University of Central Florida
Senior Design EEL 4914

UGV (Unmanned Ground Vehicle) Landmine and IEDS Detector

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Group 11

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1 Executive Summary

The purpose of this project is to gain real world experience in a classroom environment. This project will allow this group to go throughout a significant part of the product creation lifecycle. Although it isn't necessary to create something completely unheard of, the process allows the group to go through the process of creating something from nothing. This entails creating the initial idea, creating a basic outline of what is required of the project, designing this idea completely and thoroughly, and then prototyping the device from this thorough design.

For this project, our group wanted to deal with a specific few categories. The first of these categories was LIDAR. There is an immense hype behind LIDAR and its applications in robot vision, and because of this our group wanted to make LIDAR one of the primary focuses of the project. Our group also decided that we would like the robot to be autonomous, and be able to scour land and create a "safe path" from a known starting point, to a known ending point while avoiding and marking the location of landmines along the way. These were the main focuses of our group, and all subsystems were designed with these two ideas in mind.

The entire system, including the controller and device scouring for landmines, will consist of many subsystems including but not limited to mine detecting sensors, mobility, power systems, wireless communications, avoidance collision, and the ROS (Robot Operating System). For the mine detecting systems, our group will be using a metal detector for the primary method of detecting mines. This will be a custom made metal detector designed for a mobile mine detection system. For mobility, we will be using a track system that will allow for turning without forward movement. This is best to avoid mines directly in front of the device, once detected. Our group will be dealing with an AdHoc wireless communication network to allow for advanced computation to be handled by an external computer that would work as a controller. Our group will also be utilizing a multitude of sensors for avoidance collision. We would like to implement a LIDAR system that will create point cloud data to give real time 3D awareness to the robot, but must be filtered to be able to be used in direct sunlight. There will also be the implementation of sonar sensors to aide in detection of physical obstructions that the LIDAR may not have directly picked up due to sunlight. The ROS will serve as the backbone for this project, allowing us to design an autonomous robot based on preexisting tools to allow for ease of use and to avoid larger design problems that would naturally occur if we were to design the project completely from scratch. ROS will serve as a valuable tool with plenty of API's to allow for the smooth production of an autonomous robot with a significant quantity of customized aspects.

All of these subsystems will combine to create the Unmanned Ground Vehicle Land Mine Detector that will be used to scour lands and determine relative safeness of any particular area. This project will unite a significant amount of different disciplines, will allow for our group to truly work as a team, and allow our group to go through the primary functions of an engineer: design, build, and test. We expect the project to be challenging, but rewarding for all members of our group.

2 Project Description

2.1 Motivation and Goals

2.1.1 Motivation

Most people in the United States don't have to worry about stepping on a landmine or triggering and Improvised Explosive Device (IED) when they go about their personal lives; however, in many other countries around the world, this is a significant concern. Around the world, there are about 110,000,000 active landmines, waiting to be stepped on. According to the UN Mine Action Service, landmines kill 15,000-20,000 people every year (mostly children) and many countless more. Furthermore, the use of Improvised Explosive Devices has become a preferred method of engagement in guerrilla warfare. According to icasualties, more than 50% of all casualties in Operation Iraqi Freedom and Operation enduring freedom have been caused by land mines and IEDs. We are aiming to design a device that will autonomously scour lands, detecting and marking the location of possible land mines for safe removal or detonation. We will be creating a rover platform that is sturdy enough to support a sizeable lever arm that will contain a metal detector to detect the metal landmines and a LIDAR system to provide local area vision.

At the current rate of clearing mines, it will take humans thousands of years to clear all active landmines in the world, and countless more detecting for buried Unexploited Ordinance (UXO) that can be used for IEDs. There is an overbearing concern for land mines in many other countries, and this system will be designed to combat these problems. That is where the motivation for our Senior Design project resides.

2.1.2 Goals

The device will operate in such a fashion that will allow it to autonomously cover a predetermined path, and determine if this path is "safe", or free of landmines.

The device will be about 1.5 feet wide by 1 foot long at the base, with a lever arm that will extend approximately 1 foot beyond the length of the base. The device will sit at about 0.5 feet tall, to allow for room for a proper moving mechanism. There are plenty of other land mine detectors, but ours will use a combination of ultrasonic sensors, LIDAR detection, and metal detection to ensure the most accurate results, so that neither mines, nor Improvised Explosive Devices (IEDs) go undetected. Also, we will implement a physical and geographical marking system to create an immediate clear path and a mapping system that will document the mines detected within a certain area.

2.2 Objectives

The goal for this project is to create an autonomous vehicle that will be able to start at an established starting point and end up at and established end point, determining a clear path along the way. To do this, there will be a combination of quite a few complex systems.

The device created should be able to do a few different things. These objectives can be broken down into five major groups: mine detection, autonomy, mapping of location of mines, obstacle avoidance, path finding from start point to end point safely, and platform design.

The first of these objectives is the most important to the device itself, being able to detect mines. Without this, the entire project makes no sense. To be able to detect mines and make decisions based off their location is a very important objective. The next objective being that the device must be completely autonomous. This is an important objective because otherwise the device would rely on input that may not be able to be received at the time that is needed. Since this is completely impractical for a device that is searching for explosives, it is pertinent that the device will be able to roam and make decisions on its own.

The mapping of mines objective is heavily reliant on the mine detection system. Without that system working completely properly, there will be no way to register the location of a mine. This leads to a lot of other problems as well, because the system will simply not work if there are no mines found. This also means that even if the device doesn't explode, a clear path will not be able to be determined without the location of mines. Therefore, it is crucial that these two systems work well together.

To be completely autonomous, the device needs to make sure that it can see what's in front of itself. This brings in the importance of obstacle avoidance. There will be three functional systems that play into obstacle avoidance: LIDAR, sonar detection, and the database of mine location knowledge. Therefore, it is a major objective to make sure that this device functions properly.

The final objective will be to for the MCU to create a clear path based on all of the systems mentioned previously. This is highly dependent on the united functionality of all systems, and is one of the last objectives to be completed.

With all of these systems functioning properly, and all of the objectives being well defined, the project culminates into a device that will be able to create a safe path for any location.

2.3 Project Specifications

After researching all the necessary information for the different components of the project, a list of project specifications can be generated. Knowing the current objectives, the device will have a set list of specifications that must be met. These are the goals of the project that will aid in the design choices to be made for the device.

Design of Mobile Unmanned Ground Vehicle

- Metal Detection System
- LIDAR Based Navigation and Mine Detection
- Beagle Bone Black Head Unit
- Motor Controls that will run their individual systems
- Utilize wireless capabilities to MCU
- Utilize Linux and ROS for robot design
- Platform Design
- Design Custom MCU Application

3 Research

3.1 Platform

In this section, we will be talking about all the components that make up the platform, starting with the materials that can be used to build the chassis, followed by the measurements and the reason as to why we are going with this platform, then we will talk about the type of drive systems that could be used in the platform, and finally the possible motors to be used for this drive system.

3.1.1 Materials

In this section we will discuss the possible building materials to be used to give the best durability and performance to the vehicle. The main factors that are being looked at are the weight of the material, sturdiness of the material, and cost. The vehicle needs to be sturdy enough so that it does not wobble as it moves, and as the detection system sweeps from left to right detecting for land mines, and since the head of the metal detector will have to be at least 12 inches away from the vehicle in order to give it enough space to sweep from left to right, and not get any interference and maybe get a false reading because of the vehicle, it will also have to be heavy enough to keep a good center gravity and keep the vehicle better balanced. Although the vehicle will not be carrying any payloads, it will need to be reasonably light, so to it can be deployed by two persons. Lastly, it also has to be reasonably inexpensive so that the system can be produced for third world countries where it is needed the most.

3.1.1.1 Plywood

The use of plywood is widely used in many different projects, it is relatively inexpensive, and is readily available in many stores therefore if a mistake happens while putting a project together, it is not a big inconvenience to get another sheet of plywood and carry on with the project. Since plywood is made of layers of timber, it is very strong, and relatively light compare to other types of wood, it is also easy to cut with most garage tools.
However, this material may contain natural defects, such as knots, fabrication defects, or flaws from not being stored properly. Since plywood is made up of layers, it is not suitable for joints, and is affected if constantly exposed to certain weather, which can increase the probability of the layers in the plywood to come apart.

3.1.1.2 Aluminum

Aluminum’s weight to strength ratio makes it very useful when having to build many strong structures, and compared to other metals used for construction, it is less expensive. Aluminum is easy to cut and drill into, making it a good material to use for structures consisting of different sections or joints.
However, it is a metal and will get very hot when exposed to the sun for long periods of time, which is not a good thing for the electronics that will be stored inside, it is also a corrosive metal, which will lower the lifetime of the vehicle if not maintained properly at certain weather conditions, and it is very conductive, meaning that it might make interference with the metal detector

3.1.1.3 Plexiglas

Plexiglas is a light and fairly strong material, it is high impact resistance, and it is not affected by exposure to different types of weather, making it a great material to use for many outdoor projects. Plexiglas is very easy to cut, and drill into, it is very easy to use for making junctions and is also easy to glue together, this material can also be formed into different shapes without losing its strong and durable physical properties, this can be done by a process called thermoforming, where the Plexiglas is heated until it becomes flexible, it is then shaped into the desired shape, usually by a mold, and then letting it cool down, this can be a very useful for making parts that have a corner at an awkward angle, instead of having to connect to separate pieces together, you can just slowly heat the material and bend to the desired angle. The small Remote Controlled (RC) car shown below has a Plexiglas body composed of bent parts and parts that have been cut and put together. This material also works as a great electrical insulator, which is very useful for our project, lowering the chances of any interference with the metal detector.

Nevertheless, this material is not perfect, under certain conditions, it can cause a static discharge in the surface of the material, which could interfere with the electronics of the vehicle, this material will also undergo expansion under high levels of heat, which could compromise the vehicle's structure if proper precautions are not taken when the vehicle was designed and built, not only that, but it is also combustible under similar conditions as that of wood.

Figure 1 RC Car with a Plexiglas Chassis (Permission Pending)

3.1.2 Measurements

After researching and selecting the detection system for this project, certain dimensions like the height of the metal detector from the ground, and the minimum distance of the metal detector to the vehicle had to be employed in the design in order to make sure that we can get optimal readings from the detection system, another dimension was that of the height if the LIDAR's mount, so that better imaging can be collected by the LIDAR and lowering the chances of blind spots, due to this components necessity to be at this distances from the main body of the vehicle, the design had to be made with the dimensions shown below in order to make the vehicle stable, sturdy and to make sure enough space is available for all the motors, and batteries that will be inside the vehicle.

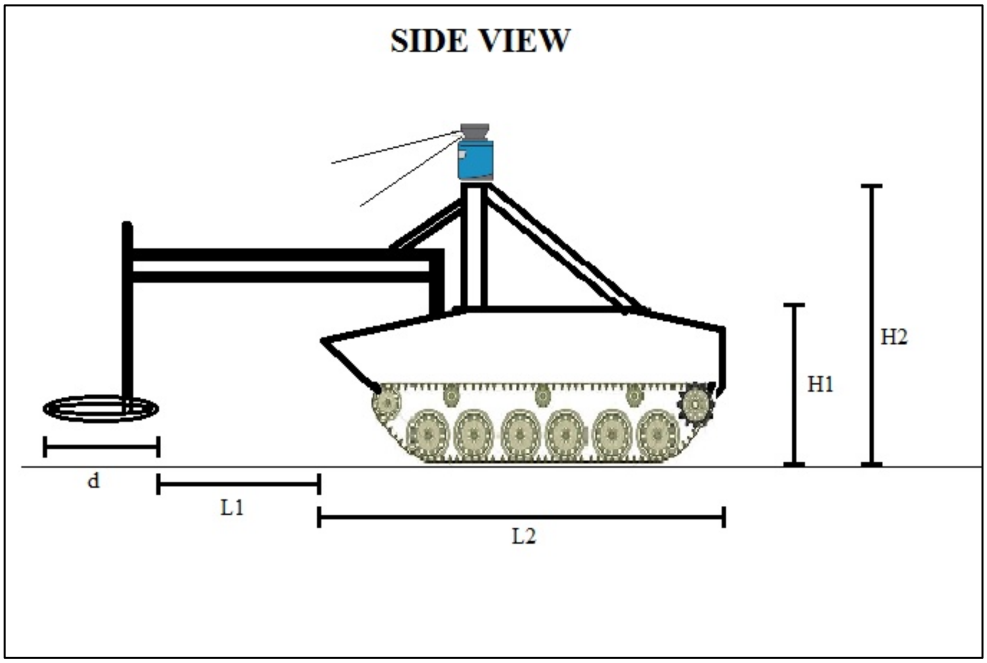


Figure 2 Side View of Design Specifications

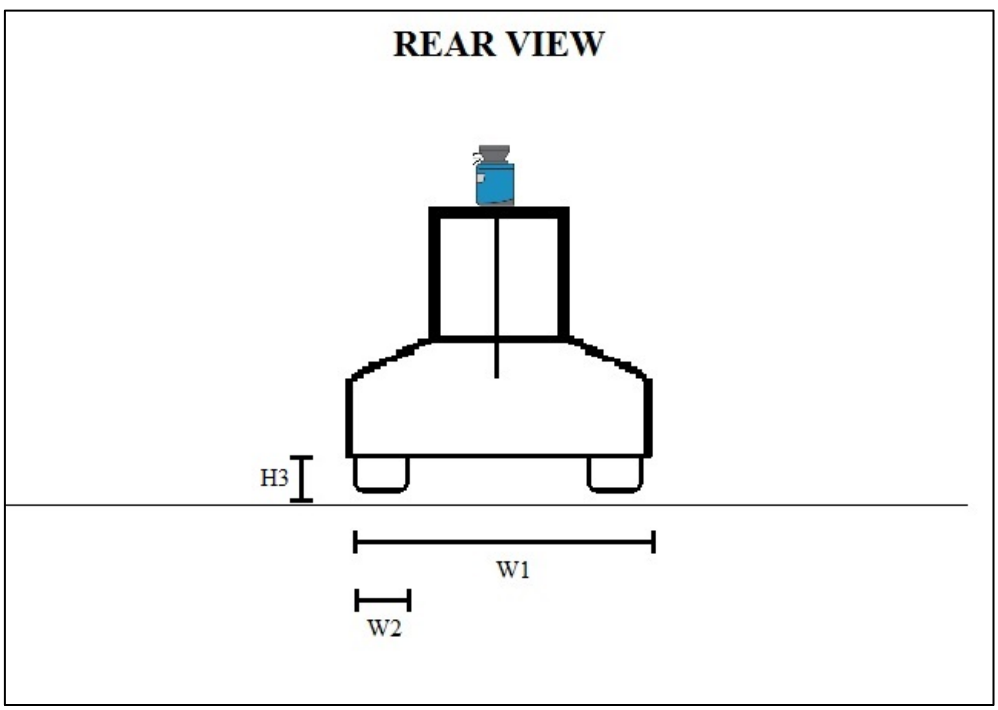


Figure 3 Rear View of Design Specifications

Table 1 Design Specification Measurements

Label	Description	Measurement (in)
d	Diameter of coil	7.87
L1	Distance from coil to platform	12.00
L2	Length of chassis	30.00
H1	Height of chassis	10.00
H2	Height to LIDAR	20.00
H3	Clearance	2.50
W1	Width of chassis	14.00
W2	Width of track	3.25

3.1.3 Drive System

The drive system for this project is very important, and plenty of research had to be done in order to make sure that the correct one was chosen. In order to accomplish the goals of this project, a drive system is need that will drive the vehicle in a smooth motion without any, or with minimum jerking motion, and with minimum slippage, while the detection system accurately sweeps the area for land mines or explosives, this will also contribute to a clearer image collection and processing from the LIDAR, also, the vehicle should not move too slow, or it will not be able to accomplish the task in a reasonable time, or move too fast, not giving the detection system enough time to scan the area and possibly driving over a land mine.

3.1.3.1 Wheels

Most ground vehicles use wheels to move around, making wheels less expensive, and more readily available, and also giving users a wide variety of types and sizes of wheels to choose from, wheels will give the vehicle the capability of being able to move fairly fast. Wheeled vehicles can also have more than four wheels, which will usually require multiple motors to make the vehicle more efficient, and consequently will also reduce slippage, and this makes the design of the vehicle easier to plan and implement.

However, wheeled vehicles have a tendency to lose traction in certain types of terrain or conditions, in autonomous vehicles this is a big problem, since this might cause the vehicle to get stuck, or lose calibration with its surroundings, this might be very dangerous for our project, even with more wheels added, slippage can still occur, this is due to the fact that only a small portion of each tier is in contact with the ground at any given second.

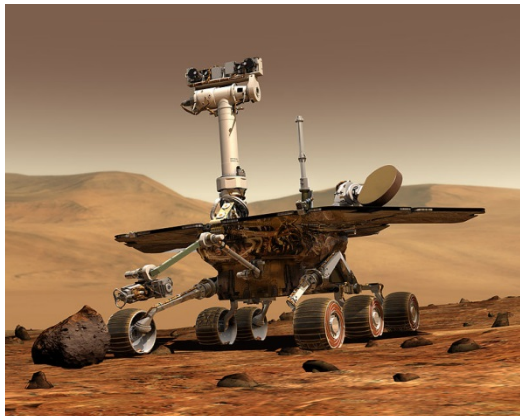


Figure 4 Portayal of NASA Mars Rover (Permission Pending)

3.1.3.2 Track System

Many big and heavy military vehicles, like tanks and amphibious assault vehicles use track systems to move around effectively, contrary to common misconception, tracks do not give extra torque to a vehicle, nevertheless, since the whole weight of the vehicle is evenly distributed throughout a bigger surface area, the slippage of the vehicle is greatly reduced, and making this vehicles very useful in soft and lose ground terrains, giving big heavy vehicles like amphibious assault vehicles the capability to come out of the water into very lose sand and keep moving without getting stuck. Track systems give vehicles the ability to turn in place, reducing the turning radius of the vehicle to zero, unlike wheeled vehicles that have to account this restriction into their navigation, they also give robotic vehicles the ability to move slowly and precisely without jerking motion, making them ideal for bomb removal robots like those used by the police and the military.

However, this vehicles turn by either only running one track, or by running one track opposite to the other, this motion puts a lot of strain in the track system and the ground, for big heavy military vehicles with very reliable track systems, there is nothing to worry about, but if you are to make your own, or buy a less expensive one, this might result in a track coming off place, or maybe even breaking, leaving the vehicle immobilized, track systems are also more expensive to buy, and harder to find, meaning that if a vehicle is being designed to use a track system, it might end up having to design the vehicle around the best track system found, or having to design one on your own, which is more difficult, and increasing the complexity of the whole design of the vehicle.

Figure 5 Bomb Removal Robot Carrying Military Ordinance (Permission Pending)

3.1.4 Motors

This section will be comparing the types of motors that should be used for the vehicle, the drive system will need two motors, in order to have a smooth drive, and be able to accomplish our goals, the motors do not need to be fast, the vehicle will actually need motors with enough torque to be able to pull all the weight of the whole system, and be able to be controlled smooth and precisely in order to be able to clearly detect land mines, and prevent jerkiness of the vehicle and help the LIDAR get a clear imaging of the terrain.

3.1.4.1 Brush DC Motor

Brush DC motors are composed of four parts; the stator, electromagnetic windings, commutator and brushes. The Stator is the outside shell or the case of the motor, attached to it will be two magnets with opposing magnetic fields pointing towards the center of the motor, in some cases, electromagnetic windings producing opposite magnetic fields are used instead of magnets, the rotor is in the middle of the motor, which has multiple electromagnetic windings, this windings are connected to different segments of what is known as the commutator, this is made of a sheet of copper, and it is located in the axel of the rotor, the two DC electrical inputs are connected to brushes made of carbon, that brush against the different segments of the commutator, charging the different electromagnetic windings, creating magnetic fields, and enabling the rotor to rotate, this makes it possible to control the motor without having to change the current in the electromagnetic windings, however, the brushes are prone to wear, and will leave carbon residue inside the motor, which over time will reduce the effectiveness of the motor. Brush DC motors are low on cost, and simple to control, they require more maintenance and have a lower life span when used intensively.

3.1.4.2 Brushless DC Motor

Brushless DC motors have very similar components to brush DC motors, however they are almost opposite to each other. The brushless DC motor has the magnets in the rotor instead of the stator, these magnets have opposite magnetic fields pointed outwards from the rotor to the stator. The stator therefore has the multiple electromagnetic windings, this windings are set in phases, so that symmetrical opposite windings have inverted currents, using an electronic sensor, current is switched through the different phases, creating a switching magnetic field through the phases making the magnets rotate. Brushless DC motors have longer life spans and due to the lack of brushes, there is little to no maintenance, however this motors are more expensive, and are a bit more complicated to control,

3.1.4.3 Stepper Motor

Stepper motors are similar to brushless DC motors, they both use permanent magnets in the rotor that are moved by the change in current in the electromagnetic windings surrounding the rotor, however the magnets in the coil are axil and not radial. The stepper motor works by sending different pulses to the different sets of electromagnetic windings, this windings magnetize the salient poles with teeth, each pulse results in one step, this steps can be larger or smaller depending on what is required of the motor, this results in a precise motion of the motor, and is usually less expensive than DC motors, however, this stepper motors are bigger and heavier than brush and brushless DC motors, this motors also draw more power from the constant current that is needed to turn on and off the poles, which also makes this motors get hotter than others, they also require an increase in voltage to increase the speed, due to the rate of steps limitation, they do not operate as well at higher speeds, this motors can be more difficult to control than brush and brushless DC motors, they also have torque disturbance problems, and do not provide any feedback, making it harder to use in uneven terrain.

3.1.5 H-Bridges

In our project, we require motors to move the platform to and from its defined destination. When working with directional movement, speed, and torque, a motor controller is required for any form of electrical motors. A key factor in finding the right motor control will dependent on if the device will be able to meet the specifications and capabilities, such as: stopping quickly enough when an obstacle and/or metal are detected from the sensors communicating with the platform. Another important characteristic to consider is how the vehicle will be able to turn and avoid an obstacle when detected.

Our IED/Mine detector will need to have all these capabilities to carry out its objectives, because when working with potential explosives it is important that the mobility and accuracy of motors are able to avoid the identified obstructions. These motor controllers work by using switches that are designed to allow current to flow through a certain directions when connected to a power source. The switches can be used in a form of relays, contractors, and MOSFETs, in order to limit or supply current in specified directions and value. H-bridges are the commonly used motor controls when it comes to working with DC motors.

The design of the h-bridge is meant to allow reversible capabilities with the placement of four switches that form the shape of the letter H. By taking an input voltage and turning on the correct combination of switches the motor will be able to take a load in both directions. This allows the current to flow through the motor causing the shaft to move in a certain direction (Forward or backwards). Remember that one should never close both transistors on the same side (in Figure X1, Q1 and Q2, or Q3 and Q4) because this will create a path of least resistance straight to the ground. This will cause a short within the power supply, and will most likely destroy the h-bridge.

As seen in Figure X1 and X2 below by changing the polarity, the motor will spin in a certain direction when the switches are opened as shown. Also, shown in Table X1 when applying voltage to the designated inputs of the specific components, (In this case FET transistors) this will cause the current flow through the motor to make it urn forward, reverse, or stop entirely.

