8:30am – 10:15am |
|            | C: Write/finish all assigned sections |               |
|            | B: 4/21(morning): Document ready for review |               |
|            | B: 4/23(noon): Document ready for printing and delivered to printing press |               |
|            | B: 4/24: Final document printed and ready to be turned in |               |
|            | A: Discuss any concerns with final document | 4/23 – 8:30am – 10:15am |
|            | A: Absolute final document review | 4/23 – 8:30am – 10:15am |
|            | C: Review and revise final document |               |
| 4/26 – 5/2 | B: 4/28: Document Due at Noon! |               |
|            | A: Finals Week |               |

### 7.2.2 Summer 2009 Schedule

The project schedule for the Summer 2009 semester has not yet been revised at the time of this document. A schedule will be included in future revisions of this document. The objectives for this semester are to complete the final design, build and prototype this design, and to finalize documents describing project requirements and the design. The following list describes some of the critical events slated for the Summer 2009 semester:

- Review and confirm designs
- Order and obtain parts
- Build robotic vehicle base frame (battery, motors, steering)
- Build and test microcontroller module
• Build and test metal detecting module
• Build and test GPS receiver module
• Build and test obstacle avoidance module
• Write software to test individual modules
• Write user interface software
• Write autonomous software for overall operation
• Combine all modules
• Test combined system
• Modify system to resolve issues and test
• Finalize system; prepare product for delivery
• Present final project

8.0 Project Summary and Conclusions

The first semester research state of the project proved to be a success. The design from the beginning changed throughout to whole to semester to adjust for complications. The design also changed for the mere fact that the group members felt a better interest in a particular feature relating to the project. The group met several times throughout the semester to talk about designs and to just generally work on the project. When the meetings involved working on the project, many ideas were bounced around to fine tune the design and to make some unique changes for the group to get the most out of senior design.

The whole research process opened up a whole new level of engineering for the group. As compared to the boat design class and the marshmallow launch of 1006 and 1007, senior design is what puts our passion as an engineer into perspective, and it lets our creative minds and weird gizmos a reality. The project itself is well on its way to making a tangible prototype. All the designs are laid out and ready to be run and tested. The group has a set date for the first prototype to be up and running. If we make this date (beginning of July) we should be able to have a fully working project completed and polished by the time we have to present. To conclude, this paper has been doing a lot of talking. It’s now time to put our money where our mouth is.
9.0 Appendices

9.1 Works Cited

9.1.1 Global Positioning System (GPS) (3.2.2)
http://www.kronosrobotics.com/Projects/GPS.shtml
http://www.gpsinformation.org/dale/nmea.htm
http://www.gps.gov/
http://en.wikipedia.org/wiki/Wide_Area_Augmentation_System
http://www8.garmin.com/aboutGPS/waas.html
http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/waas/howitworks/
http://www.gpsreview.net/why-you-should-or-shouldnt-care-about-sirf/
http://www.mitre.org/news/digest/advanced_research/09_03/ar_gps.html

9.1.2 Metal Detectors (3.2.3)
http://www.gi.alaska.edu/~jesse/treasure/misc/howdetector.html
http://metaldetectingworld.com/reviews_pulse_metal_detector.shtml
http://www.hobby-hour.com/electronics/metal_detectors.php
http://www.vias.org/basicradio/basic_radio_30_06.html
http://www.onsemi.com/pub_link/Collateral/CS209A-D.PDF
http://www.datasheetcatalog.org/datasheet/CherrySemiconductor/mXutsur.pdf
http://www.zen22142.zen.co.uk/Circuits/Misc/metaldetector.htm

9.1.3 Sensors (3.2.4)
http://www.cs.brown.edu/~tld/courses/cs148/02/sonar.html
http://www.cs.brown.edu/people/tld/courses/cs148/01/sensing/sensing.htm
http://www.kronosrobotics.com/an150/DAN150.shtml
http://http://www2.lifl.fr/~decomite/caroll/caroll.html
http://www.acroname.com/robotics/info/articles/sharp/sharp.html
http://en.wikipedia.org/wiki/LIDAR
9.1.4 Power Supply (3.3.1)
http://support.radioshack.com/support_tutorials/batteries/bt-cazi-main.htm
http://www.mpoweruk.com/alkaline.htm
http://support.radioshack.com/support_tutorials/batteries/bt-siox-main.htm
http://www.zbattery.com/Connecting-Batteries-in-Series-or-Parallel
http://www.steatite.co.uk/batteries/battery_why_lithium.htm
http://www.batteryuniversity.com/partone-5.htm
http://batteryuniversity.com/partone-4.htm