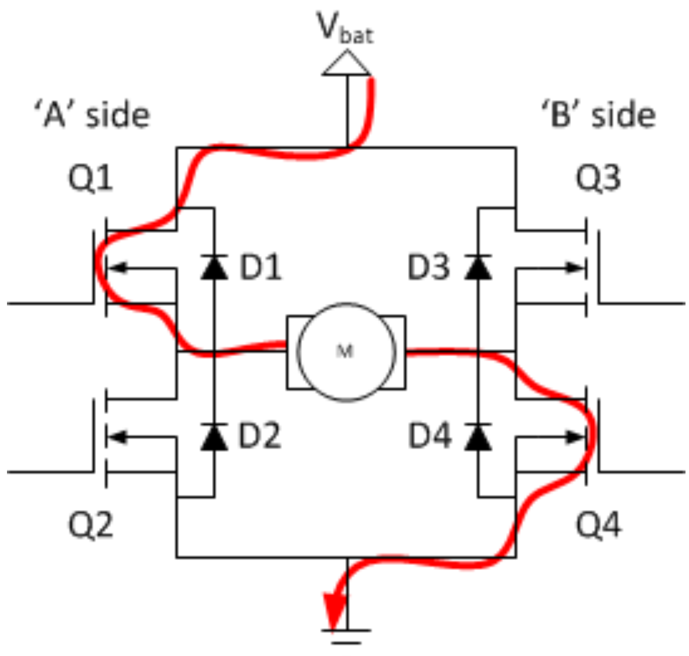


Figure 6 (Permission Pending)

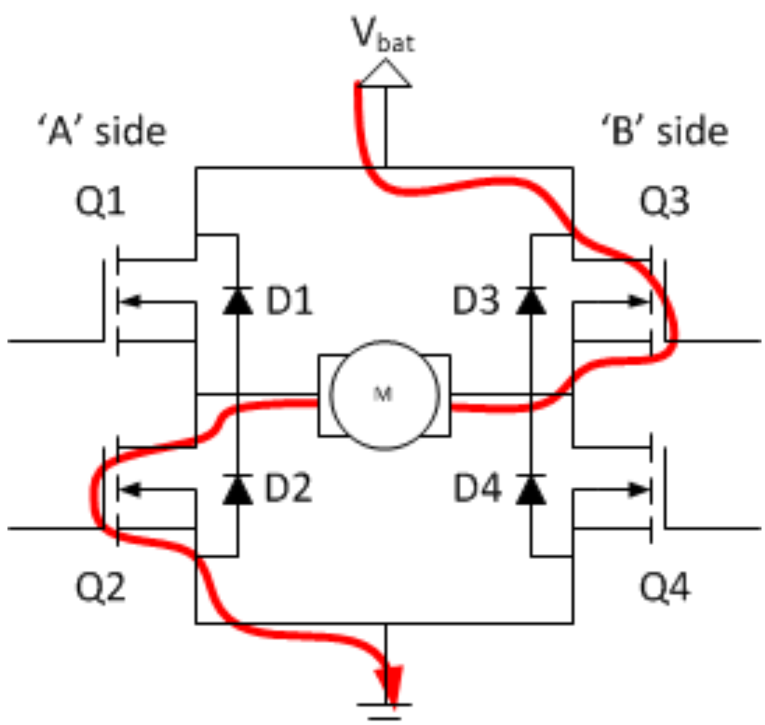


Figure 7 (Permission Pending)

Table 2

Function	Q1	Q2	Q3	Q4
Forward (Figure X1)	High	Low	Low	High
Reverse (Figure X2)	Low	High	High	Low
Brake	High	Low	High	Low
Brake	Low	High	Low	High

Another important component to consider is diodes. The diodes are not only used as their common application to block current, but instead create a path for the energy still in the coils to discharge themselves. This also prevents any voltage still in the coil of the relay from creating any initial spikes to the motor, and also prevents the high returning voltage from damaging the MOSFET's and other transistors being used in the circuit (Known as fly back diode, and catch diode). Their application differs depending on the type of h-bridge being used on the design as will be explained in the following sections.

In the following sections, different types of h-bridges will be discussed along with the advantages and disadvantages of each. Important attributes such as power consumption, design specifications and cost will be taken into consideration when selecting the h-bridges used in our design.

3.1.5.1 Relay H-Bridges

H-bridges composed of relays are function equivalent to those that use semi conductive materials. They are controlled and powered the same as other h-bridges, however the configuration and design differ. Schottky diodes are a necessity when using a relay h-bridge, because they are needed to prevent spike voltage stored in the inductors from damaging the motor control. The advantage of this style of h-bridge is that the parts are easy to come by and the power needed to control the speed is varied by the duty cycle (on/off ratio) of the power supplied. This can also be seen as a disadvantage because it can be viewed as an inefficient way of controlling the speed, compared to using a pulse width modulator (which will be described later in this section. Also, compared to semiconductor material, this form of h-bridge takes up more physical space, and components are worn out easier. Shown below in Figure X3, is a schematic of a relay h-bridge that is powered using 12V. As seen below, the functionality is equivalent to its alternatives, but design varies slightly.

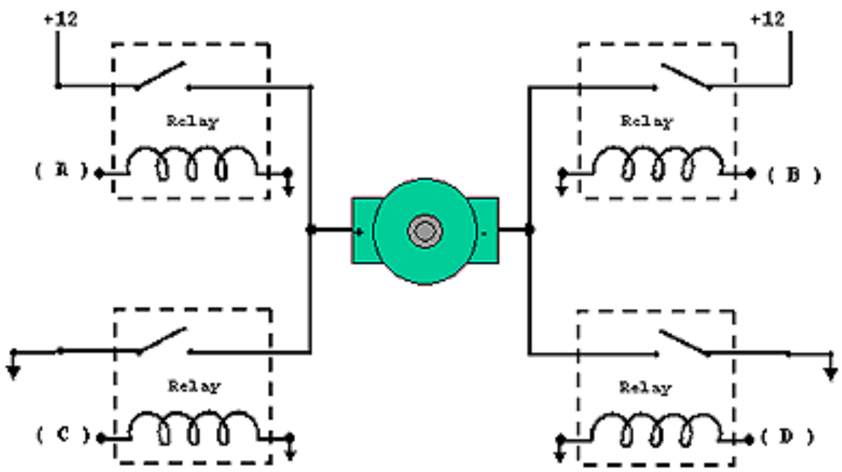


Figure 8 (Permission Pending)

3.1.5.2 FET (Field-Effect Transistor) H-bridge

Field effect transistors are commonly known and used as MOSFET's (metal-oxide-semiconductor field-effect transistor), and as described in the introduction to h-bridges they act as switches when voltage is applied at the gate terminal. Although this h-bridge uses a semiconductor material, compared to the relays, they serve the same purpose. As shown in Figure X4, the MOSFET h-bridge configuration requires diodes for reasons discussed earlier. In particular Schottky diodes are a common choice for the catch diode. Characteristics such as a 0.2V turn on voltage and its ability to be used in advanced switching applications are reasons for preferred method of diodes for an h-bridge.

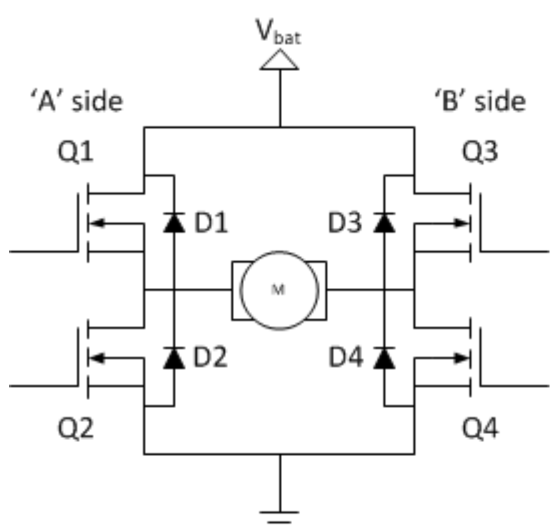


Figure 9 (Permission Pending)

An advantage of using a MOSFET design is that there are both N-channel and P-channel MOSFET's, which provide the luxury of allowing the high-side drivers (P-MOSFET) to perform as current sources and the low-side drivers to act as current drains (N-MOSFET). Also, MOSFET's are more efficient than relays and BJT's (Bipolar junction transistors), because there is very little internal resistance and no current is wasted through the gate. Some drawbacks are that these designs take up a relative amount of space on a printed circuit board and can dissipate a substantial amount of heat.

3.1.5.3 Integrated Circuit H-bridges

As described before there are many different types of h-bridge designs such as relays, BJT's, MOSFET's and many others not described in this report. The different variations have their pros and cons, but ultimately fall short to the benefits and advantages that integrated circuit h-bridges provide. They take the best designs and attributes, and place them on a compact circuit.

Integrated circuit h-bridges provide many extra perks that normal h-bridge designs can't support. For example, some IC h-bridges have pulse-width modulators that provide the ability to control speed by controlling the width of the pulses of equal voltage using logic and series. In technical terms it controls analog circuits with digital inputs, using square wave pulses, and duty cycle. This is more beneficial than controlling the output linearly, and allows the battery life to be extended.

IC h-bridges also have the ability to be designed to a specific application, in our case DC motors, and designs the characteristics around its application. Some of these features include: PWM control (extremely useful when controlling speed), ability to carry high current and wide supply voltage range, thermal surface mounts (provide a stronger resistance to heat), and protection features. The protection features are under voltage lockout, overcurrent protection, thermal shutdown (if too hot), and fault condition indication pin. There are many different features that prove to be worth the cost, because when prototyping and testing materials, things go wrong. However, with the right measures of protection used in IC h-bridges, this will prevent damaging components within the h-bridge and most importantly the motor control unit.

The application for our project will benefit from the features and perks of IC h-bridges. By having pulse width modulators, protection features, and dual motor capabilities, our project will minimize cost, space, and time that is required to provide complete functionality to our vehicle. There are several IC h-bridges that fit our portfolio, such as the Texas Instruments DRV8848 Dual H-Bridge Motor Driver that will be discussed in the selection portion of this report.

3.1.6 Pulse-Width-Modulators (PWM)

When dealing with dc motors one would use h-bridges to control forward movement, reverse movement and braking. However, to control the power and torque desired from the motors, a pulse width modulator is used. The pulse width modulator works by delivering square wave pulses to make up an analog signal without having to continuously alter the analog signal.

This works by sending a digital input to provide a square wave form, controlled by a duty cycle, to produce a modulated output wave form. For example, as shown in Figure XX below, when a series of square wave pulses are sent to a PWM an output modulated signal is produced to mimic that of an analog signal. The duty cycle is the 'high' input signal which creates the waveform as shown below, which will be varied depending on desired output voltage.

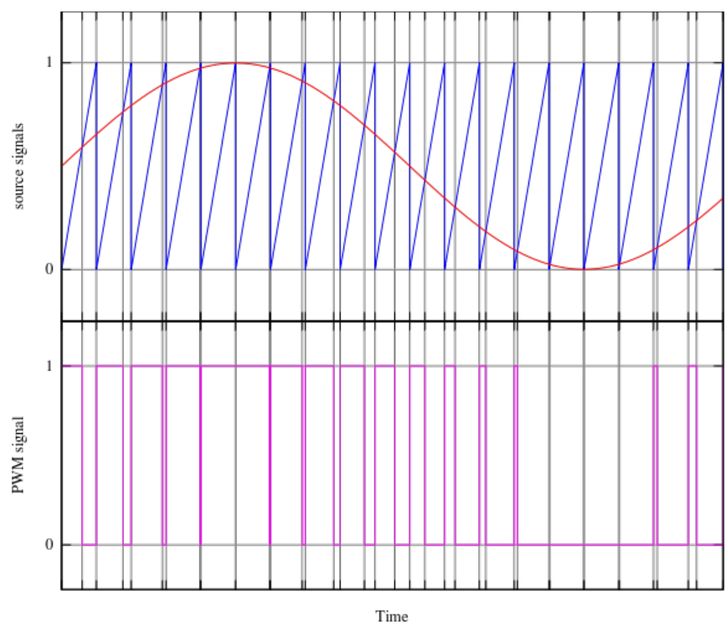


Figure 10 (Permission Granted from maxima)

Pulse width modulators are commonly used because they require a lot less energy to power the system, which in turn creates an extended battery life. This is because the power loss in the switching devices is minimal, when off no current is delivered and when on the voltage drop across the load. One of the key factors to consider is to create a high frequency when controlling the input signal to ensure clean yet immediate controls. This is needed because if the ground vehicle in the project detects a mine or IED, it is imperative that the vehicle comes to an immediate stop so that it does not set off and explosives. This will be an important characteristic to consider when choosing the correct controller.

With further research, instead of purchasing and using a pulse width modulator connected to an h-bridge, there are several alternatives to h-bridges that have an internal PWM interface on the IC. In particular when looking at the DRV8848 dual H-Bridge Motor Driver we have the capability to control the PWM using the digital signals sent from the controller (in this case a MSP430 Launch Pad).

3.2 Power System

For our unmanned ground vehicle (UGV), we will have many devices that will require a power source. This power source will need to be wireless, because our vehicle will support the following components: metal detection, LIDAR system, Beale Bone Black (single board computer), and a wireless, motor controller and serial communication cape (PCB's) that will be shielded onto the single board computer. In the following sections we will evaluate various battery selections, power supply methods, and the different power controls attributed to the components.

When evaluating the different power sources, we will evaluate whether we will have a single power source to supply all components, or provide each individual component with its own power source. In the following sections when evaluating the different battery types we will discuss the size of the battery, durability associated with extensive use, charge rate, discharge rate, operating voltage, and capacity.

3.2.1 Battery Selections

3.2.1.1 Alkaline Batteries

The most common form of battery used worldwide, alkaline batteries, are a type of primary batteries that produce charge from reactions between zinc and manganese dioxide. Since they have a higher energy density and can be stored for a great amount of time without depreciation, these batteries are used in most day-to-day electronics. The capacity associated with these batteries is dependent on the load, given that most provide a voltage output of around 1.5V. They normally have finite charge produced per-unit; however, there are rechargeable alkaline batteries available. The only issue associated with its rechargeable capabilities is that each charge cause the physical battery to lose its optimal capacity making them inefficient for reliable applications.

The main benefit of using an alkaline battery is that they are low cost and easily replaceable. This is also a drawback because the cost will add up when having to constantly replace them. For our applications if used efficiently these can be cost efficient, but with the components being utilized in our project they can become more of a liability if a constant charge is not supplied to our power sensitive components.

3.2.1.2 Lithium Ion Batteries (LiON)

Lithium Ion batteries are secondary cell batteries (rechargeable) that are generally lighter in weight when compared to same size batteries of different elements. They are very popular and widely used in consumer electronics, because of their light weight lithium and carbon composition. The elements that lithium ion batteries are composed of are very reactive, which allows a lot of energy to be stored in its atomic bonds. They are popular batteries used in handheld electronics, because of its high energy density no memory effect and slow discharge when inactive make them ideal for chargeable electronics. The composition of the lithium ion batteries consist of positive electrodes, negative electrodes, and electrolytes. The negative electrode (anode) is made up of carbon and the positive electrode (cathode) is made up of metal oxide. And the electrolyte is a lithium salt that acts as a carrier between the positive and negative electrodes when there is current flow. When charging the cylindrical cells, the lithium ions move from the positive to negative electrodes and when discharging the lithium ions move from negative to positive electrodes.

The capacity associated with lithium ion batteries are based on the size. The manufactures of lithium ion batteries will decrease with the increase in the number of charge cycle that it endures. It is approximated to drop linearly 80 percent over 500 recharges assuming ideal conditions (no age depletion, or self-discharge due to limited use). Other factors such as temperature can affect the life span of the battery, for example if you leave your laptop (with lithium ion battery) in the car when it is hot, the battery life will be greatly reduced.

When being charged from an external power source, the power source provides a higher voltage than the battery, which causes the current to reverse direction making it go from discharging to charging. In essence the source is applying a constant current until the voltage limit in each cell is maximized. Once the voltage limit is reached the battery balances the charge of each cell until they are equal throughout. Lastly, the constant voltage phase applies a voltage equivalent to the maximum cell voltage multiplied by the number of total cells. The voltage-current relation to charge time is shown below in figure 11.

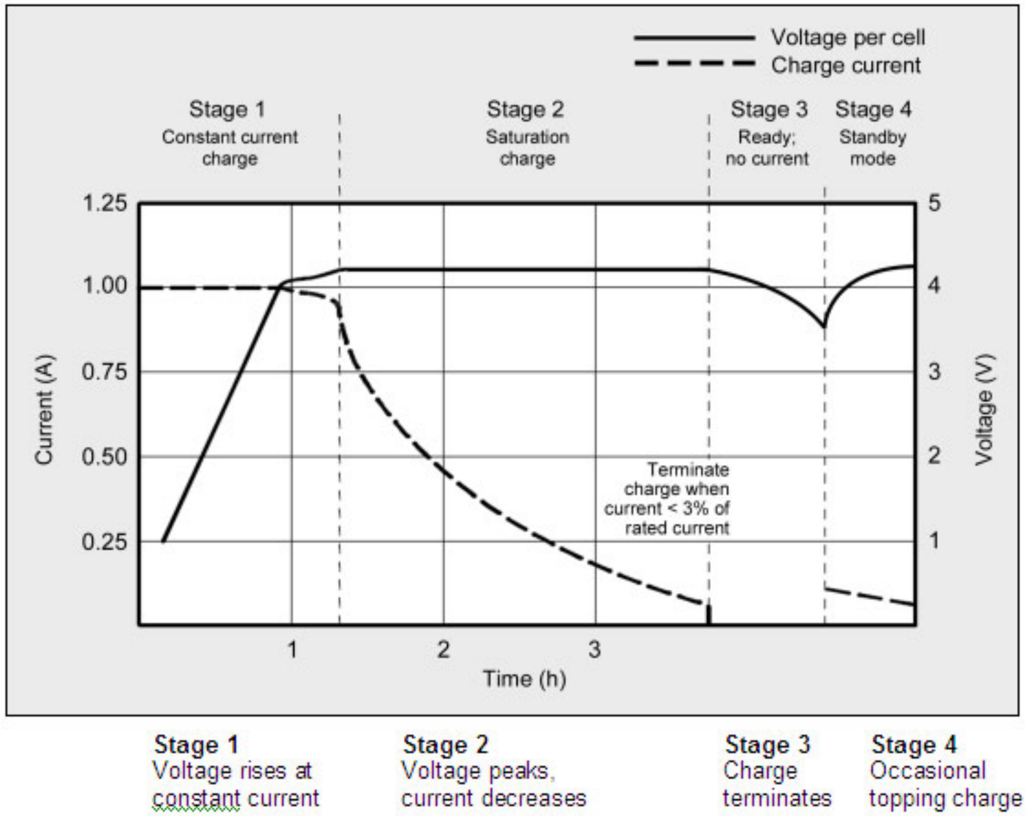


Figure 11 (Permission Pending)

Discharging occurs as soon as it is disconnected and/or not delivering any form of current. The lithium ion battery has an average self-discharge rate of 1% to 2% per month, and will increase proportionally to the lifespan of the battery. On average the average battery life cycle lasts about 400 to 500 cycles or charges. As described earlier, any exposure to extreme temperature results in decreased lifespan of the battery. Shown below in Figure XX, the current discharge is related to the cell voltage capacities associated with the battery.

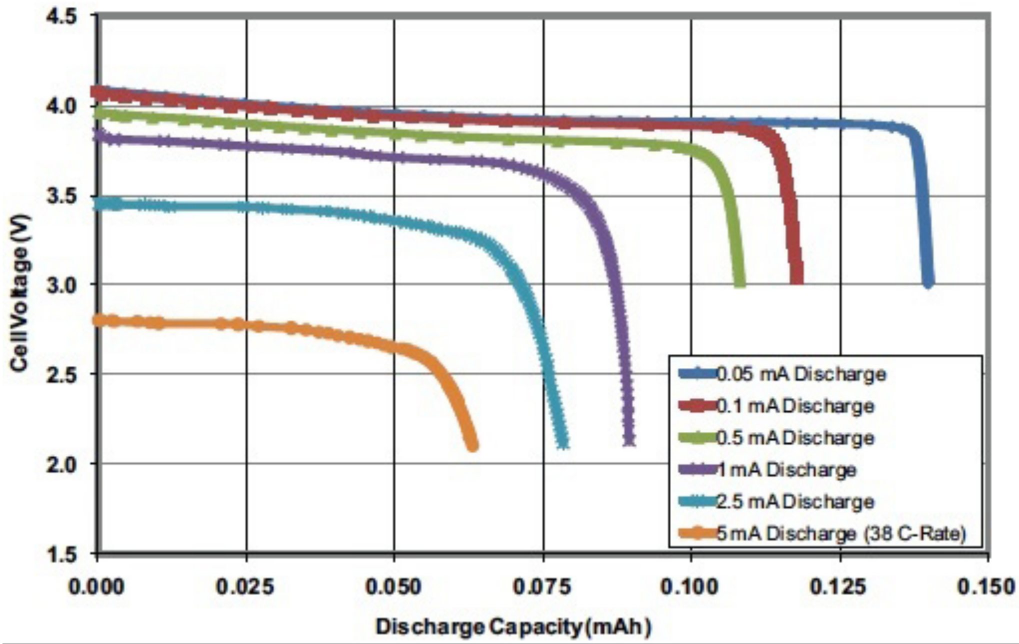


Figure 12 (Permission Pending)

3.2.1.3 Lithium Polymer Batteries (LiPo)

Lithium Polymer batteries are similar to the lithium ion battery in that they are both rechargeable, and function the same way when charging and discharging. They are composed of the same anodes and cathodes; however the electrolyte used is a polymer electrolyte instead of the lithium electrolyte used in lithium ion batteries. Another minor difference comes from the shape of the cells. As you may recall in the lithium ion battery, the cells are cylindrical compared to the flexible pouch like cells used in lithium polymer batteries. This can be seen as an advantage because it makes them lighter in weight and flexible to a certain degree. At the same rate it is more prone to damaging and leakage.

The charging speciation's for lithium polymer batteries is shown in figure XX below. The fully charged LiPo is about 4.2 to 4.35 volts and discharged ranges from 2.7 to 3.0 volts. Since lithium polymer is a hybrid version of the lithium ion battery, the charging and discharging methods are equal for both, however, the electrical characteristics deviate slightly. Shown below is the charging time relation to the voltage and current of the battery.

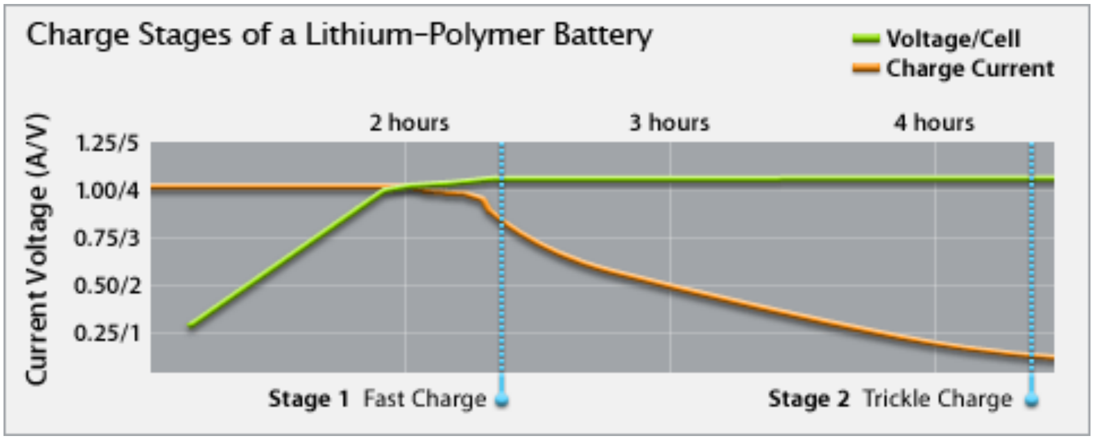


Figure 13 (Permission Pending)

3.2.1.4 Nickel Cadmium (NiCd)

Nickel cadmium rechargeable battery is composed of nickel oxide hydroxide and metal cadmium that serve as electrodes. Nickel Cadmium batteries have been used since the early 19th century and were the preferred method of choice until lithium ion batteries were discovered. This is attributed to the fact that nickel cadmium batteries suffer from the memory effect, which results in the sudden drop in voltage from when the charge cycle began to recharge. Another charging issue is that over charging the battery can cause the battery to appear to be fully charged when in reality it is not. Also, cadmium is a toxic heavy metal, so the cost incorporated with these batteries are much higher than regular 1.2 volt batteries.

Nickel cadmium has just as many benefits as it does disadvantages. For example, because of the heavy metal, they are very difficult to damage, and have a significant number of recharge cycles than most rechargeable batteries (about 2,000 cycles). Also, they have a higher energy density, and are lighter and smaller to their counterpart lead-acid batteries. Below in Figure XX

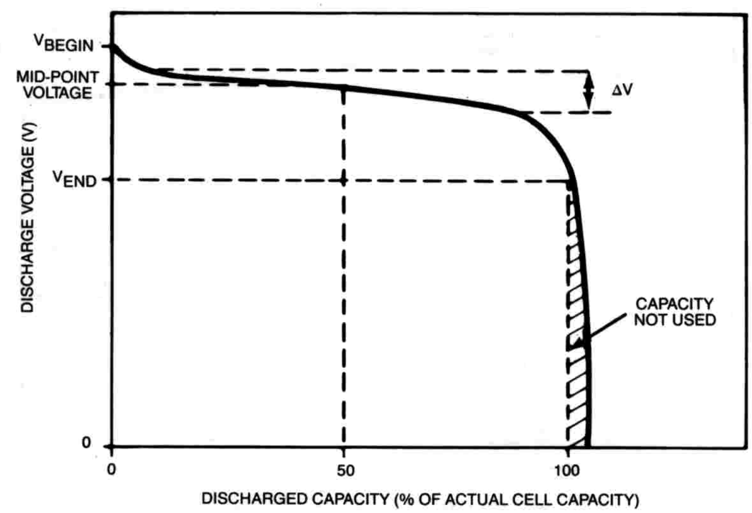


Figure 3-4 Nickel-Cadmium Cell Discharge Curve

Figure 14 (Permission Pending)

The charging of nickel cadmium can be done a different charge rates depending on the brand an specifications. The charge rate is based on the amp-per-hour capacity and is supplied a steady current during the charge period. The battery has a discharge rate of 0.90 to 1.0 volt and a steady charge rate of 1.2 volts. The risk associated with the memory affect and over charging, gives an uncertainty as to whether this battery would serve as a useful option because of the risk of the batteries ability to provide reliable voltage.

3.2.1.5 Nickel Metal Hydride (NiMH)

Nickel metal hydride batteries are rechargeable batteries that have high capacities that are two to three times the size of nickel cadmium batteries. The difference between the two is that nickel metal hydride uses a hydrogen absorbing alloy instead of the heavy toxic cadmium metal used in nickel cadmium. Also, the memory effect is no longer an issue when working with nickel metal hydride batteries, which gives it the capabilities of sustaining 500 to 2000 cycles depending on the brand of the battery. The trade-off that comes along with the eliminated memory effect is that are less durable (because it does not use a heavy metal) and has a high discharge rate, meaning that by the time someone receives their battery after purchase, the battery would have (on average) lost approximately 30 percent of its initial charge.

Similar to its prior counterpart the nickel metal hydride battery maintains a constant voltage throughout most of it discharging. This small margin of difference creates an issue when identifying when the battery level is low, but when comparing to alkaline batteries this magnifies its longer lifetime as shown in Figure XX below.

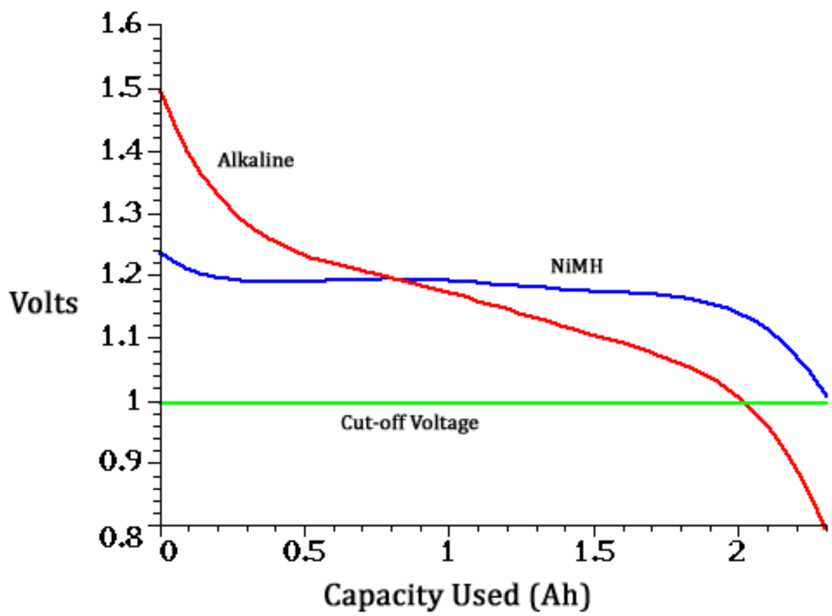


Figure 15 (Permission Pending)

3.2.1.6 NiCd vs NiMH Batteries

Although both nickel cadmium and nickel metal hydride batteries have very similar characteristics, they have different applications. NiMH has about double the discharge rate that is produced by NiCd, which results in more frequent charge cycles. However, NiMH does not suffer from the memory effect preventing underlying issues to come about, unlike its derivative Nicd. NiCd has the ability to handle high rate charges, and because of the low internal resistance it allows the battery to achieve a higher maximum discharge rate when using high powered applications. Both have their advantages and disadvantages, so when deciding between the two is dependent on the application.

3.2.2 Voltage Regulators (Power Control)

When working with a variety of components and parts, a regulator is essential to vary voltage and current needed to run each subsystem. Selecting the desired power needed to operate each system is important to have a consistent functioning system, because if a component is supplied with too much current and/or voltage it can damage parts or give inaccurate outputs causing an error with the circuit. There are several methods of regulating input voltages, but we will discuss the main methods: switching regulator, linear regulator, and Zener diode circuit regulator.

3.2.2.1 Switching Regulator

Switching regulators are one of the most commonly used voltage regulators in the market. Its efficiency compared to other alternatives makes this voltage regulator popular, because it has the ability to convert any supplied voltage to a desired output without any limitations on the efficiency. The inductors and capacitors provided this benefit, because they in an ideal scenario do not dissipate any power. The switches duty cycle (on time vs off time) controls the amount of charge applied to the load. A transistor will act as the switch that controls the duty cycle, when "on" there will be no voltage drop and the current will flow freely and when "off" there will be no current flowing and an applied voltage. Essentially, the switching regulator will take in an input voltage in sections, store the energy needed in the capacitors and inductors, and then control the applied load voltage by using duty cycle to control the switch. Basic switching regulators have similar configurations to that shown below in Figure XX.

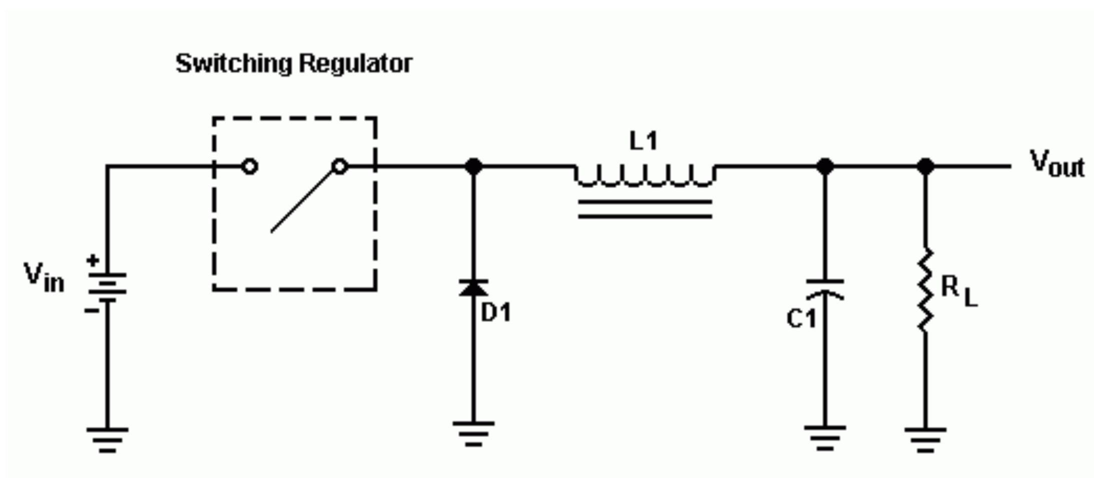


Figure 16 (Permission Pending)

The benefit of a switching regulator is the efficiency, which allows power to be conserved within the system. Also, because of the use of capacitors, inductors, and diodes they do not dissipate as much energy and heat. They can also have the ability to provide a higher output voltage than the input voltage supplied to the regulator, and the ability to output inverted polarity in case a negative output is needed.

There are some disadvantages to the switching regulator that make other alternatives more useful depending on the application. To begin with, switching regulators tend to make a lot of noise and ripples because the constant switching rate (duty cycle) used to control the voltage applied to the given circuit. Another disadvantage is that the complexity of the integrated circuit requires an inductor, capacitor, diode, and sometimes filters. This causes an increase in cost for these IC's compared to linear regulators and also an increase in size/space needed when designing a PCB.

3.2.2.2 Linear Regulator

A linear regulator uses the basic properties of voltage divider, using resistors to control the amount of output power desired. The variable resistor is manipulated to keep the desired constant output voltage, which causes heat to be dissipated from the change in the input voltage compared to desired output voltage. This causes the linear regulator to be very inefficient, because much of the energy is dissipated through heat. In figure XX below you can see the basic design of a switching regulator and as noticed the variable resistor can be seen as a potentiometer that controls the power supplied to the load.

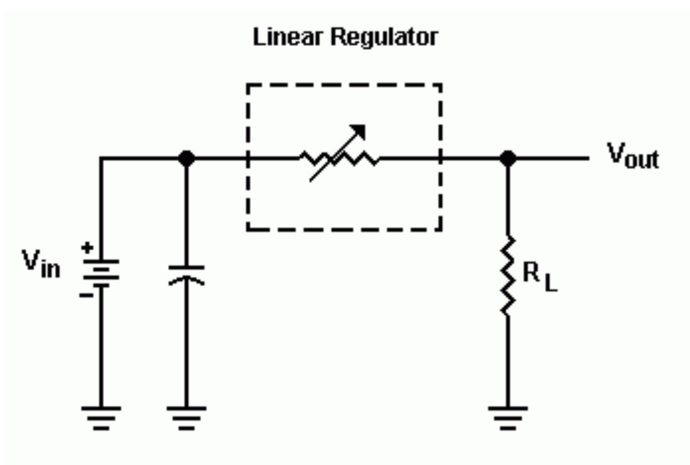


Figure 17 (Permission Pending)

The benefits of using a linear regulator are associated with its simple design. Since the voltage control is determined by a variable resistor, the circuit design will only require minimal components making it low cost for development. Another attribute derived from its simplistic design is small size; this is important to consider when designing small PCBs where space is essential.

Although the simplicity of the design can be used to its benefit, it is also one of its weaknesses. For starters, the linear regulator is very inefficient when compared to the switching regulator. This has a lot to do with the voltage drop (loss), and can become a noticeable issue when using high voltage regulations. Also, compared to the switching regulator, the linear regulator does not have the ability to output a voltage higher than its input voltage. So ensuring that your input voltage is higher that the desired output is important to the design.

3.2.2.3 Zener Diode Regulator

As seen below in Figure XX, the Zener diode regulator has an identical configuration to that of a voltage divider circuit. The main difference between the linear and zener diode regulator is that the zener diode acts as the voltage regulator. It does so by controlling the amount of current supplied to the load (in this case R2), and ensures that the output voltage does not exceed its maximum capacity.

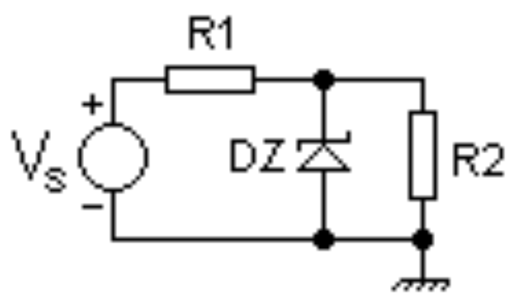


Figure 18 (Permission Pending)

The advantages associated with zener voltage regulators are its cheap cost and simple design. However, there are many issues associated with the limits of the voltage regulation. For example, the zener diodes characteristics can be a limit on how high of a voltage can be regulated without destroying the component. Also, there will always be a 0.6 to 0.7 V drop due to the diode, and can also cause a lot of noise.

Although the zener diode has its benefits, there are too many issues that will occur with the application of the UGV IED and mine detector.

3.2.2.4 Switching vs. Linear Regulators

Both switching and linear regulators have their benefits for their specific applications. As discussed in the previous sections switching regulators have a more efficient application, but a more complex design. In the following Table XX there will be a side-by-side comparison between the two regulators, to evaluate what would be the best option for this project.

Table 3

	Switching Regulator	Linear Regulator
Capabilities	Step up, down or inverting	Step down
Design	Complex (requires inductors, capacitors, Filters, and FETs)	Simple (Usually composed of resistors and capacitor)
Cost	\$0.50-\$8.00 (depends on complexity and application)	\$0.50-\$4.00 (For most applications less than a dollar)
Size	Medium (Can be smaller depending on power regulated)	Relatively small (ICs tend to be small regardless of application)
Efficiency	High, throughout almost all applications	Low, but can be negligible if the change from input to output voltage is minimal
Noise Dissipation	There is a good amount of noise that can be dissipated, which is dependent on the rate of the duty cycle	Little to none

Based off of the comparisons provided in Table XX, a switching regulator seems to be the most suitable choice. This is attributed to the fact that the efficiency is an important factor, for we have many components that will need to be powered. This will allow us to have longer battery life and prolonged runtimes for our project. Also, the noise associated with the regulator will not have a severe impact on the dc motors and sensors being used. Later in this report the exact product selection will be discussed based off of this research.

3.2.3 Power Distribution (Power Supply)

There are several methods to consider when supplying power to a system. Accessibility, practicality and efficiency are important aspects to consider and will be discussed below.

3.2.3.1 AC Power Supply

By using a power supply that is AC, such as using an outlet, one can have an infinite supply of voltage to the components needing power. It would require AC to DC power supply converters, which would provide the required voltage needed for each system. Although, this method would be ideal for we would not need to charge batteries, it is not compatible with the UGV IED and mine detector. It would limit the range of detection for our vehicle, and with an extension cord being dragged around it can cause a mine or IED to be set off.

3.2.3.2 Individual Power Supply (DC)

When using DC power supplies with multiple systems that require power, one must evaluate what is most efficient and practical. When supplying each component individually the design is very simple; just wire each supply to its specific system. One could see how this can be easy, yet impractical if a lot of systems require power. Also, when dealing with different batteries sizes, and mAh (capacity), the timing and amount of charges needed will become an issue. If one wants to test the project, all batteries would have to be tested to make sure that they are fully charged or else the platform may be going along its designated path, but the metal detection system can be dead, thus causing the system to set off an IED or mine. Though there is a middle ground, where the user could have components with similar input voltage requirements connected to the same power supply.

3.2.3.3 Multiple Output Power Supply (DC)

When creating integrated power supplies the user has to create a complex design that will contain voltage regulators, dividers and transformers to ensure the correct constant input voltage for each system. This can become difficult when designing the PCB, because the accuracy and reliability of the circuit can be the difference from an ideal working circuit to a possible destructive circuit that can damage components. So it would be ideal to utilize a reliable design or purchase an off the shelf component that meets the requirements of the systems.

3.3 Obstacle Detection

One of the main objectives of the UGV is to have the capability of autonomously navigating in unknown environments. Thus, many forms of sensors can be used to estimate the distance between the robot and obstacles. But, the challenging aspect of these sensors is their reliability to reach its destination safely by avoiding obstacles and determining drivable conditions.

The sensor that will be used to determine obstacles is the LIDAR and ultrasonic sensor. The following section outlines LIDARs, laser range finders, and ultrasonic sensors that will meet the requirements for detecting obstacles indoors and outdoors.

3.3.1 LIDAR

LIDAR, which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure the distance of a target. This type of sensor consists of a transmitter that illuminates a target with a laser and a receiver that detects the components of light. This device produces a range estimate based on the time needed for the light to reach a target and return.

There are different ways of measuring the time of flight for a light beam. One method is to measure the phase shift of the reflected light. As shown in the figure below, the transmitter pulses a 100% amplitude modulated light to a target at a known frequency. The phase shift between the transmitted and reflected signal can be measured. The wavelength of the modulated signal can be measure using the equation $c = f \cdot \lambda$ where c is the speed of light and *f* the modulating frequency. The total distance *D'* covered by the emitted light can be found using the equation $D' = L + 2D = L + \frac{\theta}{2\pi}\lambda$ where D and L are the distance showed in the figure below. The required distance D, between the beam splitter and the target is given by the equation

$$D = \frac{\lambda}{4\pi}\theta$$

where θ is measure phase difference between the transmitted and reflected laser signal. λ is the known modulating wavelength.

As shown, the range from the transmitter to a specific object can affect the sensor's accuracy since the range is inversely proportional to the square of the receiving signal amplitude. This means distant, dark objects will not accurately produce as good range estimates compared to bright, close objects.

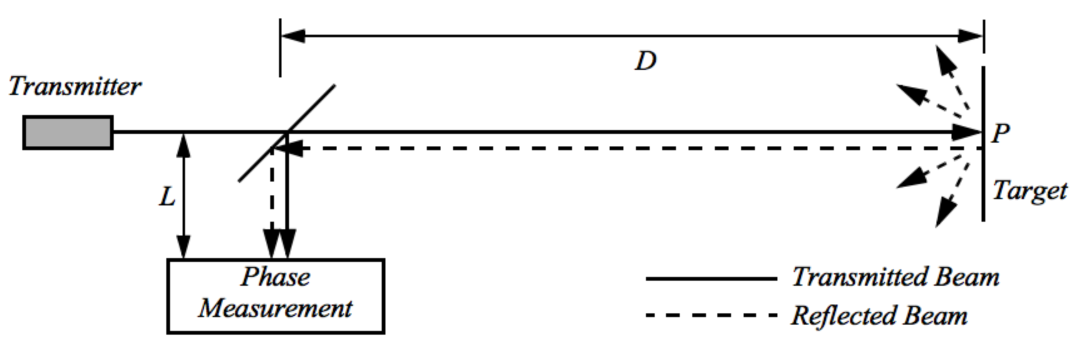


Figure 19: Measuring the time of flight with the phase-shift measurement method (Permission Pending)

Another form of finding the distance of a target is using the triangulation-based active ranging technique as shown below. The transmitter projects a known light onto the target and a receiver captures the reflection of the known pattern. With the system's simple triangulation and geometric values, the distance can be approximately measured.

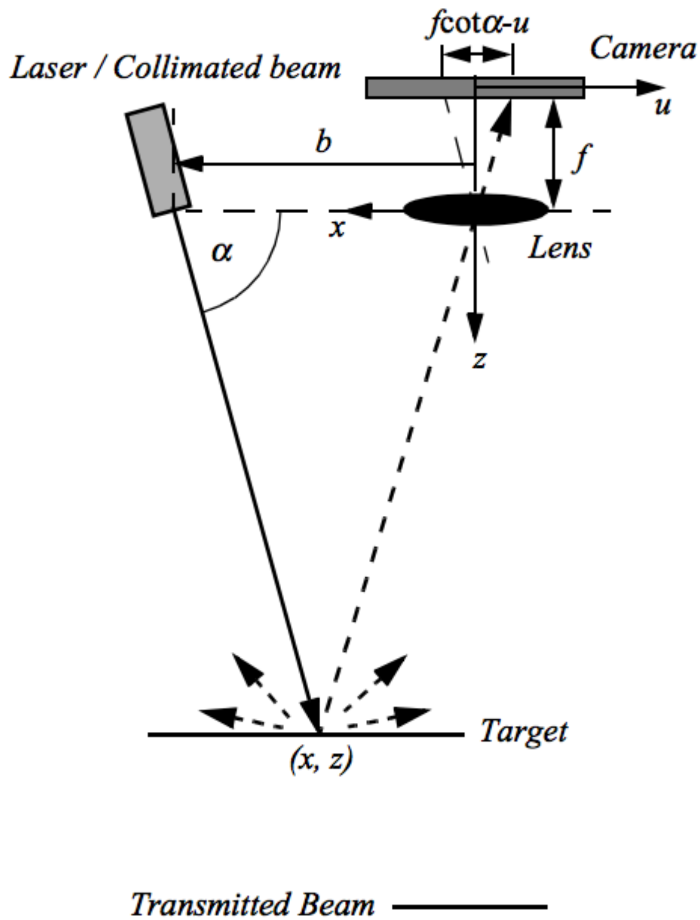


Figure 20: 2D laser triangulation (Permission Pending)

Although LIDAR technology contains a lot of advantages compared to other sensors for obstacle detection, they also have many disadvantages. One of the largest drawbacks with LIDAR is the cost of unit. A good LIDAR system can cost anywhere from several hundred dollars for a used system to tens of thousands of dollars.

In this project, we are going to analyze different LIDAR systems that use the methods mentioned to find the distance of a specific target.

3.3.1.1 Robopeak RPLIDAR System

RPLIDAR is a low cost 360-degree 2D laser scanner that is able to have a detection range of up to 6 meters. The produced 2D point cloud data can be used for simultaneous localization and mapping (SLAM) and object/ environment modeling. The RPLIDAR emits a modulated infrared laser signal that is reflected by an object and detected by the system. The returning signal is sampled by vision acquisition in the RPLIDAR and the DSP embedded processor receives the sampled data and processes the data, distance value, and angle value between the RPLIDAR and the object.

RPLIDAR uses a 3.3V –TTL serial port (UART) as the communication interface. This will be necessary when communicating to the embedded Linux single board computer. Other communication interface such as USB can be customized accordingly. The sampling data will output the following data type: distance (in mm), heading (in degrees), quality of the measurement, and the start flag of the signal.