9.1.5 GPS (3.3.3)
http://www.locosystech.com/

9.1.6 Sensors (3.3.4)
tult.aspx?SortField=ProductName,ProductName
http://www.hobbyengineering.com/H1145.html
http://itp.nyu.edu/physcomp/sensors/Reports/SRF04SonarRanger
http://www.acroname.com/robotics-parts/R93-SRF04.html

9.1.7 Voltage Regulators (3.3.5)
http://www.britannica.com/EBchecked/topic/632467/voltage-regulator
http://www.dimensionengineering.com/datasheets/DE-SW0XX.pdf
http://www.datasheetcatalog.org/datasheet2/1/03cgthpfat4t4ly5kfp51pwladfy.pdf

9.1.8 LED (Light Emitting Diodes) (3.3.6)
http://en.wikipedia.org/wiki/LED
http://www.superbrightleds.com/leds.htm
http://www.superbrightleds.com/specs/r2_specs.htm
http://www.superbrightleds.com/specs/r_specs.htm
http://www.superbrightleds.com/specs/w8045_specs.htm
http://www.superbrightleds.com/specs/W18030.htm
http://www.superbrightleds.com/specs/g3_specs.htm
http://www.superbrightleds.com/specs/g7532_specs.htm

9.1.9 H-Bridge (3.3.7)
http://en.wikipedia.org/wiki/H-bridge
9.1.10 Metal Detecting Design (4.1)

http://ecow.engr.wisc.edu/cgi-bin/get/ece/342/schowalter/reports/howametaldetectorworks.pdf
http://www.zen22142.zen.co.uk/Circuits/Misc/metaldetector.htm
http://issuu.com/mbhutta/docs/electronics_projects_for_dummies/307

9.1.11 GPS Design (4.6)


9.1.12 Sensors Design (4.8)


9.2 Permission Requests

Figure 3.2.2.2-1: The WAAS and GPS Network
To whom it may concern,

I am a student at the University of Central Florida and am currently working on a Senior Design project with two other students. As part of this project we must create design documents regarding the parts and technologies we are using. We wish to ask permission to use figures, tables, and information present in your data sheets, manuals, and website to enhance our documents.

The information we wish to use is located in this document/webpage:
http://www.mitre.org/news/digest/advanced_research/09_03/ar_gps.html

Thank you in advance,
Bob Augustine

Table 3.2.2.3-1: SiRF/NMEA Output Messages
To whom it may concern,

I am a student at the University of Central Florida and am currently working on a Senior Design project with two other students. As part of this project we must create design documents regarding the parts and technologies we are using. We wish to ask permission to use figures, tables, and information present in your data sheets, manuals, and website to enhance our documents.
The information we wish to use is located in this document/webpage:

Thank you in advance,
Bob Augustine

9.2.1 Metal Detectors (3.2.3)

http://www.bobsdata.com/index.html

- Basic Radio is licensed under a Creative Commons License, which means that this eBook is copyrighted, but you are allowed (and encouraged) to copy and distribute it. Click on the image at the right to see the details of the license. (vias.org)
  - The material including text and graphics can be printed, copied or stored on your computer for personal or internal company use but cannot be modified and redistributed.

- (ST.com and Cherry Semiconductors)
  - To whom it may concern,

    - I am a student at the University of Central Florida and am currently working on a design with a three man group in which we are considering purchasing and using one of your proximity detectors. As part of our requirement for this project we must compile a final report including all of our research and designs. We wish to ask permission to use figures, tables and information present in your data sheets and manuals in this final report.