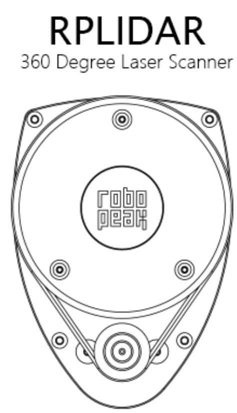


Figure 21 RPLIDAR 360-degree Laser Scanner (Permission Pending)

3.3.1.2 Neato XV-11 LIDAR Sensor

The Neato XV-11 laser scanner is an included sensor in the Neato XV-11 robot vacuum. The XV-11 LIDAR sensor can be removed from the XV-11 vacuum and be used in robotic projects with the help of the Robot Operative System (ROS). The LIDAR sensor found in the Neato vacuum scans the surrounding area 360 degrees with a 1-degree resolution and has a maximum detection range of 6 meters.

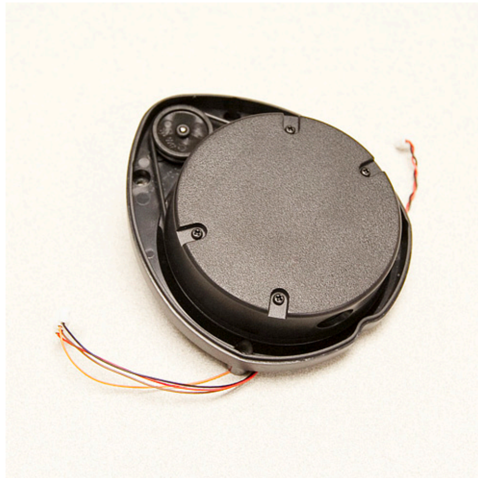


Figure 22 Neato SV-11 LIDAR (Permission Pending)

3.3.1.3 SICK LMS-200

The SICK LMS-200 Laser Measurement System is a non-contact measuring system that was designed for industrial applications in area monitoring, object measurement and detection, and determining positions. The system scans the surrounding area with a two-dimensional radial field of vision using the infrared laser beams.

The LMS-200 measures the time of flight of the laser pulse that is emitted from the system and returns back. The impulse of the laser and the time is directly proportional to the distance between the LMS-200 Laser Measurement system and the object. Real-time measurement data is available for further evaluation. The measurement data corresponding to the scanned environment is outputted into binary format

With a field of vision of 180 degrees and a range of up to 30 m, the SICK is far more superior to other range detectors mentioned before. Although the LMS-200 was not ideally made to work outdoors, the system can be used effectively in an outdoor environment for several meters. Higher sensitivity in detection improves in darker ambient settings.

One of the largest drawbacks of the system is the power consumption. The required operating voltage for the LMS-200 is 24V DC ± 15 % with a power consumption of ≤ 20 W. This large consumption of power will lead to requirements of a second power supply for the project.

Figure 23: SICK LMS-200 (Permission Pending)

3.3.2 Ultrasonic Sensors

The basic principle of an ultrasonic sensor is to transmit an ultrasonic wave and measure the time it takes for the wave to deflect off an object and return to the receiver. The distance *d* can be calculated based on the propagation speed of sound c and the time of flight t. The equation below measures the distance of an object and the speed of sound c in air.

$$d = \frac{c \cdot t}{2}$$

$$c = \sqrt{\gamma R T}$$

where γ = ratio of specific heats
R = gas constant
T = temperature in degrees Kelvin

When an ultrasonic transceiver emits sound to a surface perpendicular from the source, most of the sound energy will be reflected perpendicular to the surface and will be detected. Only a small amount of energy would be scattered in other directions.

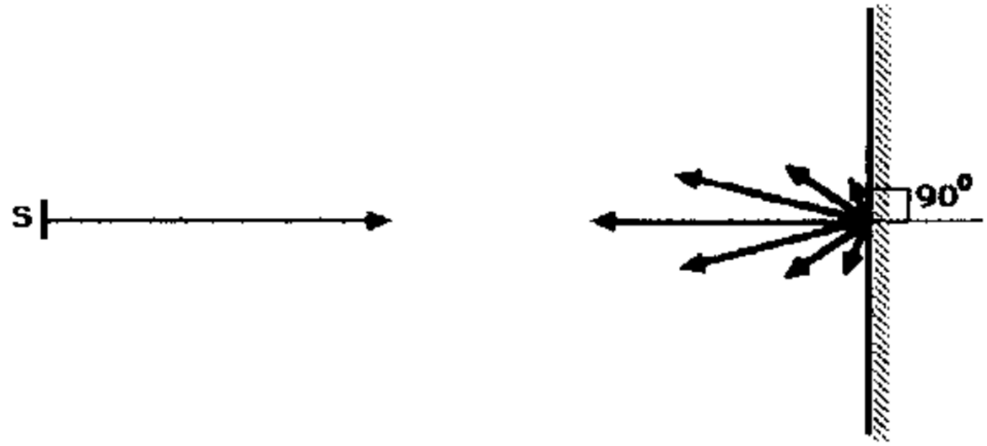


Figure 24: Reflected sound waves from smooth surface perpendicular to the acoustic axis (Permission Pending)

Even though ultrasonic sensors play a substantial role in many robotic applications, they also deal with some drawback that may limit the usefulness of mapping and accurately recognizing the environment. As shown in the figure below, if the surface of an obstacle is tilted relative to the axis of the ultrasonic sensor, a small amount of energy is reflected back. This would mean that the obstacle would not be detected.

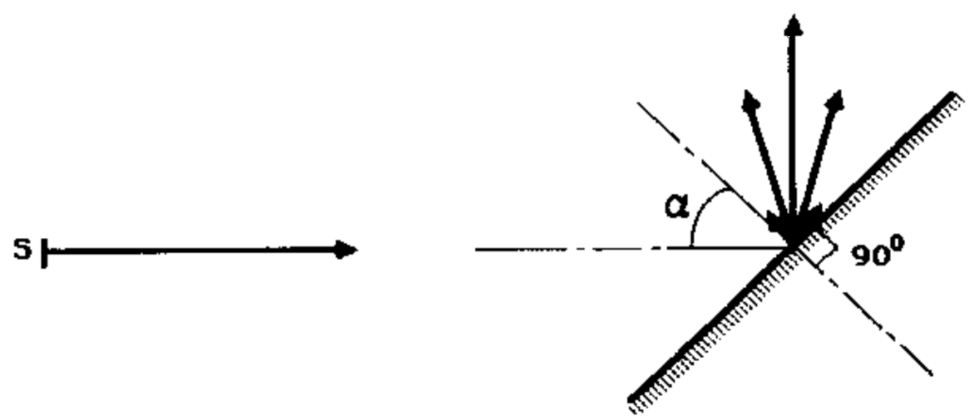


Figure 25: Reflected sound waves when angle α is large (Permission Pending)

In this project, we are going to analyze different ultrasonic sensor that uses the method mentioned above to find a specified target.

3.3.2.1 HC-SR04 Ultrasonic Sensor

The HC-SR04 is a low cost ultrasonic ranging module that provides 2cm – 400 cm (4 meters) non-contact measurement function and ranging accuracy that can reach to 3mm. The basic principle of how this module work is it sends eight 40 kHz signal and detects whether there is any pulse signal back. Unlike laser range finders, sunlight or dark materials do not affect operation. The test distance can measured multiplying the high level time by the velocity of sound (340 m/s) divided by 2.

The dimensions of the unit is 40 mm x 20 mm x 15 mm. The sensor requires a 5 V supply and a 15mA working current.

3.3.2.2 LV-Maxsonar-EZ2 High Performance Sonar Range Finder

The XL-MaxSonar-EZ2 is a high performance sonar range finder made by Maxbotix that has a maximum range of approximately 254 inches (6.45 meters). With a 2.5 V – 5.5 V and a 2mA typical current draw, this sonar range finder is an excellent choice for multiple sensor or battery based systems. The output format from the interface includes pulse width output, analog voltage output, and serial digital output. The sonar readings can occur up to every 50 mS (20-Hz rate).

3.3.2.3 MB7092-XL-Maxsonar-WRMA1

The XL-MaxSonar WRMA1 is a high-resolution ultra sonic range finder by Maxbotix that was built for outdoor use. These sensors feature a high-power acoustic output along with real-time auto calibration for changing conditions. This rugged ultrasonic sensor component module provides very short to long distance detection and ranging in a compact PVC housing.

A virtually noise free distance reading is possible with the real-time background automatic calibration, real-time waveform signature analysis, and high output acoustic power combined with continuous variable gain. This module has a long maximum range of approximately 7.65 m (~300 inches) with a narrow detection zone. A 3V – 5.5V supply with a 3.4 mA average current is required to operate correctly.

3.3.2.4 Ultrasonic Sensor Specification Comparison

Below is a comparison of specification of the ultrasonic sensors that were mentioned.

Table 4: Ultrasonic sensor comparison

	HC-SR04	XL-MaxSonar-EZ2	MB7092-XL-WRMA1
Environment use	Indoor	Indoor	Outdoor
Supply voltage	5 V	2.5 V – 5.5 V	3V – 5.5 V
Min. Distance	2 cm	0 m	0 m
Max. Distance	4 m	6.45 m	7.65 m
Connection	Serial	Serial	RS232 Serial
Dimensions	45 x 20 x 15 mm	22.1 x 15.5 x 22.1 mm	71.09 x 43.84 x
Cost	$0.99	$24.95	$84.95

3.4 Obstacle Avoidance

3.4.1 ROS

ROS has built in API to aid in the mapping of any room or area, given that the spatial sensors are functioning properly. These tools and awareness allow the developer to either implement their own avoidance algorithm based on these mappings and built in tools, or to use these tools as their own tools for obstacle avoidance.

The navigation stack within ROS provides an ample amount of development tools to get a robot from point A to point B with obstacle avoidance. However, these tools come with their own rules and guidelines. Once installed into the device of choice, ROS allows the developer to do a variety of things. SLAM mapping and autonomous navigation are included in the navigation stack, but the main problem in the foreseeable future is the combination of mapping and obstacle avoidance at the same time. The main reason for this becoming a glaring issue is that if this device was not able to do this, and required a predefined map of an area before it could scout for mines, this would require an additional device.

This could be circumvented by the implementation of a navigation stack that is based on the current GPS locations of the known (and to be known) mines, which would avoid these points based on certain criterion that would help the device to stay in one piece and unexploded.

The ROS navigation stack allows for the developer to give the robot goals, programmatically. These goals do not have to be determined at the time of compilation, but can be decided at run time. This leads to a smarter device with the capability to determine any clear path for an open area within a certain range. This range would be determined by the final schematics of the metal detector, and LIDAR system.

Conventional OS	ROS
Explicitly a general purpose OS	Exclusive for Robotic Platform
Ortho-Operational	Meta-Operational
Native Language Programming	Language-independent architecture
Sequential Architecture	Asynchronous Distributed architecture
Programming IDE	Software Frameworks
Propriety/Open-Source	Open-source under BSD license
Heavily coded frameworks	ROS frameworks are very light
Programs	Nodes
Communication	Messages
Kernel is Included	Kernelless

Figure 26 (Permission Pending)

3.4.2 Dijkstra's and Prims

Should there be a problem with implementation of the navigation stack of the ROS API, there would open an opportunity to develop a proprietary Dijkstra's or Prim's algorithm implementation. This would be the more development heavy implementation, of course, but a great opportunity to strengthen the developer's ability to apply a fundamental algorithm to a more general, real life application.

Dijkstra's and Prim's algorithms were designed to do the same thing, and that is to find the shortest path between a collection of nodes that is assumed to be safe. This determination of safe is to be determined by the device in real time.

Dijkstra's algorithm involves analyzing the shortest path node by node, but Prim's algorithm involves looking at a collection of nodes as a whole and determining a starting point at random.

This would presumably lead to the developer leaning more towards Dijkstra's as their preference in development, as they would only know about the current point that the device is located; what is directly in front of the device, and what the end location is going to be.

In theory, once a clear path is determined, the history gained from locating mines along the path that were avoided in determining of the clear path could help the creation of wider areas of safeness by starting the device at a separate corner and crossing the new path with the safe path. If done multiple times, the device would not just be able to determine a clear path, but a clear area as well.

The only limitation of Dijkstra's is that it benefits from knowing the existence of the mines already. This algorithm provides great information after information about the mines are found, but when put into a searching situation, it begins to degrade in quality.

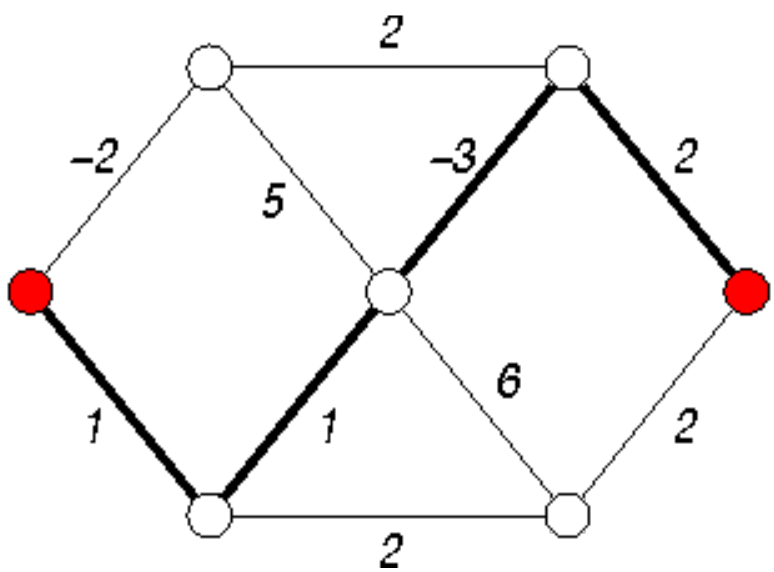


Figure 28 (Permission Pending)

3.4.3 A*

A* (or 'A star') is a searching algorithm that doesn't just do graph traversal. In fact, if that were all it did, Dijkstra's would be the more obvious choice, because it is more efficient when doing just that. However, A* is also a path finding algorithm which means that it doesn't benefit by knowing the graph ahead of time.

This would allow for a more fluid process, especially because the device will not be driving beyond a moderate pace. Therefore, computation speed wouldn't be as important in the case of the current project. Therefore, A* would be the more natural choice if the project required a proprietary implementation of a search algorithm.

3.4.3.1 Pseudocode of A* Algorithm

from Artificial Intelligence: A New Synthesis by Nils Nilsson

1. Create a search graph G, consisting solely of the start node, n_o. Put n_o on a list called OPEN.
2. Create a list called CLOSED that is initially empty.
3. If OPEN is empty, exit with failure.
4. Select the first node on OPEN, remove it from OPEN, and put it on CLOSED. Called this node n.
5. If n is a goal node, exit successfully with the solution obtained by tracing a path along the pointers from n to n_o in G. (The pointers define a search tree and are established in Step 7.)
6. Expand node n, generating the set M, of its successors that are not already ancestors of n in G. Install these members of M as successors of n in G.
7. Establish a pointer to n from each of those members of M that were not already in G (i.e., not already on either OPEN or CLOSED). Add these members of M to OPEN. For each member, m, of M that was already on OPEN or CLOSED, redirect its pointer to n if the best path to m found so far is through n. For each member of M already on CLOSED, redirect the pointers of each of its descendants in G so that they point backward along the best paths found so far to these descendants.
8. Reorder the list OPEN in order of increasing f values. (Ties among minimal f values are resolved in favor of the deepest node in the search tree.)
9. Go to Step 3.

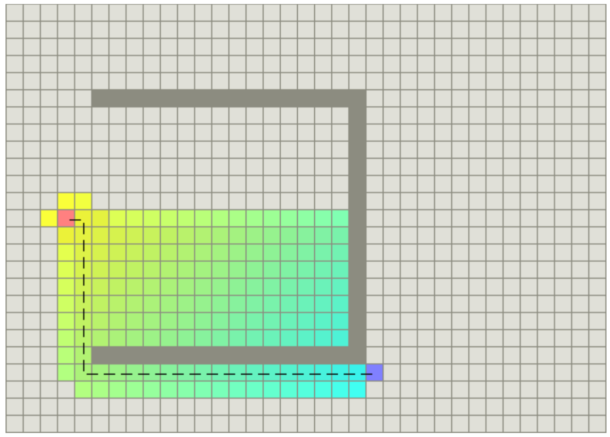


Figure 29: Showing Areas Search and Route Found with A* Algorithm

3.5 Detection System

Ever since land mines became portable for deployment, the efforts to remove land mines from the battlefield started. Throughout history, different methods have been used to detect land mines, some of these methods included training animals such as dogs and rats, but this methods were not always reliable and took a lot of money and time in training, with today's technology the military relies mainly on soldiers carrying metal detectors and manned vehicles with different attachments to find and detonate this land mines on roads and paths, but once a conflict is over it is up the humanitarian efforts to demine the rest of the areas not cleared from land mines by the military.

Humanitarian efforts have gone a long way to try to detect these abandoned land mines, and remove them without detonation; the most researched and implemented detection systems used now a day, include Ground Penetrating Radar (GPR), Infrared Sensors (IR), Ultra Sound Sensors (US), and Metal Detecting (MD). For this project, we researched these four detection systems to see which system would be the most useful for our unmanned ground vehicle.

Figure 30: U.S. Army engineer removing fuse from a land mine (Public Domain)

3.5.1 Ground Penetrating Radar (GPR)

The first detection system we researched is the Ground Penetrating Radar (GPR), this system works by continuously emitting electromagnetic waves through the transmitter part of the antenna into the ground, and collects the signal reflected from the ground through the receiver part of the antenna, once the signal encounters an object or a surface with different dielectric constants, a variation in the signal will be detected, this information is then sent to the receiver, which will then record the magnitude and the time it took the signal to get to the object and back to the receiver, in order to calculate the distance to the object.

Ground Penetrating Radars will give you the best reading if they are in direct contact with the terrain, but this is not an option when this technology is being used for land mine detection, therefore appropriate measures have to be taken to filter out the first reading of the waves which will be the surface of the terrain, further calibration and filtering also has to be done in order to deal with random clutters of soil and rocks in different areas of the terrain being demined, this filtering and calibrations are one of the major problems being faced in Ground Penetrating Radar data processing.

The data gathered by the Ground Penetrating Radar can be represented in three different ways, initially when the sensor is not moving, the data gathered can be represented in a graph of signal strength versus time delay, once the sensor is moving in a linear motion, the data gathered can be represented in a two-dimensional image, displaying different colors in relation to the intensity of the signal being collected by the antenna, which will give you a better image of where the object is located underground, and an idea of the shape of the object, and lastly, by moving the sensor in multiple directions, the data gathered can be represented in a three-dimensional structure which can be displayed in multiple two-dimensional images parallel to the ground at different depths.

The reliability of a Ground Penetrating Radar is affected by the type of terrain it is used in, as the conductivity of the terrain increases, the depth that it will be able to detect will decrease, the most common change in terrain conductivity is how moist the terrain is, the more humid the terrain, the more conductive it is, because of the great difference in terrains that demining is done in, before being able to use this technology, either a controlled test in such environment and terrain has to be done, which is not only time consuming but might not be feasible for some types of operations our project is aimed for, or parameter estimation can be done using data from previous tests done in different types of terrain, this option might be more feasible but comes at the great risk of being wrong and give you wrong readings and possibly not detect land mines that are there.

Ground Penetrating Radars use different frequencies, high frequency waves which give you a better image resolution of the terrain, but does not penetrate as much as lower frequencies do, and use more energy also, which would lower the battery life of the unmanned vehicle, however, lower frequencies have a tendency to not give you a clear image resolution of the terrain, and sometimes not even detect land mines in certain conditions, this is why in order to get the best readings using Ground Penetrating Radar for land mine detection, it should be used in dry terrain, at lower frequencies, however, further electromagnetic waves will not be able to penetrate water, hence if it is raining or there are puddles in the field, it will not be able to detect anything in those areas, this restricts this technology from being effectively used in a great number of places where demining is being done.

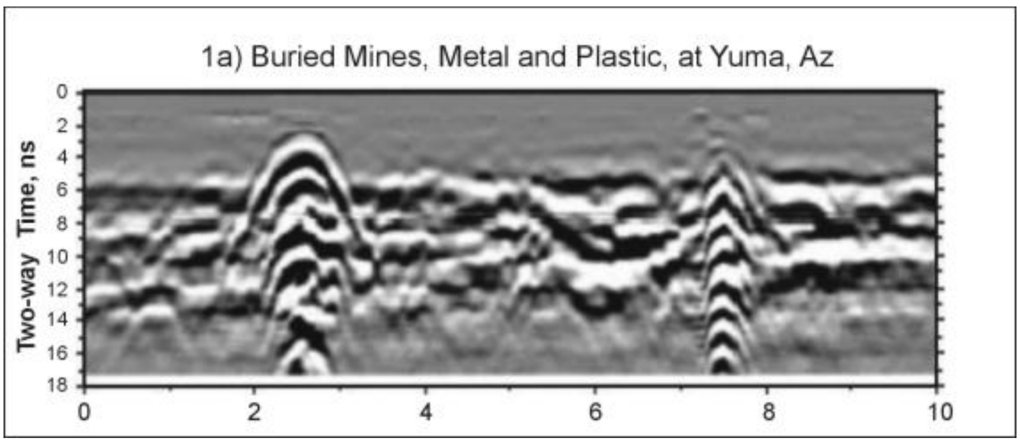


Figure 31: 2-D Image Display of Ground Penetrating Radar Data (Permission Pending)

3.5.2 Infrared Sensor (IR)

Another method that could be used to detect land mines is by using Infrared Sensors. Visible light is only one form of radiation, infrared radiation, also referred to as thermal radiation, is not visible by the human eye, however, we can detect it as heat, by using Infrared Sensors, the infrared radiation can be interpreted into an electrical signal, which is then processed into an image, we can then see the heat or in other words the infrared radiation of objects.
Infrared radiation can be detected by using two methods, passive, by sensing the radiation of an object, or active by artificially heating up the object and sensing the radiation created, since it would be very difficult and unpractical to artificially heat up a possible mine field, only the passive detection will be covered.

Most of the terrain where land mines can be found is naturally and evenly heated by the sun. By using infrared sensors, one can see that the infrared radiation emanating from the whole terrain being demined will be mostly the same; however, there are certain things that will change the temperature of small areas of the terrain, this anomaly is what will be analyzed in order to find possible land mines.

One of the things that will make a change in the infrared radiation of an area, is recently disturbed soil, this happens when soil is dug and put back into place, which might be a possibility that a land mine was deployed in that area, but it is not a certain possibility, and this can only be detected within hours of the soil disturbance being made, another thing that might change the infrared radiation of an area, is the composition of the land mine, since land mines are made of different materials than the terrain that it is buried in, the infrared radiation in the area where the land mine is buried will be different than that of the rest of the terrain, however, changes in the infrared radiation of an area can happen due to non-explosive objects buried in the ground, or clutters of rocks underground.
Nevertheless, this is accounting near perfect conditions, passive detection is affected heavily by the environment, there are two periods of the day when the infrared radiation contrast of the areas where the land mines are deployed, is almost impossible to compare, this usually happens sometime in the morning or in the evening, also, if the temperature outside is very high, it also becomes very difficult to compare and detect anomalies in the terrain temperature.
The most effective way that Infrared Sensors can be used, is by observing an area over time, recording the changes in infrared radiation, giving you a better detection of anomalies in the terrain, an advantage of using Infrared Sensors is that the imaging does not require large amounts of processing, and the images are easy to read, however, Infrared Sensors like Ground Penetrating Radar, cannot detect through water, which restricts this technology from being effectively used in a great number of places where demining is being done.

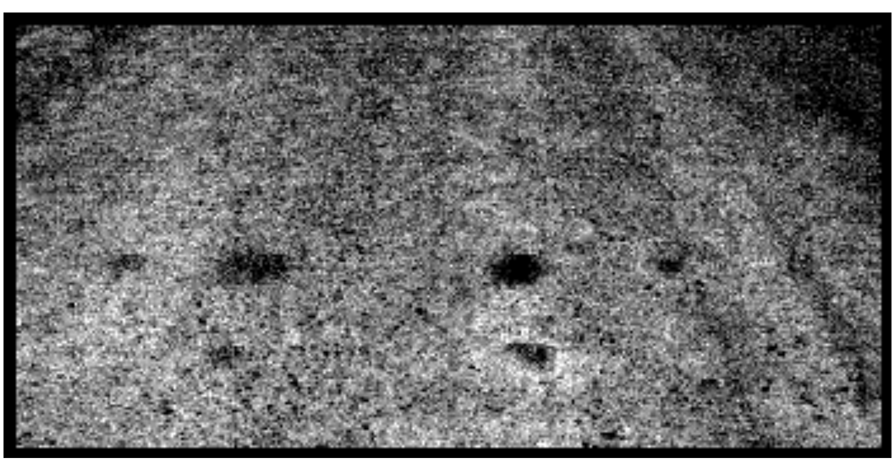


Figure 32: Infrared Sensor Image Display Showing Recently Buried Land Mines (Permission Pending)

3.5.3 Ultra Sound Sensor

Ultra Sound Sensors work very similarly to Ground Penetrating Radar devices; it uses an antenna with an emitter to actively send a wave and then collects the reflection through the receiver part of the antenna, the main difference is the type wave that it uses. Ultra Sound Sensors emit a sound wave, inaudible to humans, which we know move in a mechanical way bumping from one molecule to another as it travels, meaning that although it doesn't change the terrain, it does cause a physical disturbance on the terrain as it travels through it, unlike the electromagnetic waves that Ground Penetrating Radar emit.

This difference between the two waves makes these sensors behave opposite to each other in certain conditions. Ultra sound waves travel better in humid terrains, or water, which is why underwater mine detection is done most of the times using sound waves, something Ground Penetrating Radar could not do, nevertheless, sound waves are weakened faster traveling in through the air, while electromagnetic waves are barely affected in this condition.

However, like Ground Penetrating Radar, Ultra Sound Sensors will give their best reading if they are in direct contact with the terrain, meaning that not only it has to deal with the same filtering issues, but the ultra sound waves will initially weaken before even getting to the ground, also these waves will penetrate further at lower frequencies, but will also give you less clear reading of the terrain. Once this wave signals have been collected by the receiver, this information is represented the same three ways as the Ground Penetrating Radar, as a graph of signal strength versus time delay, a two-dimensional image of a linear slice of the ground, and a three-dimensional structure, displayed in multiple two-dimensional images parallel to the ground at different depths.

3.5.4 Metal Detector

The most commonly used land mine detection system is the use of metal detectors, although this is the oldest method to detect land mines, thanks to current technological advances, this detection system has been able to keep up with the advances and efforts to make land mines less detectable, with the exception of no-metal content land mines.
There are three main types of Metal Detectors;

- Very Low Frequency (VLF) Metal Detectors
- Pulse Induction (PI) Metal Detectors
- Beat Frequency Oscillation (BFO) Metal Detectors

However, they all work using the same basic components, which consists of an oscillator, a transmitter and a receiver coil of electrical wire, and a circuit to measure the signals detected.
The oscillator works by sending an electric current to the transmitter coil, producing an alternating magnetic field, if any metal object gets close to the coil, it will then become magnetized, producing its own magnetic field, the receiver, either being the same coil or another coil, will then have a change in electric current due to the small magnetic field of the object, the circuit will then detect this change and make a noise to let the user know of the presence of the metallic object, the closer the object is to the coil, the stronger the signal will be.

Newer metal detectors are smaller, lighter, more power efficient, and use more complex integrated circuits to give the user the option to change the sensitivity, and discrimination of different types of metal, to allow the user to use the same metal detector for multiple purposes.

3.5.4.1 Very Low Frequency (VLF) Metal Detector

This type of metal detector uses an outer coil and an inner coil, the outer coil is the transmitter, and the inner is the receiver, this is the most commonly used type of metal detector due to its ability to discriminate between different metals, this is done by the circuit which uses both the transmitter coil frequency and the receiver coil frequency, to calculate the phase shift of the objects being detected, only making noise when an object detected is within the parameters chosen by the user, allowing the user to ignore objects he does not want to detect, and only focus on certain types of metal.

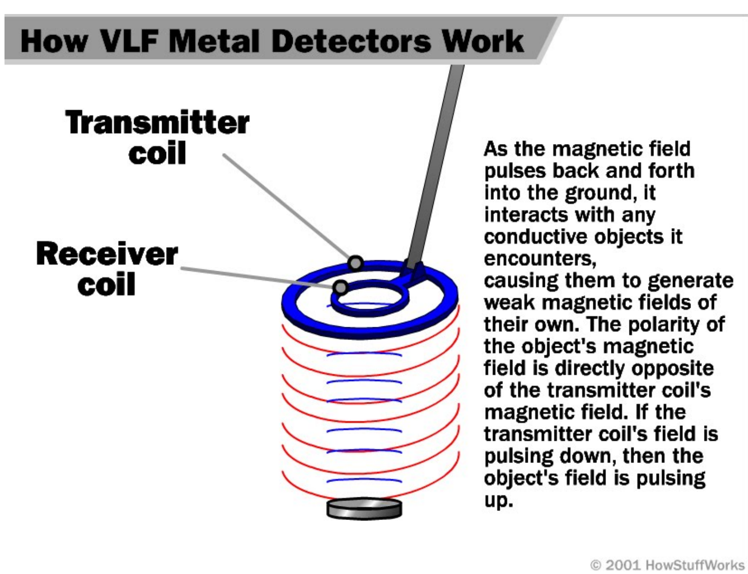


Figure 33: Example of Very Low Frequency Metal Detector and How it Works (Permission Pending)

3.5.4.2 Pulse Induction (PI) Metal Detector

This metal detector can use anywhere from one to three transmitter coils working simultaneously, the oscillator will transmit short bursts of electrical current to the coil or coils, creating brief magnetic fields, this fields create a voltage spike, and the time that it takes for the voltage to drop is recorded by the circuit, if a metal object is close to the coil, it will become magnetized, and the magnetic field from the metal object will affect the length of time it takes for the voltage to drop, the circuit will detect this change and make noise to let the user know of a metal object close to coil.

Pulse Induction detector are not able to discriminate different types of metals due to the way that the detection is measured, however, for this same reason, this type of detector is able to detect, metal objects deeper in the ground, better than other type of metal detectors, and since the coil or coils emit brief magnetic fields and not a continuous magnetic field, it is not affected by highly mineralized terrain, black sand and salt water.

Figure 34: Pulse Induction Metal Detector Used Underwater (Permission Pending)

3.5.4.3 Beat Frequency Oscillator (BFO) Metal Detector

This is the most basic type of metal detector; it uses a larger coil close to the ground, and a smaller coil next to the circuit, the oscillator then sends the electric current through both coils, smaller coil will create a radio wave which is picked up by the circuit, and make a series of tones, once a metal object gets close to the larger coil, it will get magnetized, and the magnetic wave emitted from this metal object will interfere with the radio frequency and change the tone, letting the user know there is a metal object.

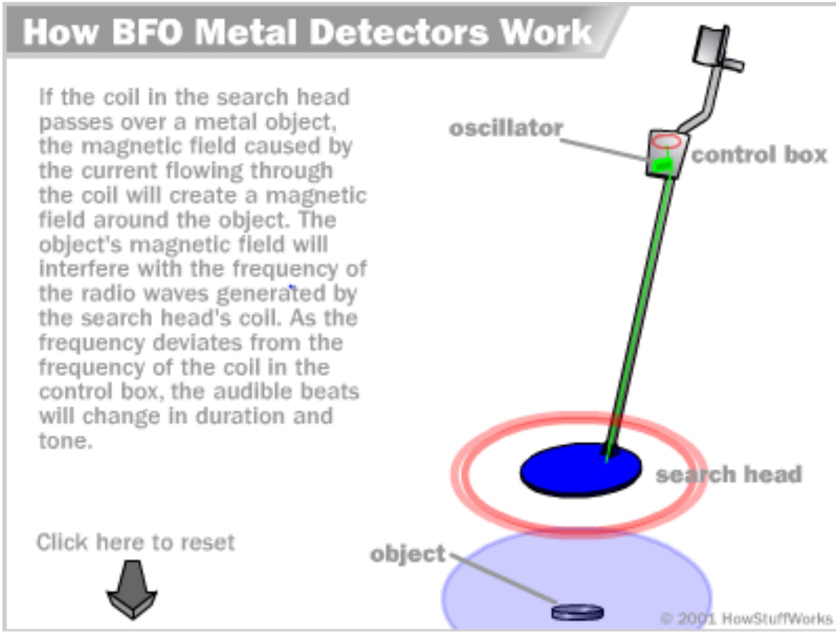


Figure 35: Example of Beat Frequency Oscillator Metal Detector and How it Works (Permission Pending)

3.5.5 Summary

Ground Penetrating Radar and Ultra Sound Sensor detection systems are both very similar on how they work and the way that the data is gathered and displayed for the user to analyze, they both are capable of producing really clear images and help humans detect land mines, they are each the best detection system to use under certain conditions, but at the same time, they are both greatly affected by certain terrain or environmental conditions, meaning that calibration has to be done before being used, due to different properties of terrain, and making them unreliable to use in many places where demining is being done.

Infrared Sensor imaging is the easiest method to visualize, and requires less filtering and calibration, making it more reliable for use in different types of terrain, nevertheless, this detection system is greatly affected by thermal conditions, making it unreliable to use at certain times of the day, or at extremely hot temperatures. Infrared Sensors just like Ground Penetrating Radar detection systems are very expensive to make and implement, making them less accessible to many countries where demining is being done, or for projects aimed at helping the humanitarian demining process.

The technology in metal detecting has advanced a lot over the years, allowing the newer models to detect the smallest metal components of the low-metal content land mines, making metal detecting the most used detection system for demining purposes, not only because it is the least expensive out of the rest, but because it is the most reliable all around, although some types of metal detectors, are affected by debris and highly mineralized terrain, other types of metal detectors have managed to deal with this obstacles.

Nevertheless, no detection system is 100% accurate right yet, even metal detectors have a very small chance of not being able to detect a mine under certain terrain or conditions, and it is impossible for it to detect non-metal land mines, which is why many groups are starting to implement combined systems that include more than one detection system.

3.6 GPS and Tracking

3.6.1 Storage Methods

When dealing with GPS coordinates, the difficult part is not receiving this information, but interpreting it. To avoid this difficulty as much as possible, there are a variety of ways to deal with the data so that the device can easily interpret the GPS coordinates and use them during the obstacle avoidance algorithm as necessary.

The simplest option in storing and interpreting these GPS coordinates is through the use of plain text. Since any working computer has a word processor, and, more often than not, a string parser of some kind, the plain text could be usable in any application of our choosing. Plaintext would be the most well rounded choice, but due to the fact that it would have to be converted to a different format for just about any application, it may not be the most efficient choice.

One of the more natural choices of storage of GPS coordinates would be in the form of UTM coordinates. There is only one real reason that this is one of the more natural choices, and that is because it fits in so neatly with the ROS navigation stack. There would be no conversion necessary if we could operate the whole system on UTM coordinates. This would lead to a very nice, and less demanding computational process. This would end up freeing more resources, but is reliant on the whole system being compatible with these UTM coordinates.

Other alternatives that have reasonable appeal are storage of GPS coordinates in JSON or XML objects. These two options are different in structure, but very similar in application. Their niceties are in that these structures were made for transportation over a communication protocol of some kind. They are very often used in Internet applications for these reasons. The reason it would be beneficial for this project is that the device will be wirelessly communicating with a Linux computer, and because these data types are known for being able to be reliably transported through a network, it is a valid choice if it is more feasible to do the obstacle avoidance computation on the back end Linux computer compared to on the local single chip computer.

Another variation on plaintext, and depending on the support, is the selection of storage in a CSV or Comma-Separated Value file. This file format is favorable because the format of the document must be decided, and therefore can only be interpreted in one way; leaving very little room for error. However, this selection doesn't vary much from a Plaintext file, and has minimal room for an efficiency gain unless the system fully supports the file.

The last, and most broad, variation on storing these GPS coordinates within our system is the conversion of GPS coordinates to binary, and processed as such. Based on the support for binary storage, whether it is user implemented or through ROS, this could be the most efficient way to process this information. This takes away the need for the computer, either locally or on the back end, to convert the GPS coordinates down to machine code. Since this happens regardless of what file format these GPS coordinates are in, this would be the fastest way to process this information should it be accessible.

3.6.2 ROS

ROS can handle many different types of coordinate values, but only because they are eventually converted to UTM coordinates. In an ideal world, the whole system would run purely on UTM coordinates. This may not be the case, but it would be wise to choose this option as often as possible when available.

If there are a finite number of conversions that have to be made to GPS coordinates, it would also make sense to store these converted values on the same SQL table that has a unique identifier already to reduce computational complexity regularly.
Within ROS is a navigation stack that allows these coordinates to be used to autonomously drive across a mapped area. In conjunction with the obstacle avoidance information (LIDAR, metal detector, ultrasonic signals, etc.), the ROS navigation stack should allow for a smooth transportation from A to B whilst mapping the marked locations of the found mines and also avoiding them. Although the device will not move at a rabbit's pace, it will find the a safe zone to walk without worry of stepping on a physical mine.

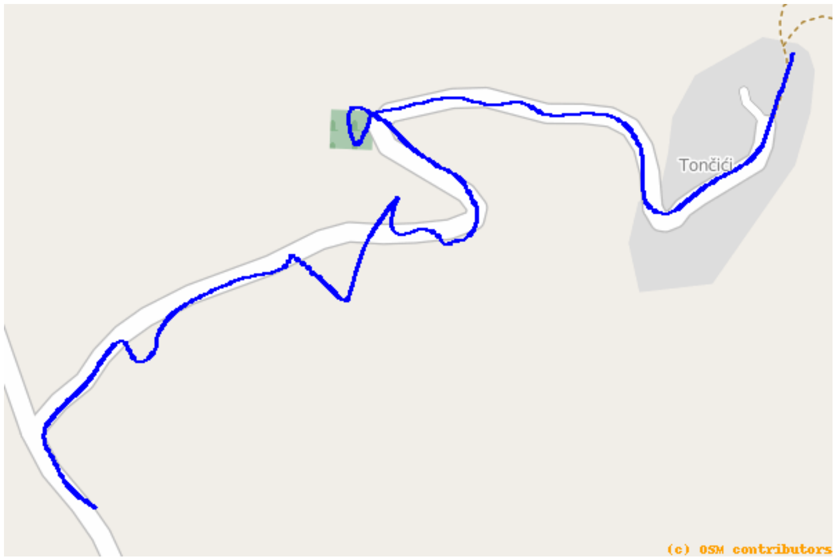


Figure 36: Ideal Route Mapping after Processing GPS Points (Permission Pending)

3.6.3 Physical Marking System

To prevent immediate danger to any walking traffic between the time that the mine has been marked for removal or safe detonation and the time that it is actually removed or safely detonated, the device will mark the physical location of a mine accurately for at least a five foot radius. In a real world application the device would use a semi-permanent paint that would last long enough for someone to find and remove the mine from that location. However, in this project, it would make more sense to use a less permanent solution to mark the location of mines such as silly string, or something in the same neighborhood.

3.7 Wireless Communication

3.7.1 PAN

PAN or Personal Area Networks are a relatively consistent network from a minimal range. The biggest benefit of PAN is the compatibility. Bluetooth communication is a well-known form of a PAN, but its largest limitation is the range, which is around 10 meters. To be able to operate and receive information from any PAN requires the devices to be within a 10 meter radius, and it is safe to presume there cannot be too many people who would be willing to stand within a 10 meter radius of any device that was looking for mines.

Although it is a very consistent form of network, the range is unreasonable for this project. Therefore, it is significantly improbable that it will be used as a solution for this project. However, if this was a remote controlled device that the user could be within the range of the device, Bluetooth or any other PAN is a reasonable solution.

3.7.2 LAN

LANs or Local Area Networks are the most consistent type of network, but are also the most unreasonable. The user is restricted to however long the cord is that you have from the control unit to the device itself. There is almost the unlimited option to make the cord as long as you could possibly need.

This would make for an interesting situation if you were to need to connect to a device that is over a mile away, because you'd need an Ethernet or equivalent cord to connect all the way from the device to the control unit. There is also the concern that the cord could directly set off mines if it were to accidentally trip one of them. The device could be close to the mine, and it would get destroyed. It also puts the user in unnecessary risk, because the cord could set off a mine close to the user, and far away from the device. Albeit a solution, it is just a completely unreasonable solution.

3.7.3 WLAN (Wi-Fi)

WLANs or the marketing term Wi-Fi, stands for Wireless Local Area Networks which in very many ways is similar to Local Area Networks (LANs as described above), but without the wire or cord. The communication is done wirelessly, as the name implies. The communication distance between controller and device could be up to 20 meters indoors, and significantly greater outdoors because there is less obstruction of the frequencies from and to the device.

One of the main benefits of Wi-Fi is that it is known to be very reliable within its range, and allows for synergistic communication between a device and a network. The only problem with using it for this project is there is no need for a centralized network. It would be better if there were no centralized hub, because that would require an additional piece of equipment. Removing the necessity of a network hub would be ideal for this project for monetary value, and ease of use.

Luckily, a sub-category under Wi-Fi exists called Wireless Ad Hoc Network (or WANET), which removes the need for a centralized hub. In fact, it does not rely on a pre-existing infrastructure at all. There is simply device-to-device communication, and either device can send or receive at any moment. Here lies the brilliance in this; no device on the network is required to be dependent on another device on that same network. They can receive instructions, interpret them, and send them back upon request if need be. This is the best choice on paper so far.

Wireless communication is also becoming a normality of these days. Human beings don't tend to use wires these days, because they may or may not be aesthetically pleasing. This normality from wireless communication leads to a rise in production of more sophisticated wireless senders and receivers. Therefore lowering the prices of these sophisticated wireless senders and receivers. This only benefits this project.

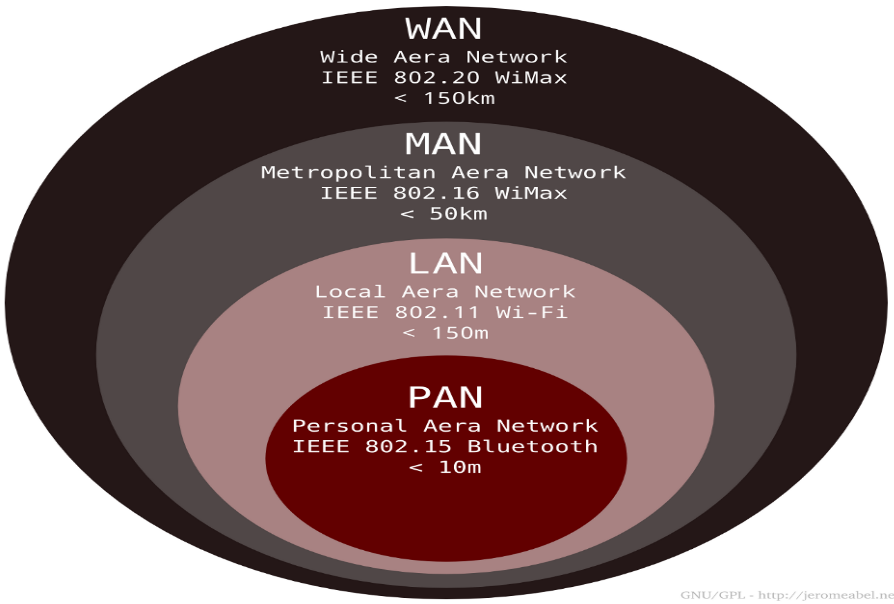


Figure 37: Wireless Network Range

3.7.4 WAN

WANs or Wide Area Networks are mobile telecommunication cellular networks. These types of networks are what power cell phone data. Whenever someone searches something on his or her phone, they are a part of a WWAN. Knowing this, it is relatively simple to pick out its immediate flaw.

There is a huge detail that can make or break any WAN, and that is signal. If the user is under a circumstance where they may not be able to reach cell signal, and the device required them to have cell signal, they would have a useless device. WAN signals are not accessible to everyone, and not particularly cheap to buy and construct. This limits the areas of use of the device from many parts of the world as well. There are many countries that have mostly no cell phone coverage, thus limiting the use of your device to a small majority of all places in the world.

In the case of this project, it is of great need to be able to use this device even in the most isolated places in the world. It does not stop someone from planting a mine, because there is no cell phone signal. It is also relatively expensive to have any communication on a cellular signal, because you are only renting time on the network. The more data you send/receive, the more you pay to use the service.
Although it sounds great on paper, WANs are not the most practical for all situations. Should this device been used only in populated areas, then it would be significantly more powerful in a number of ways. The developer could allow the device to be run from a location miles away, which would allow for extremely safe handling of the device. No one would be in harm's way of tripping on the mines if they were controlling this device on a WAN. If WANs were more popular worldwide, this would be the significantly more efficient way to go.

3.8 Main Controller Unit

To control the device in this project, there are several possible routes. The developer could create a proprietary tablet app that would interface with the device, but this could be considered an entire project in and of itself. The most reasonable alternative would be to directly interface through a computer of the same operating system.

Since the mechanism controlling the device is a Linux based single-board computer, it makes the most sense for the device to communicate with a controller of the same operating system. This allows for more of a natural handshake between devices, instead of defining exactly how the devices will communicate.

There are some pitfalls to using a computer as the controller device. One of the main problems is lack of portability. Anywhere the device goes, the computer can't be too far away. If the person responsible for bringing the controller happens to forget to bring the controller, no information can be received from the device.

This prompts the idea that the device could be able to store all information locally for it to be computed at a different time. This would still require the use of a controller device, but would allow for the "just in case" scenario. The device would then return to the location of computation to compute the results. If this were implemented, it would cover a lot of cases that could happen should the controller crash for whatever reason as well. It is never a bad idea to have a safeguard.

A standard RC controller instead of a whole computer controller, (just like you would find on a standard RC toy today), controls most wheeled RC devices and is great in a lot of ways, but also creates its own problems. The RC controller would be beneficial if precise movement was a pertinent concern of this project. Most RC controllers don't have any kind of heads up display or any screen for that matter. This would require a separate screen to accomplish this. This isn't incredibly difficult to accomplish, because there are plenty of mounts that would allow the user to put their phone on the controller.
This relapses to the idea that the project would require an application of its own just to display feedback information from the device. Since this will be more difficult than necessary, it seems to only create problems instead of expediting the process, and is not favored. Since precise movement isn't going to be user controlled in this project, and the device will be making its own decisions to get from point A to B, an RC controller is not a favorable solution.