    - Thank you in advance,
    - Mike Grasso

9.2.2 Sensors

Figure 3.2.4.2 – 1: Demonstration of Optical Object Detection
To whom it may concern,

I am a student at the University of Central Florida and am currently working on a Senior Design project with two other students. As part of this project we must create design documents regarding the parts and technologies we are using. We wish to ask permission to use figures, tables, and information present in your data sheets, manuals, and website to enhance our documents.

The information we wish to use is located in this document/webpage: http://www.cs.brown.edu/~tld/courses/cs148/02/sonar.html

Thank you in advance,
Bob Augustine

9.2.3 RC Vehicle

9.2.4 Power Supply (3.3.1)

- www.zbattery.com
  - I am a senior electrical engineer at the University of Central Florida. My group, which is comprised of three students all together, are doing a research report for our final senior design project. We're researching at this stage different batteries to put into our project and we would like you to grant us permission to use the figure of how you connected the batteries in series and parallel located on this webpage: http://www.zbattery.com/Connecting-Batteries-in-Series-or-Parallel

- Thank you for your time,
- Mike Grasso
- Undergraduate BSEE
- University of Central Florida

- Response:
  - Mike,

  We grant permission for you to use that article as long as
Zbattery is listed and there is a reference to our website.

Please let me know if need anything else.

Regards,
Karl Oehling
Zbattery.com, Inc.
800-624-8681
Fax 269-983-0029

  - I am a senior electrical engineer at the University of Central Florida. My group, which is comprised of three students all together, are doing a research report for our final senior design project. We're researching at this stage different batteries to put into our project and we would like you to grant us permission to use figures of your silver oxide battery located on these webpage: http://www.lasermax.com/product.php?id=106.
  - Thank you for your time,
  - Mike Grasso
  - Undergraduate BSEE
  - University of Central Florida

- Response
  - Mr. Grasso
  - Thank you for contacting us in regards to use of photos on our webpage and use of them in your research report. Please feel free to use the photos located on our webpage http://www.lasermax.com/product.php?id=106 to support your report.

  Cory Walton
  Marketing Coordinator
  LaserMax
  Ph: (585) 272-5420
  Fx: (585) 272-5427
  www.lasermax.com

9.2.5 Microcontrollers
9.2.6 Sensors
9.2.7  H-Bridge (3.3.7)


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  a. Hello,

  I'm a student at the University of Central Florida majoring in Electrical Engineering. I am apart of a Senior Design group that is made up of 2 other people. I would like to request permission to use your figures of your h-bridges being implemented using relays and transistors to be used in my final research report. These figures can be found here: http://www.dprg.org/tutorials/1998-04a/

  Thank you for your time,
  Mike Grasso
  BSEE Undergraduate
  University of Central Florida


  a. Approved

  Hello,
  
  I'm a student at the University of Central Florida majoring in Electrical Engineering. I am apart of a Senior Design group that is made up of 2 other people. We are researching different H-Bridges and we are considering yours to purchase. I would like to request permission to use the figures in your datasheets of your H-bridges to be used in my final research report.

  Thank you for your time,
  Mike Grasso
  BSEE Undergraduate
  University of Central Florida

  I'm not sure if the images you mentioned are our copyright or not, but if they are Jameco copyrighted material you have my permission.

  Regards,
  Greg

  Greg Harris
9.2.8 GPS Design

Table 4.6-1: EM-406a Manufacture Specifications

To whom it may concern,

I am a student at the University of Central Florida and am currently working on a Senior Design project with two other students. As part of this project we must create design documents regarding the parts and technologies we are using. We wish to ask permission to use figures, tables, and information present in your data sheets, manuals, and website to enhance our documents.

The information we wish to use is located in this document/webpage:

Thank you in advance,
Bob Augustine

9.2.8.1 GNAC

- Michael,
  - I would first like to say that I am a brother of Theta Tau (Gamma Class) and my senior design group members chose your senior design group as a similar project. I thought it was funny that you happened to be apart of the group that designed GNAC. Back to formalities, I wish to ask permission to use the figures you took and made in your GNAC report to use in our report. We will give the appropriate credit when approved.

  - In H&T,
  - Mike Grasso

- Response
  - Mike,

    You have my full permission to use the figures from our document for your report. Good luck!

    -Mike C.