3.9 Single-Board Computers

The single board computers are becoming highly prevalent in the development community because of their PC like functionality in a small compact, cost effective, low-powered platform. Although small in size, these computers are powerful enough to run a real operating system. In this section we will look into different single-board computers that will be used for the Unmanned Ground Vehicle.

3.9.1 BeagleBone Black rev. C

The BeagleBone Black rev. C is the latest addition to the BeagleBoard line of single-board computers. It is designed for the Open Source Community and to anyone who is interest in owning a low cost ARM Cortex A8 based processor. This single-board computer includes 4GB of eMMC, 1 GHz processor, 512MB onboard DDR3 RAM, pre-installed Debian Linux, and much more. This makes the BeagleBone Black an ideal development board.

The BeagleBone Black contains a total of 92 possible connection points (two 46 pin headers on each side of the board). This gives flexibility for the system to allow a large variety of plugins. Numerous amounts of plug-in boards (called capes) can be plugged-in immediately by simply stacking the cape onto the board's expansion headers.

Compared to the Raspberry Pi, there is a robust OS support for the BeagleBone Black. With a 4 GB eMMC flash for its primary boot source, the board contains enough memory to store a full operating system. This board also contains the possibility of booting from a microSD if one chooses to. This gives the user the flexibility of picking a large variety of Linux distributions.

3.9.2 Raspberry Pi Model B+

The Raspberry Pi was developed by a UK based foundation with the intentions of teaching basic computer science in schools. The design is based on a Broadcom BCM2835 system that includes an ARM1176JZF-S 700 MHz processor, VideoCore IV GPU, and 512 MB RAM. The design relies on a SD card for booting of the OS and long-term storage.

The Model B+ contains 4 built-in USB ports that will give users the flexibility of connecting a mouse, keyboard, and much more. The board also includes a 40-pin GPIO header that gives access to the user to 26 GPIO, UART, I2C, SPI, 3.3V and 5V sources.

Since Raspberry Pi was the forefront of the low-cost embedded Linux single board computers, there’s a large active community. Many examples, tutorials, and projects can be found on the Raspberry Pi website.

3.9.3 Raspberry Pi Model A+

The Raspberry Pi Model A+ is the low-cost variant of the Raspberry Pi. The A+ replaced the original Model A in November 2014 in which contain more GPIO header, microSD capabilities, lower power consumption, better audio, smaller design than the original model.

This board is designed for the minimalist. This low-cost Raspberry Pi uses the same processor as the model B+, but has less peripheral such as the Ethernet jack and three less USB ports. Without these peripherals, the board is significantly smaller at 65mm x 56mm. This makes it a low powered, less expansive and much lighter single board computer. The model A+ is still compatible with all the Pi operating systems and software and has the same amount GPIO pins and camera/display sockets as the model B+.

The design is based around a Broadcom BCM2835 SoC, which includes an ARM1176JZF-S 700 MHz processor, VideoCore IV GPU, and 256 Megabytes of RAM. This is a decrease in memory compared to the 512 MB RAM found in the Raspberry Pi Model B+.

3.9.4 Intel Galileo

The Intel Galileo and Galileo Gen 2 Board is an Arduino-certified development board based on the Intel architecture. This board is designed for students, educators, and DIY hobbyist who want to have the capabilities of working on the Arduino microcontroller Development Environment and working in a Linux OS.

Some of the Intel's Supported features include 12 GPIOs, serial console UART header that is compatible USB converters, 12-bit PWM for precise control of servos, console UART1 that can be redirected to Arduino headers in sketches, and a 10-pin Standard JTAG header for debugging.

3.9.5 Arduino Yun

The Arduino Yun is considered a microcontroller-based board in which the Atheros AR9331 processor supports a Linux distribution. This open-source physical computing platform is one of the first line of microcontroller/single-board computers with a built in WiFi for ease of networking.

The board also contains Ethernet support, micro-SD card slot, USB-A port, 20 digital inout/output pins 97 can be used for PWM outputs and 12 as analog), ICSP header, and 16 MHz crystal oscillator.

To communicate with a computer, another Arduino, or other microcontroller, the Yun's ATmega32U4 provides a dedicated UART TTL serial communication. The ATmega32U4 also allows communication over USB that appears as a virtual COM port when connected to a computer. The CPU also supports I2C (TWI) and SPI communication. The Arduino IDE simplifies the use of the I2C bus and SPI with the use of predetermined SPI and Wired libraries.

Programming is simple with the Arduino Yun. The Yun can be programmed with the Arduino IDE and uploaded easily with the ATmega 32U4 which contains a pre-burned bootloader that allows uploading new code without the use of an external hardware programmer. Also, the bootloader can be bypassed and programs can be uploaded straight into the microcontroller through the ICSP (In-Circuit Serial Programming) header using the Arduino ISP.

3.9.6 Single-Board Computer Comparison

The following table compares the specs of each board described.

Table 5: Single Board Computer Comparison

	Arduino Yun	BeagleBone Black (rev. C)	Intel Galileo	Raspberry Pi Model B+	Raspberry Pi Model A+
SoC	Atheros AR9331	Texas Instruments AM3358	Intel Quark X1000	Broadcom BCM2835	Broadcom BCM2835
CPU	ATmega32U4	ARM Cortex-A8	Intel X1000	ARM1176	ARM1176
Architecture	AVR	ARMv7	i586	ARMv6	ARMv6
Speed	16mhz	1ghz	400mhz	700mhz	700mhz
Memory	2.5 KB	512MB	256 MB	512 MB	256 MB
GPU	None	PowerVR SGX530	None	Broadcom VideoCore IV	Broadcom VideoCore IV
Internal Storage	16MB	4 GB	8 MB	None	None
External Storage	MicroSD	MicroSD	MicroSD	SD card	MicroSD card
Dimensions	2.7 in x 2.1 in	3.4 in x 2.1 in	4.2 in x 2.8 in	3.4 in x 2.2 in	2.6 in x 2.2 in
Price	$75	$55	$80	$35	$25

3.10 Database Management System

3.10.1 MySQL

MySQL is the classic open source SQL option that most would choose, and not think twice about. MySQL is the most reliable, well-known, open source, relational database in the industry right now, and for good reason. It simply works. However, much like any system, it has its downfalls. If the project one is working on does not need the relational aspect of databases, it almost becomes pointless. At this point, the device will only need to manage a list of GPS coordinates, so the relational aspect of MySQL does not help. If the project were to implement some kind of relational aspect, this may be a favorable preference.

Beyond the scope of this project, a NoSQL database would more than likely be more efficient. However, the implementation of any NoSQL database would require a significant amount of focus on such a small aspect of the project. Therefore, this is not a reasonable option, as it would take too much time to

develop for and learn before the time that this project needs to be finished. If time weren't an issue, this would be the better choice.
Given that MySQL is the most widely known, it is also safe to assume that it has the least compatibility issues. This grants a little wiggle room when it comes to implementation, and will only make that aspect slightly better to deal with in relation to the whole system at large. MySQL is also known for its simplicity. Any developer who knows SQL will be able to jump into any application that uses MySQL without difficulty. This leads to great scalability in any project; and, although that aspect may not make a huge difference in this project, adds value to any project if it can be worked on beyond the initial scope of the project.

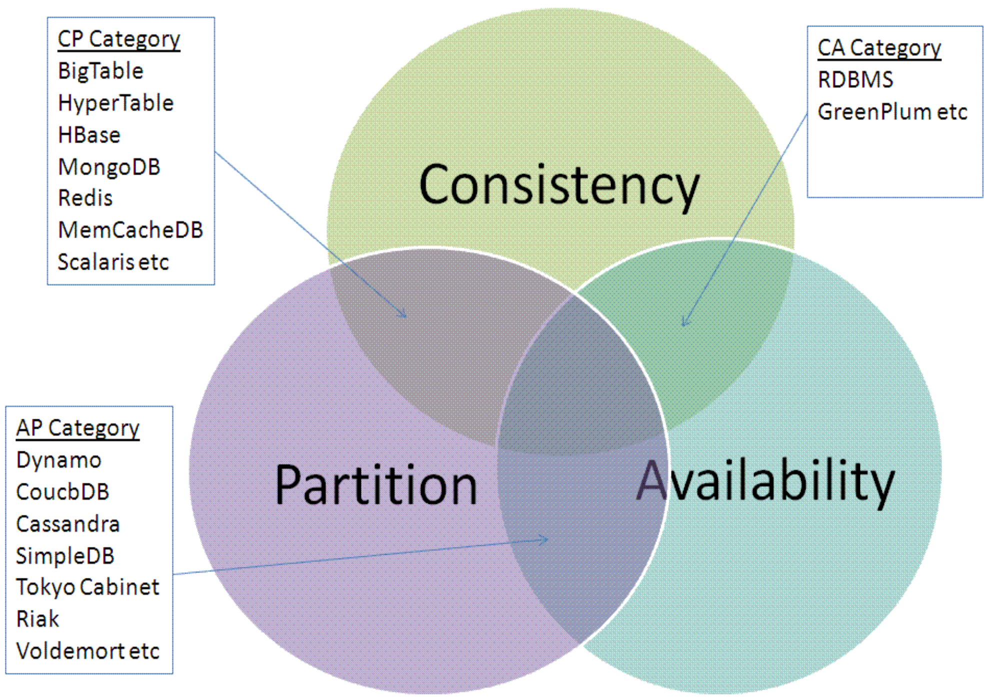


Figure 38: Database Type Comparison (Permission Granted due to being Royalty Free)

3.10.2 NoSQL

NoSQL is the other large category of storage methods. The main difference between NoSQL and other database management systems is that NoSQL is not relational. It can be equated to the comparison of a manual transmission car to an automatic car. The automatic car, in this case, is MySQL; because it does all the hard work for you. This hard work can only be done based on the relationship aspect of SQL. That's where NoSQL comes in, because it is like the manual transmission car. Because there is no relational aspect in NoSQL, the developer must do a lot more to receive the data as expected. One benefit of NoSQL is that it is easily scalable by adding more storage, but since this project doesn't consist of an army of mine detectors, this benefit may not be applicable.

The immediate benefit of choosing NoSQL would be that it can be accessed through object oriented API's. This would affect how the developer deals with the data, and in this project could drastically affect performance. There are a few different methodologies in this regard, and each will be touched on in brief detail of their benefits.

Key-Document based NoSQL databases are based around the idea that data is stored in a collection of documents. These documents are of no particular type, and can store huge lists of files with relative ease. An example of such a NoSQL database would be MongoDB. MongoDB uses a binary serialization of JSON-like objects, which would have very good synergy with the GPS dongle that is chosen if the JSON format was also chosen as the storage method in the database schema.

Key-Value based NoSQL databases like Redis and MemcachedDB are based on are similar to the standard Key-Value nature of SQL databases, but carry all the benefits of NoSQL. It is the best of both worlds, in some regard.

Ordinarily, NoSQL databases are avoided unless the developer is familiar with NoSQL databases, because these databases are only necessary if computational complexity is limited. This can be because of large scale platforms like Facebook, or small scale single-board computing limitations in the case of this project. However, it development becomes significantly smoother if a more practical resource like MySQL can be used

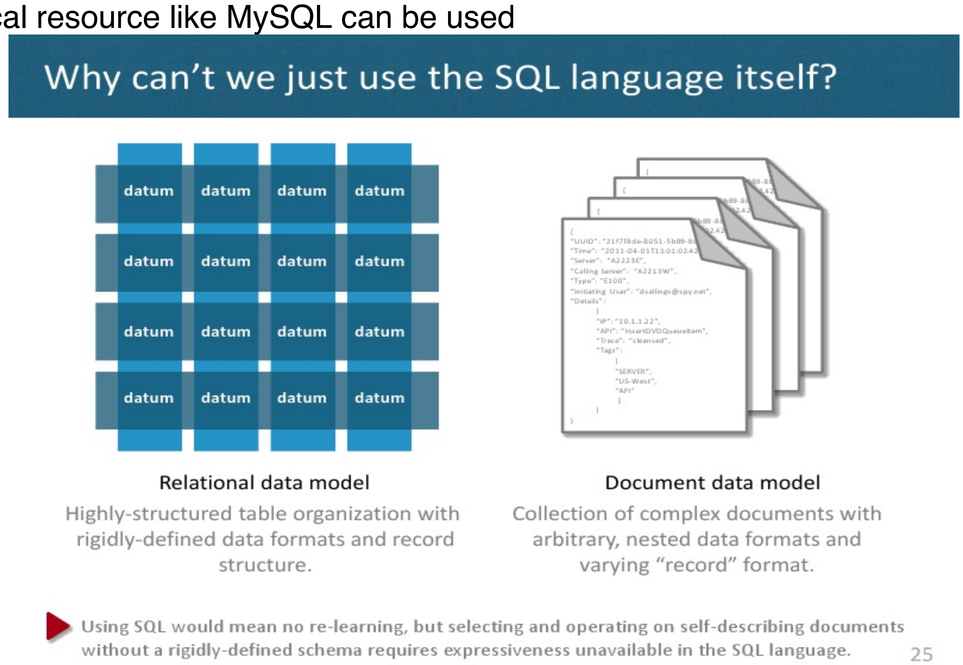


Figure 39: SQL vs NoSQL (Royalty Free)

4 Project Hardware and Software Design Details

4.1 Platform Selection

This section will have detailed explanations for the selection of the different options for the materials to be used to build the chassis, the different options of drive systems, and the different motors for the drive system, and how all the components will be implemented make the platform.

4.1.1 Materials Selected

After careful consideration on all the research done, comparing the weight, sturdiness, cost, and other factor such as the effects of outdoor weather on the materials, and the effect of the materials on the metal detection system, we came to the conclusion that Plexiglas will be the best material we can use to build the platform for our design of the unmanned ground vehicle mine detector, in order to get optimal performance and durability of the vehicle.

Table 6: Materials Comparison for Design Specifications

Material	Thickness (in)	Weight Per Square Foot (psf)	Estimated Prize For Project
Plywood	0.25	3 lbs.	$20.00
Aluminum	0.10	1.43 lbs.	$700.00
Plexiglas	0.25	1.5 lbs.	$135.00

An AutoCAD file will be created showing each part of the chassis with the appropriate dimensions and exact specifications of the material. Once the materials are acquired, this will be used to get the individual pieces of the chassis cut with the upmost accuracy using a laser machine, to make sure that all the pieces fit properly, to make sure that the vehicle is not affected by mistakes in the chassis, and to acquire knowledge on how to have materials laser cut.

Once all the materials have been accurately cut, and acrylic cement will be used to glue the corners together, once it is completely dry, small L-shape aluminum reinforcements will be drilled into certain areas to make sure it is as sturdy as possible.

4.1.2 Drive System Selected

Due to the importance of the mobility requirements for the vehicle, we decided that the track system is the best option for our design specifications, although wheeled drive is easier to design, less expensive and easier to implement, the advantages earned by implementing this system will bring us a lot closer to being able to achieve our goals with this project.

Since it is very hard to find a set of tracks with the specific dimensions needed for the design of our vehicle, it is better to design our own track system than to re-design the whole vehicle to fit a specific set of tracks, and it will also be less expensive to do so.

For our track system design, a conveyor belt, like those used in factories or plants to easily move objects linearly from one location to another, will be used as the track, this conveyor belt kits already con with a sprocket, in this case a two 12T drive sprockets will be used in each side to make sure that the tracks feed through evenly, in order to keep the design specifications clearance, three wheels with a 5.5 inch diameter will be used in the center of each track, for optimal sturdiness, this wheels will be connected by a rod to a wheel in the opposite side, and two 4.2 inch diameter wheels will be used in each side as the track idlers to keep the tension on the track, this idlers will also be connected by a rod, a total of four rods will be used.

4.1.3 Motors Selection

On section 3.2.4 different types of motors that could be used for the drive system were compared, and after a lot of research, we had a good idea on which motor we could use, however, we also had to account the weight of the vehicle to figure out if the motor were going to be able to drive all the weight, a lot of research had to be done to calculate the estimated weight of the whole system. First we had to get the design measurements of the chassis, after adding up all the sides of the chassis, as shown in Table 7 below, the overall amount of the material that will be used for the chassis was calculated, this calculation was used to calculate the estimated weight of the materials making up the chassis in accordance with the weight per square foot of the material being used, as shown in Table 8 below.

Table 7: Chassis Dimensions

Chassis Dimension		
Panel	**Dimensions (in)**	**Size of Panels (in^2)**
Right Side	[(10 x 20) + ((10 x 10)/2)]	250
Left Side	[(10 x 20) + ((10 x 10)/2)]	250
Front Side	(14.142 x 12)	170
Back Side	(10 x 12)	120
Bottom Side	(20 x 12)	240
Top Side	(30 x 12)	360

Table 8: Estimated Weight of Chassis

Estimated Weight of Chasis Using Plexiglass	
Total size (in^2)	1390.00
Total Size (ft^2)	9.65
Weight Constant (lbs psf)	1.50
Total Estimated Weight (lbs)	14.48

Once the weight of the chassis was estimated, the weight of the drive system had to be calculated, to do so, we had to calculate the length of the belt that would be needed for each track, once again by using the information provided by the manufacturer of the belt that will be used, we calculated an estimated weight for the belts of the track system, as shown in Table 9 below.

Table 9: Belts Weight

Estimated Weight of Intralox Tracks	
Width of tracks	3.25
Estimated length of tracks	5.00
Total size of tracks (ft^2)	1.35
Weight of track (lbs psf)	1.90
Total Estimated Weight (lbs)	5.15

The rest of the drive system was not so easy to estimate, most of the weight specifications for the parts that were intended to be used was not available, multiple contacts were attempted with the manufacturers to find this information, however, due to time constrains different parts with the similar characteristics which included this specifications had to be found, after a lot of research, the weight for this parts were finally able to be calculated, as shown in Table 10 below, and the weight of the overall drive system able to be summed up as well as shown in Table 11 below.

Table 10: Other Components Weight

Estimated Weight of Other Drive System Components	
Unite	**Weight per unit**
Wheels (lbs)	1.00
Iddlers (lbs)	0.50
Sproket (lbs)	0.25
Plastic Rods (lbs)	3.10
Total Estimated Weight (lbs)	21.40

Table 11: Overall Drive System Weight Estimation

Estimated Drive System Weight	
Tracks (lbs)	5.15
Other Components (lbs)	21.40
Total Estimated Weight (lbs)	26.55

The rest of the components for the vehicle, including the motors for the drive system, had to be researched and estimated. For the motors the average weight of standard size DC motors was used, since this was the most likely motor to be used, the weight of the LIDAR was readily available to find, and once again an estimation of the weight for the LIDAR mount had to be done using the same materials as those used for the chassis, for the batteries, we decided to use the heaviest batteries that we might be using, in order to account for worst case scenarios, we decided to overestimate the weight of the vehicle, so most of this estimations have been round up a bit, for the last components labeled as other on the table, we included the glue to be used to hold parts together, cables for the batteries, and LIDAR, and any nuts and bolts that have to be used, the overall estimation of our vehicle can be seen in Table 12 below.

Table 12: Estimated Weight of Entire Vehicle

Estimated Weight of Entire Vehicle	
Chasis (lbs)	14.48
Drive System (lbs)	26.55
Metal Detector (lbs)	3.00
Motors and Gears (lbs)	5.00
LIDAR (lbs)	9.90
LIDAR Mount (lbs)	3.00
Batteries	16.00
Other	5.00
Total Estimated Weight (lbs)	82.93

Once we figured the estimated weight of the vehicle, we realized that the best option would be to get a combination of a motor and gears to make sure that enough torque can be accomplished in order to move the vehicle.

The detection system will also need two motors, one for the sweeping motion of the metal detector, and another one for the tilt of the arm holding the metal detector, this option is going to be implemented in the system in order to make sure that the system keeps the metal detector at an optimal height while operation, and in order to avoid hitting the detector against the ground in cases there is a sudden change of elevation in the terrain such as mounds of dirt or holes. These two motors will also be discussed and explained in the section.

4.1.3.1 Motors Selected for Drive System

After comparing the different types of motors that could be used for the drive system, we were inclined to go with the stepper motor, because of its precision, however, after careful consideration, we realized that a brushless DC motor would be easier to control, would not overheat, use less power, use less space, and with the addition of a set of gears, which after estimating the overall weight of the vehicle, we realized it was most likely going to be implemented, even though DC motors are not meant for torque but for speed, the implementation of the gears will lower the speed and increase the torque, also this would help achieve the same accuracy of movement.
A set of motors and gears was found in the ServoCity website, this set comes already implemented as displayed in Figure 40 below, and has the specifications needed for our vehicle, as shown in Table 13 below, this set has a shaft with the exact dimension of the shaft needed to connect to the sprokects which will be translating the force to the drive system, this makes it easier to implement, since no modifications will have to be made.

Figure 40: Inside Mechanism of Motor and Gear Set
(Permission Pending)

Table 13: Motor and Gear Set Specifications

RPM	Torque	No Load Current	Weight
10	13.56 Nm	100 mA	1.816 (lbs)
23	6.214 Nm	100 mA	1.824 (lbs)

The motor and gear sets drive forward and backwards, they also come so that it is simple to screw into the platform and connect to the rest of the track system, since one motor is going to be driving one set of tracks, while the other drives the other set of tracks, it will be easy to move the vehicle, if both motors rotate forward, the vehicle will move forward, if both motors rotate backwards, the vehicle will move backwards, if the vehicle needs to turn while moving, the motor on the side that the vehicle will be turning towards will lower the speed while the opposite motor increases the speed, making the vehicle turn, the sharper the turn that is needed, the more speed should be decreased by the turning side while more speed should be increased by the opposite side, and finally if a turn in place needs to be done, which is a great capability of a tracked vehicle, both motors should be put to the same speed but rotating opposite to each other.

4.1.3.2 Motor Selected for Detection Sweep

The International Pilot Project for Technology Co-operation (IPPTC) made an evaluation of a number of metal detectors used to detect land mines and explosives by humanitarian demining groups, one of the tests performed was an optimal sweeping speed test, although the results varied by metal detector, the results showed that the accuracy of detection decreased if the sweeping speed was not constant, and in some cases metal detectors would not detect land mines while they were stationary, the results also showed that most metal detectors have optimal detection capabilities if swept at a constant speed between 0.12 m/s to 1.0 m/s, therefore the detection system for our project needs to be controlled by a very precise motor to make sure that optimal detection is kept throughout the operation of the unmanned vehicle.

After researching multiple types of motors, it was not hard to select a servo as the motor to control the sweeping motion of the detection system. A servo motor is composed of a DC motor, with a set of gear reduction connected together with a position sensor, usually a potentiometer, and an integrated circuit, servos rely on the feedback of position sensor to operate, which is a great advantage and makes it more accurate to operate.

The servo motor that will be used for the sweeping motion of the metal detector, will be a standard size ServoCity S3151, this servo has the specifications needed to make sure that it will be able to handle the arm and electromagnetic coils that make up the detection system, the specifications of this servo are shown in Table 14 below.

Table 14: Servo Motor Specifications

Operating Voltage	4.8 - 6.0 Volts
Stall Torque (4.8V)	43 oz/in
Stall Torque (6.0V)	56 oz/in
Current Drain (4.8V)	7.2 mA/idle
Current Drain (6.0V)	8 mA/idle
Weight	1.5 oz

The detection system will need to be connected to the servo, to do so, a pan system will be used to make sure that the system is stable, and that the servo motor does not get damaged. The DDP 115 Base Pan system by ServoCity will be used for this, as you can see in Figure XX below, the detection system can be easily attached to it.

Figure 41: Servo Sweeping Mount (Permission Pending)

This pan system is perfect for our design, it gives us plenty of room to make sure that changes in the elevation of the detection system can be made, it is easy to attach to the chassis of the vehicle, it also has more than enough space inside, to fit the servo motor, as shown in Figure XX below, and it is also meant to work with the chosen servo motor.

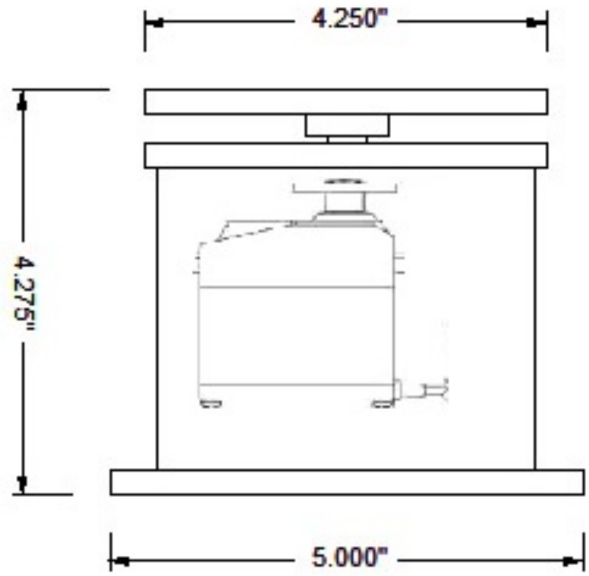


Figure 42: Dimensions of Pan System Showing Servo Motor Inside (Permission Pending)

4.1.3.3 Motor Selected for Detection Tilt

Another test that the International Pilot Project for Technology Co-operation (IPPTC) made, was to test the optimal distance from the ground to sweep the metal detectors, the results showed that in order to get the best readings possible and still keep the metal detector at a safe distance from the ground, the head of the metal detectors should be kept around 2.5 to 5 cm above the ground. A linear actuator will be used be used as the tilt controller for the detection system, it will be attached from the bar holding the metal detector, to the bar with the mount for the LIDAR, this way if there are any sudden changes in the terrain being swept, the metal detector can be adjusted in order to keep optimal height from the coils to the ground for better mine detection, and also to keep it from hitting the ground in the case of a change in the terrain.

4.2 Power System Selection

After completing the research on the power systems and all of its components, coming up with an efficient, yet practical, design to power the system was difficult due to the many variables. Our required voltage needed to supply our sub systems ranged from 3.3 volts to 24 volts. So in the following sections: voltage requirements, battery selection, voltage regulators, and diagrams of each integrated power supply will be discussed.

4.2.1 Voltage Requirements

Before determining what batteries and power systems will be used, the systems power supply requirements must be reviewed. This information will provide the necessary information needed to select size and battery type, but also the organization of the system as a whole. Below in Table XX we have listed the systems that will require power and how much their ratings are.

Table 15

System / Component	Required Input Voltage	Required Input Current
LIDAR	24 V	250 mA
2 x (DC Motors)	12 V	2 A (each)
Beagle Bone Black	5 V	1 A
Motor Controller	5 V	4 A
Metal Detection System*	12 V (8 AA) and 9 V for Amp	8 mA

*Will have its own battery sources supplied by Alkaline Batteries

As seen in the table above the beagle bone black and motor control will only need 5 Volts to power on their individual systems which will allow us to pair both of them to one source. Also, the LIDAR requires 24 volt input voltage, and the two DC motors will run on 12 volts. As described by the footnote, the metal detection system will be supplied by alkaline batteries that will be used and replaced as needed. In regards to all the other components, a rechargeable battery of some sort will be the most efficient and plausible method to supply our system.

4.2.2 Battery Selection

Based off of the research conducted for the different types of potential batteries we will consider Lithium Ion, Lithium Polymer, Nickel Hydride, and Nickel Cadmium batteries because of their ability to be recharged and also their battery life will be able to sustain the amount required to run our system. However, after conducting research and comparing Lithium Polymer has the rating qualifications needed and also have sizes that support our initial power system design.

When reviewing the different sizes and forms, we will reference Table 15, which describes the voltage requirements for the sub systems. In the Power System section of this report, it will explain how we are separating our power supply systems into two. So to determine the batteries needed, Table 16 below contains the power needed for each sub system.

Table 16

Sub-System	Max Voltage Required	Total Current Needed
SYS1 (Beagle Bone Black, and Motor Control)	5 V for BBB 3.3 V for MC	5000 mA
SYS2 (LIDAR, and two DC motors)	24 V for LIDAR and 12 V for DCM	4250 mA
Metal Detection*	12 V (8 AA) and 9 V for Amp	8 mA

*Metal detection is not considered as one of the sub systems

For the first system because it does not require a high voltage but the current rating is high we will use two voltage sources of 11.1 V 3300 mah 50 C Lithium Polymer batteries connected in parallel using a T-plug battery harness. This will allow us to have 11.1 V 6600 mah supplied to the system allowing us to have ample current to power both the beagle bone black and the motor controllers with ease. The calculations made to achieve the max output current are equal to the capacity (C) times the discharge rate (mah). For the battery selected this would produce a max of 165 A per battery. In regards to addressing the voltage regulation for the first system, there will be specifics for each component being used in the voltage regulation section.

For the second system, we will need to meet the requirements for a 24 V and 4250 mA system. Similarly to the first system we will be using two 14.8 V 5200 mah 50 C Lithium polymer batteries connected in series. Having a total of 29.6 V 5200 mah for second system meets our requirements needed to supply power to the LIDAR system and the two 12 volt DC motors. Given, the provided information we will now have a max output current equal to 5200 mah time 50 C which is equal to 260 A. In regards to addressing the voltage regulation for the second system, there will be specifics for each component being used in the voltage regulation section.

Table 17: Battery Selection Details

Part Number / Battery	F-235 	G-731 
Vendor	EZ Flite	EZ Flite
Voltage	11.1 V	14.8 V
Discharge Rate	3300 mah	5200 mah
Capacity	50 C	50 C
Max Output Current	165 A	260 A
Weight	9.52 oz	18.6 oz
Dimensions	5.37” x 1.63” x 0.81”	6.5” x 1.7” x 1.88”
Type	LiPo	LiPo
Price	$36.95	$69.95

Permission requested from www.headsuphobby.com

The batteries selected cover most of the battery requirements set out in the selection process. This includes minimal memory effect on the battery, high capacity, and battery life that supports the system for at least an hour. Voltage requirements needed by the two systems are met, even though for the second system we needed to connect them in series to accumulate a minimum of 24 volts. Similarly, the current rating for the first system was met by connecting the batteries in parallel to add both of the batteries current discharge rate, so that it will perform to its expectations. The prices for these batteries are a little pricey; however, they have some of the best performance ratings and also provide PCB protection. The PCB safety precaution is very important because it would be detrimental to our project if when testing we were to ruin some of the hardware components being powered.

Lithium Polymer batteries are very efficient rechargeable batteries because of their complex composition and high amounts of energy. What is important is that they are handled and charged correctly to prevent failures from overcharging that can lead to overheating and even fires. With that being said, picking a reliable charger that will have preset configurations to charge the Li Po battery at its right charge rate and correct time is important. After conducting research, the Tenergy Balance Airsoft Battery charger has all the specifications to meet the requirements. Also, many of the other battery chargers run upwards to the hundreds of dollars, but for our needs the Tenergy charger is well suited and has a relatively cheap cost of $19.99. The charger is shown below in Figure XX, and some of its features include: automatic charging process, light weight, multiple protections features, ability to charge LiPo, LiFe and LiIon batteries, built-in balance for battery cells, and can charge up to 4 cell batteries.

4.2.3 Voltage Regulation Selection

The voltage regulators chosen for each sub-system are dependent on meeting the output voltage and current requirements. Since we have two subsystems that have a large difference in voltage regulation we will discuss each selection made by system.

In the first sub-system, we will only need a regulator to provide an output of 5 V and 5 A for the Beagle Bone Black and the motor controller. When making this selection, we determined that a switching regulator would be a better choice compared to a linear regulator, because of its efficiency. Our voltage supply for this system has enough voltage to account for any drop off voltage; however, we need to ensure that the load current is always a consistent 5 A. For our application of this regulator, there are several design configurations to make it a fixed or variable regulator, but since we only require 5 V, we will use the design shown below in Figure XX. Also, it was one of the few regulators that supply a high current with the input voltage provided. The switching regulator selected shown in Table ZZ, along with its specifications.

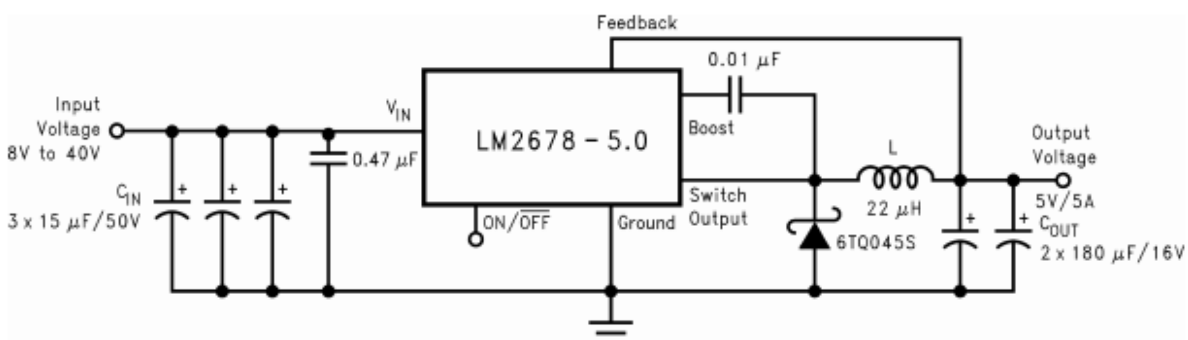


Figure 43

“Courtesy of Texas Instruments”

For the second sub-system, the power supply of 29.6 V 5200 mah will require two voltage regulators: one for the LIDAR (24 V 250 mA) and another for the two DC motors (12 V 2 A). The 12 V, 2 A switching regulator has a simplistic design requirement to achieve the desired output for the two DC motors as shown in Figure XX1.

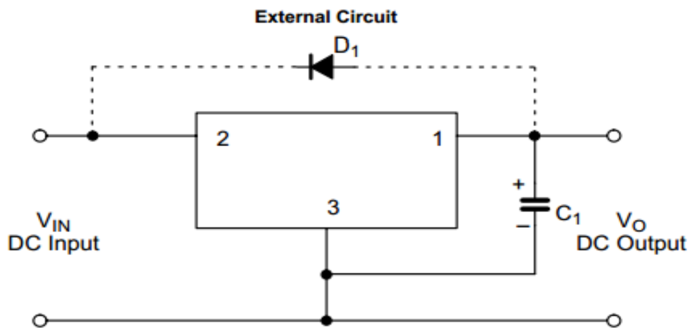
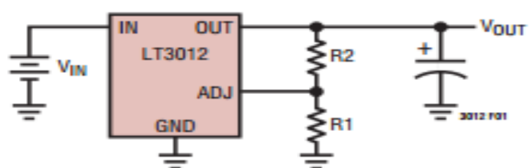


Figure 44 (Permission Pending)

However, for the 24 V 250 mA voltage regulator the design requires the use of scaling the output voltage through the use of resistors to achieve the gain. For this regulator, it seemed best to use a linear regulator, because the LIDAR system is very susceptible to noise that could be created by a switching regulator. This is important so that we can get correct mapping and also clear obstacle detection for our system. To calculate the values for the correct output, we will use the equation for Vout in Figure XX2. The ratio of R2:R1 should equate to 18.35 to ensure an output voltage of 24 V.



$$V_{OUT} = 1.24V\left(1 + \frac{R2}{R1}\right) + (I_{ADJ})(R2)$$

$V_{ADJ} = 1.24V$
$I_{ADJ} = 30nA$ AT 25°C
OUTPUT RANGE = 1.24V TO 60V

Figure 45 (Permission Pending)

4.2.4 Power Systems

The power supply for the project will be composed of two integrated power supplies that will be designed and built onto printed circuit boards. Below in Figure 46 and Figure 47, the two systems describe how each battery source supplies the subsystems used in the project. The reasoning behind this selection is due to the wide range of voltage requirements for our sub systems. By grouping each sub-system with its related counterparts allows for organization of our system, and provides efficiency to our power supply.

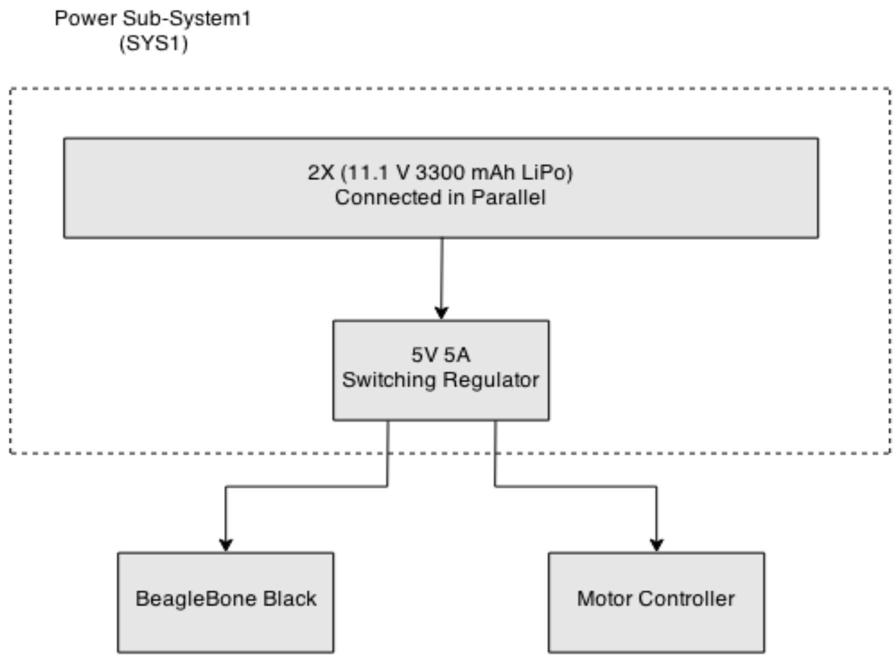


Figure 46

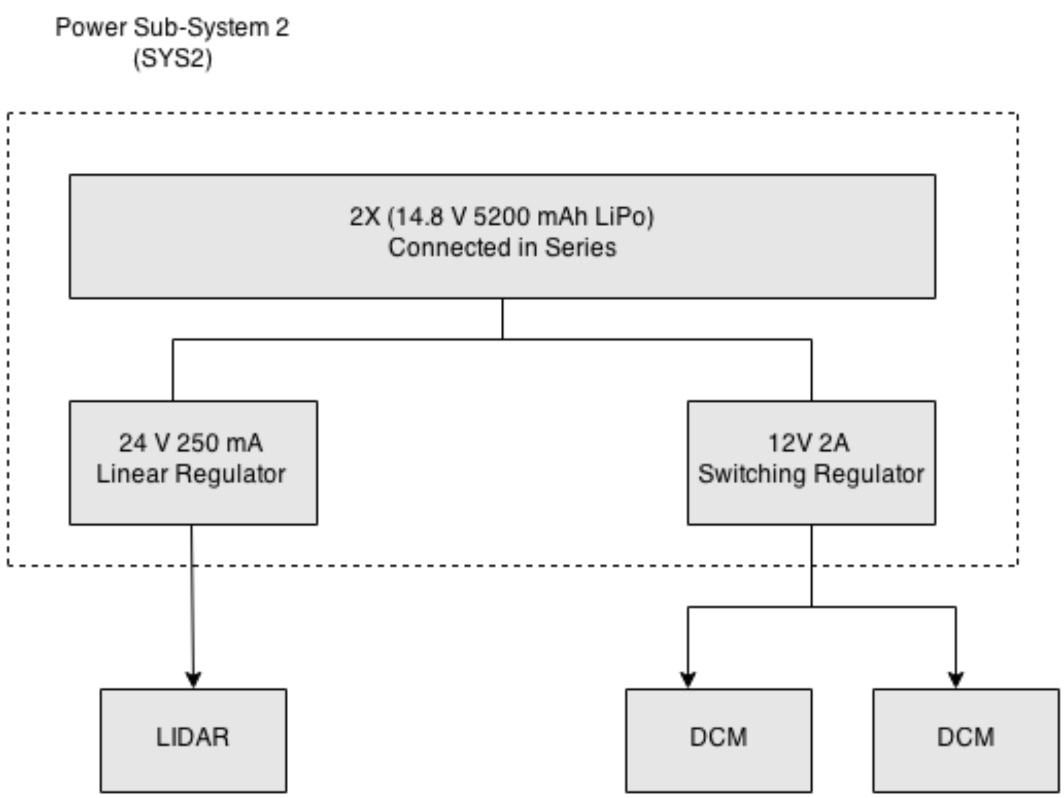


Figure 47

As seen in sub-system 1 the 11.1 V 3300 mah LiPo battery will have one voltage regulator that will regulate the battery to supply an output of 5 V and 5 A, so that both the Beagle Bone Black and motor controller can be powered. In sub-system 2 there will be two regulators, one 24 V and another 12 V to supply the LIDAR system and DC motors respectively.

With the completion of the power system it is important to regularly check the voltage of each component using a multimeter to ensure correct output. Also, given the large size of our platform, the power system has the luxury of not having spatial, nor weight requirements. This allowed us to minimalize our limits and pick parts that are most efficient.

4.3 Obstacle Avoidance System Selection

4.3.1 SICK LMS-200

Since the robot will be used outdoors, the SICK LMS-200 will be needed. Although the system is more expensive than the other LIDAR systems compared, this laser measurement system contains the best area monitoring, object measurements, and determining positions.

Another reason to use the SICK Laser Scanner is the ease of use with the Robot Operative System (ROS). ROS contains a SICK laser toolbox wrapper that interfaces with LMS2xx and LD lasers. This package contains drivers for the laser rangefinders drivers written in C++ to give ease of use for the laser rangefinders.

The LMS-200 will need a 24 V external DC-power supply just to power the laser measurement system. As stated before, the LMS200 requires an operating voltage of 24 V DC ± 15% with a power consumption of ≤ 20 W. Although the system will use a substantial amount of energy, it will provide the most reliable information indoor and outdoor.

A fan-shaped scan is made when the pulsed laser beamis deflected by an internal rotating mirror. The outline of the target objects is determined from receiving the impulses of laser data. Measurement data is sent real-time using the data interface. LMS is equipped with a serial RS 232 /RS 422 interface. By setting a jumper, RS 232 or RS 422 can be enabled. A RS 232 can be quickly added by adding a RS-232 serial level converter cape. This TTL-232 micro-cape is configured as a Device Terminal Equipment similar to a standard PC. With this cape the DB9-male pin-2 is an input to the BeagleBone (RxD) and the DB9-male pin-3 is an output (TxD). This will allow connection to the SICK LMS-200 to send data to the BeagleBone Black board.

4.4 Detection System Selection

Ground Penetrating Radar, Infrared, and Ultra Sound systems can be used to detect objects or anomalies underground, by giving humans an image display of what is underground, or a change in temperature probable from a buried land mine, however, these three systems are focused on giving humans an image which unless it is taken under desirable conditions, will need to go through filtering before a human can analyze it and decide if it is a land mine or not, in order to make any of this detection systems be able to autonomously detect possible land mines, and be able to mark it on its own, it would require extensive amounts of filtering, calibration and programming, which make this three detection systems not good for our project.

Many people argue that the use of metal detectors to detect land mines, is not reliable due to the use of non-metal content land mines, which metal detectors cannot detect, but these mines are very rare and not many where deployed before the 1997 Mine Ban Treaty, however, thanks to the advances in technology, current metal detectors can reliably detect very small metal components in low-metal content land mines, which constitutes the majority of the land mines deployed.

There are different types metal detectors, they all have the same basic components, but they work a bit different from each other, and although metal detectors are not 100% accurate, and might not be completely reliable under certain terrain or weather conditions, they are still the most all around reliable land mine detection system out of the rest, it is also the least expensive to implement, and the most feasible system that can be implemented into an unmanned ground vehicle system to autonomously detect land mines.

After extensive research on multiple land mine detection systems, we decided to implement a Pulse Induction metal detector as the detection system for our project, for the transmitter part, the differential coil method will be used, this is done by making two coils in the shape of a D, and are implemented into the system, with the straight parts to each other, making a circle with outside part of the coils, the circuit will then be configured to make sure that the system only responds when there is a differential reading between the two coils, this is done by subtracting the reading from one coil by the other coil, meaning that the system would not respond to factors that influence both coils equally, making sure that the system ignores any reading due to debris or the magnetic properties of the ground such as high concentrations of minerals in the terrain.

4.4.1 Implementation and Design

The detection system will therefore work by sweeping the area in front of the vehicle in an angular motion, while doing so, if a possible landmine is detected, the vehicle will stop it's forward motion and keep sweeping, if the possible landmine is closer to one coil than the other it will read the difference and give out an alert, the system will keep reading the alert until the possible landmine is equally as close to both coils, in this case when the possible landmine is in the center of the two coils, it will have a brief interrupt in the alert, and will continue alerting when the possible landmine is closer to the other coil, this information will be sent to the microcomputer, which will use this information to mark the exact area for a possible landmine, multiple sweeps of the same area might be implemented for more accurate results of the location of the possible landmine. This method not only makes it more accurate to identify the location of the possible landmine, but it also makes it easier to write an algorithm to deal with possible false readings.

The diameter of the coils used in any metal detector will have a big impact on the effective range that it will be able to detect. Bigger coils are able to penetrate the ground farther, making them essential for finding bigger explosives dug deeper in the ground; nevertheless, they spread the magnetic field over a larger area making it possible not to detect smaller explosives or landmines closer to the ground. Smaller coils work the opposite; they are cable of easily detecting smaller metals like those found in low-metal density landmines, but have trouble detecting anything deeper in the ground.

The average diameter of the coils in the metal detectors used for demining is 20cm, therefore this will be the size used for our coils. To build the head of the detection system, a thing sheet of Plexiglas will be used to make the casing of the coils, two D shaped compartments will be made which will hold the coils, this will also make it easier to make them, 0.25mm enameled copper wire will be used for the coils, once they have been made and tested, which will be later described in the testing procedures section, the casing will then be sealed, the head assembly will be connected to a plastic rod, which will be connected to a pan and tilt system in the vehicle.

4.4.2 Detection System Circuit

Research on differential coil pulse induction metal detection circuits was extremely difficult since most, if not all of the metal detection manufacturers have patents on their schematics and keep them private, however, we were able to find information on some schematics from metal detectors that have been reversed engineered.

The circuit for our detection system will follow the principal of the diagram shown in Figure XX below, since this diagram is for a handheld metal detector, and works by alerting the user through a loud noise through a speaker, this will be changed so that the signal is sent to the microcomputer as a feedback signal, enabling us to make the vehicle autonomous and not rely on human interaction.

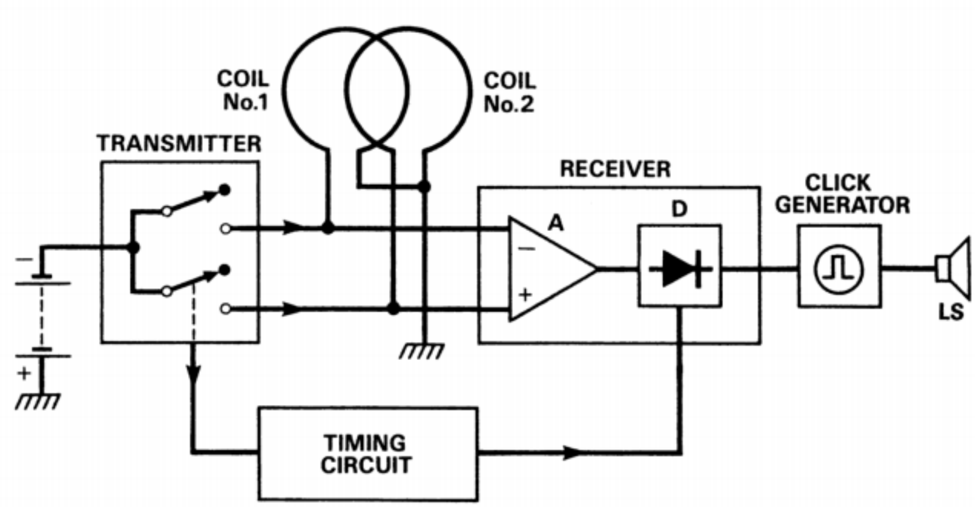


Figure 48: Diagram of Dual Coil Pulse Induction Detector (Permission Pending)

The transmitter will consist of two timers, one will be working as an oscillator, sending the signal to the second multiple times per second, each time the second timer is triggered it will send voltage to the transistors connected to the coils, letting current flow through them.

The second timer from the transmitter will also trigger a timer in the timing circuit which will then send a signal to a transistor inside the receiver, consequently, the feedback from the coils is being sent to a differential amplifier in the receiver, by using diodes only the amplified signal when something is detected will then go through the now saturated transistor into an amplifier, this signal will then be sent to the microcomputer, therefore a click generator will not be needed.

The circuit will have its own power supply, consisting of eight AA batteries to provide the current to the coils and power most of the circuit, including all the timers, and a 9 volt battery to power the amplifiers.

4.5 GPS Detection Selection

When there is a well-known brand that shines through the competition, it tends to be the one that is seen. When that well-known brand is also competitively priced, it is only the natural choice. This brand is Adafruit. Adafruit stands above the competition in a lot of ways. When searching for other embedded systems/single-board computer accessories, the only brand that shows up is Adafruit. Due to this, an Adafruit GPS module with a customizable antenna would be ideal.

The GPS unit will be mounted on the back of the device for optimal GPS signal, and would then be in an ideal spot as it would interfere the least with the operation of the metal detector hanging off the front of the device. This would put the GPS device as far away from the metal detector as possible, which would be ideal. As long as the GPS unit can connect to enough satellites to give a concise location, just about any position will be ideal.

The GPS unit's location will be polled at a mild rate. The polling rate need not be anything extravagant, because the device will not be moving more than two miles per hour. This would lead to needing to be polled no more than once every two seconds if no flags are thrown. The GPS will always be polled when a triggering event is fired off, whether that is a turn of the device itself or the finding of a mine that triggers the event.

The GPS unit can have an integrated antenna, but if this weren't sufficient enough, an ideal situation would allow the GPS unit to have a customizable antenna for more accuracy. However, it is well known that GPS is only accurate to every four meters or so.

Fortunately for this project, there are a million different options for a GPS device that will interact well with a single-board computer. This project will require a GPS device that can interact with a UART port or a USB port, preferably. Since this is the way that would work best to be able to interact, a device should be found that fits these specifications.

Because GPS is only accurate to a three-meter radius, there is the consideration of using other forms of telemetry. An example of such would be inertial positioning. Inertial positioning gives information based on motion sensors and rotation sensors to calculate the position, orientation, and velocity of an object. The main problem with this in consideration with the design of the project is that it requires significantly more sensors and attachments than just using a simple GPS location device. Since weight is already a factor for this project, due to limited battery supply and a substantial base weight with the already included components, it is simply unreasonable to account for this excess weight. There is also a concern for the simple evil that is the limitation of input and output systems within the single-board computer itself. These systems are limited, and the system doesn't need these excess concerns.

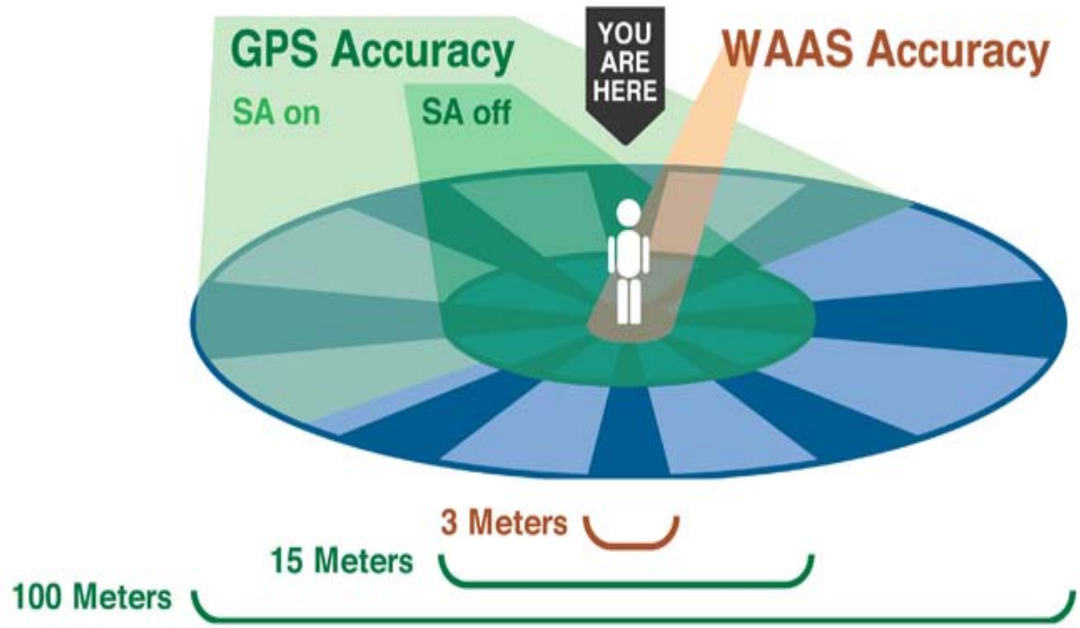


Figure 49: GPS Accuracy Diagram (Permission Pending)

This leads this project towards choosing a GPS device like the Adafruit Ultimate GPS Breakout – 66 channel with 10Hz updates. A device like this would be ideal, because it has the option to use either UART or USB to communicate with the single-board computer. This device also only uses one of each of Tx/Rx ports on the single-board computer, freeing up the USB port for something else that has less options for connectivity on the single-board computer.

4.6 Wireless Communication Selection

When designing a wireless communication network, generally power consumption is significantly less of a concern when power is readily available. Since the device will be running on a limited power supply, power consumption is significantly more important. AdHoc Wireless Networks are notoriously power hungry. When you take into account that any device on the network could receive or send information to any particular device at any particular time, this seems to make sense. There is a lot of organized chaos when it comes to an AdHoc networks, and this leads to a significant amount of power consumption.

Even with this in mind, when you simplify an AdHoc network down to the bare minimum: communication between two devices, it becomes way less of a concern. The system can be designed in such a way that the communication device will be polled at a regular rate. Since the randomness element is taken away from this type of AdHoc network, power draw becomes consistent and therefore can be prepared for. Therefore, this design choice becomes logical, and will be implemented so that it will give the lowest power draw possible.

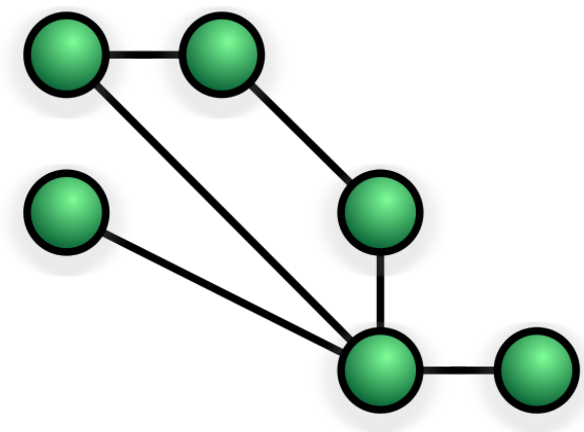


Figure 50: Example of Elaborate Mesh AdHoc Network
(Permission Granted - Public Domain)

The main reason that an AdHoc is most beneficial for this system is that isn't dependent on anything else other than the participators in the network. Due to this, the design becomes scalable. This is not the only benefit of an AdHoc network. If it later becomes reasonable that another controller would be necessary to handle other aspects of communication, the AdHoc network lends itself to this type of "problem". Instead of becoming a hassle, there would just have to be a communication channel between the new device and the rest of the devices on the network. AdHoc networks do this especially well. So, it is easily capable of being implemented with other systems if necessary.

The communication channel that will be established within this network will be handled by TCP/IP communication. This type of communication is the standard in any kind of internet application. This is because it is known to reliably send packets across a network, whether big or small, consistently and reliably. It does this by offering collision detection of packets, and reliably resending these packets based on a queue that will be only emptied when it is verified that the packet has been sent successfully.

The TCP, or Transmission Control Protocol, is the most important aspect of the communication in this regard, because of the nature of an AdHoc network depends highly on the implementation of the TCP. Packets can be sent through connection-based or connectionless networks. The connectionless protocol would be UDP, or User Datagram Protocol, and is not as error free. This leads to sending packets over again which wastes computational power. Since TCP is significantly more error free, it is the more obvious choice.

With AdHoc networks, security becomes a significant concern, because anyone configured to access AdHoc wireless networks would be able to hack the system. Fortunately, the system that is being designed doesn't strictly depend on the security of the network. This is not to say that it isn't important to make sure that outsiders are not affecting the network. To do this, the network would just have to be consistently watched to make sure that no users attach to the network. Although not the most elegant solution to security, it is one of the compromises that have to be taken to make the system function at full capacity.

The wireless network has to be able to extend far enough so that the user is safe from the mine explosions. It would not be beneficial to only be able to be a few feet away from the device that is looking for explosives. Luckily wireless networks tend to do extremely well outdoors as there is nothing blocking the frequencies that will be sending the information. Indoors, wireless transmission can occur at about 66 feet away from the access point. These numbers are not as impressive as needed, so it may be necessary on the large scale to create a boosted WiFi signal that are known to transmit data at 2000+ feet. This may not be necessary for testing purposes, but is a general concern of design in the real world application of this device. However, this then raises the concern of power consumption once again. If completely necessary, more power may have to be added to the design.

When deciding upon a specific wireless communication device, there are a few requirements. The biggest problem that needs to be avoided is compatibility. There are a million choices for wireless communication devices; but, because this is such a specific application, the device needs to be chosen with that in mind.

This project requires a small wireless dongle with the ability to communicate under Ad Hoc Wireless standards, because this is the method that this project will be using to communicate since there will only be two devices communicating back and forward: the controller and the device. The dongle also needs to have connectivity to a single-board computer.

This leads this project in the direction of choosing a wireless dongle like (if not this precise dongle) the Adafruit Industries Long Range Wi-Fi USB with antenna. This device would be ideal, because the antenna is replaceable. If the range on the included antenna were not sufficient enough, it would be possible to purchase an aftermarket antenna with even more range.

4.7 Single-Board Computer Selection

4.7.1 BeagleBone Black rev. C

The BeagleBone Black rev. C allows us to use its powerful but compact design to process the LIDAR information, motor control and the ability to send the information to an external computer for display. With plenty of I/O and processing power for real-time analysis provided by the AM335x 1GHz ARM Cortex-A8 processor, the BeagleBone Black can be used with plug-in capes to expand functionality. With its low-powered design and PC based technology, the BeagleBone Black allows us to create a powerful and complex robotic system that is an alternative to microcontrollers.

A 5VDC supply is necessary to provide power to the board. The supply current is all determined by the amount of peripherals the board contains. For typical use, a 5VDC supply rated at a 1A should be adequate. But if heavy use of the USB host port and expansion headers, higher current is required.

With the board's capability of running UbuntuARM operating system, the Robot Operative System can be downloaded. This software framework would help in the design of passing information from the LIDAR to the main controller, processing the LIDAR data into a point cloud, processing GPS data and positioning.

The BeagleBone Black contains three I2C buses that are commonly used to connect relatively low-speed sensors and other peripherals. I2C are extremely popular due to its ease-of use and ability to control multiple peripherals while only utilizing two pins from the single board computer. Since bus 2 contains 0.1" spaced expansion headers, enabling I2C is easy on the board. However, the default bus is disabled since it lacks a pull-up resistor on the board, so external pull-ups of 1.8V must be added and recompiled to enable I2C for that bus.

Compared to the other single-board computer compared in this document, the BeagleBone Black contains the most UART connections. UART, or Universal Asynchronous Receiver /Transmitter, is a feature found in microcontrollers that allows the communication of serial data. UART is extremely useful in robotics since communication from the sensors is possible. In the BeagleBone Black with a 3.8 Linux Kernel or later, the Device Tree and Device Tree Overlay can be used. The Device Tree (DT) and the Device Tree Overlay are a way to describe hardware in system such as the UART interface. This gives full access of enabling and disabling the 5 UART ports on the board. The pintable for UART on the board is the following:

Table 18: UART Pintable for BeagleBone Black

UART	RX	TX	CTS	RTS	Device
UART1	P9_26	P9_24	P9_20	P9_19	/dev/ttyO1
UART2	P9_22	P9_21			/dev/ttyO2
UART3		P9_42	P8_36	P8_34	/dev/ttyO3
UART4	P9_11	P9_13	P8_35	P8_33	/dev/ttyO4
UART5	P8_38	P8_37	P8_31	P8_32	/dev/ttyO5

4.8 PCB Design Selection

4.8.1 Motor Control Design

The motor controller will be the foundation of our projects platform. We will be using two DC motors that will provide power to move the tracks on the vehicle. We need to have the capabilities of moving each motor independently, forward direction, reverse direction and the ability to stop. Since the platform will only need two DC motors the design of the motor controller can be optimized by using a dual port h-bridge that will power both motors

For our motor controller design, we will reference the Texas Instruments DRV8834EVM design. This design is chosen because it has the design components that we planned to use in our design. The MSP430F2617 will be used as the CPU because of its ultra-low power, and PWM controls. A USB interconnection will communicate to the interface program on the main control unit, which will have a GUI interface in which the PWM duty cycles are able to be controlled.

Another important aspect of the design is its ability to control and drive two motors through one h-bridge. This was difficult to find, given that the DC motors required an output current rating of 2 A and not many H-bridges provided that for two outputs. In terms of moving forward with this design we will begin to design the schematic and then only utilizing the parts of the PCB needed to carry out our functions.

4.8.2 PCB Design Software and Assembly Vendors

One of the main objectives of senior design is to design and build a circuit board to build our project. There are two methods of implementing and building circuit boards, punch boards (breadboards) and printed circuit boards (PCB's). Both serve the same function of creating connection using conductive pathways utilized to connect components and IC's. Below both options will be discussed and evaluated based on the needs and specifications required from our UGV IED and mine detector.

Although, a punch board may be utilized to build out circuit, it will become difficult when integrating IC's, small components, and it is limited to the layers that will be utilized when developing our design. Punch boards do have the advantage of being cheap and easy to prototype and make alterations. However, when using a punch board, the components mounted on the board must be regular components, which will limit efficiency when attempting to use IC's that require many pins. The applications associated with our project would prove punch boards to be inefficient and will also create problems with dimensions.

Printed circuit boards are the common method of design when building and creating circuits. These are designed using software programs that contain libraries of components, and schematic layers to design an organized, and professional circuit board. Some of the drawbacks associated with PCB's are costs can run high based off of the dimensions of the board (in square inches) and layers needed. Also, on would need to learn the software proficiently, because once the circuit board is designed and ordered there is no way to fix a line or solve a problem without changing it on the schematic and then ordering a new one.

4.8.2.1 Eagle CAD

One of the common PCB design software is offered for personal use is Eagle CAD. For sake of saving money on our financial budget and accessibility, Eagle CAD offers a free version (EAGLE Light Edition) that is limited to a specific dimension, which will luckily meet our requirements needed to complete the PCB. However, a member of our group has access to the full version, in case that any changes are made to our design that requires a dimension larger than 4" x 3.2" and two layers. Another convenience of using Eagle CAD is that their file format is accepted by many manufactures and assembly vendors. Below are images of a imported PCB design displayed on EagleCAD software. In Figure X1 is the schematic of the circuit board and in Figure X2 is the board itself displaying all of the top and bottom layer connections.

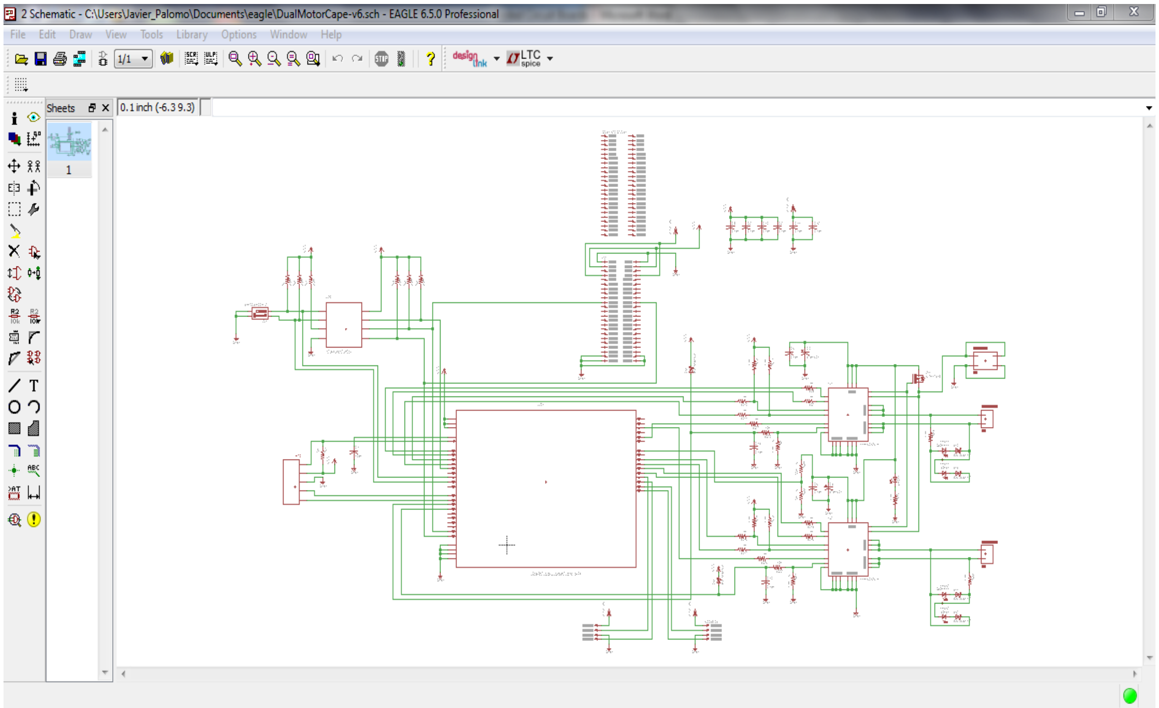


Figure 51

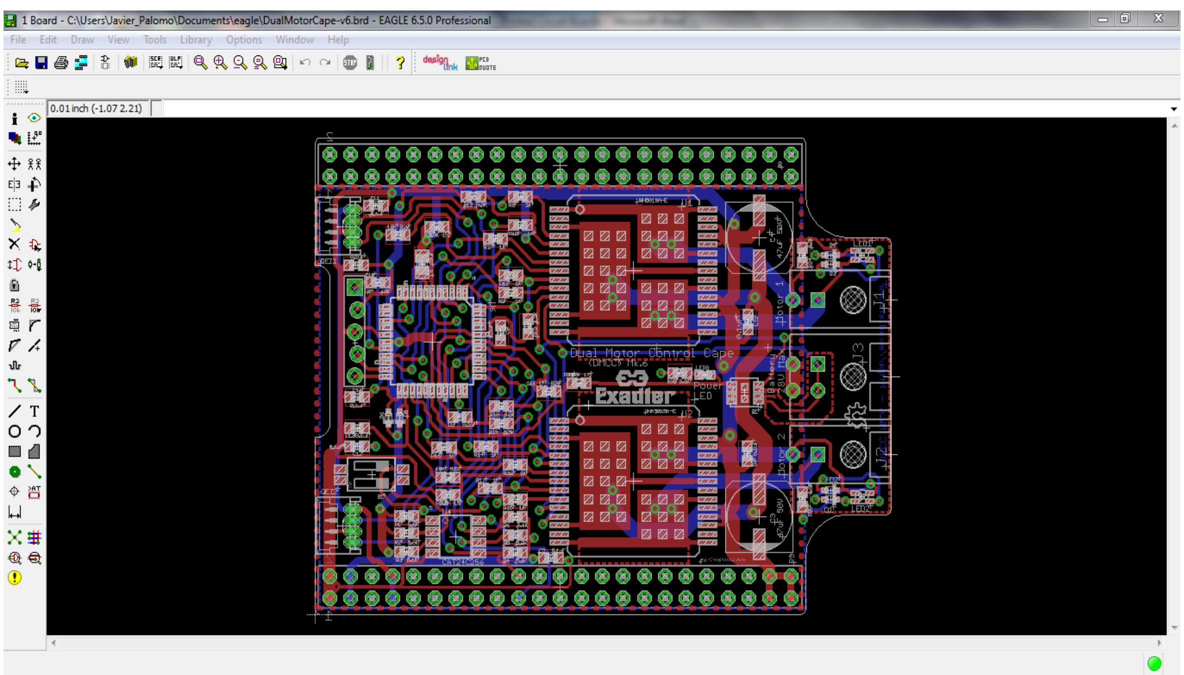


Figure 52

4.8.2.2ExpressPCB

There are other PCB design software programs that are offered, such as ExpressPCB. The benefits associated with using this software derive from the ability to go through the same company to actually build the circuit designed. However, the limitation associated with the ExpressPCB software is that one can only order through the same company, which limits outsourcing to other PCB assembly vendors. ExpressPCB offers $51.00 flat rate cost for producing three two-layer 2.5" x 3.8" *miniboard* PCB's. For a four-layer PCB the cost jumps to a $98 dollar flat rate for producing three four-layer 3.8" x 2.5" *miniboard* PCB's. Also, with a shipping rate of $10, ExpressPCB guarantees a two day delivery time during business days. This can be crucial if anything was to go wrong with the design.

4.8.2.3 OSH-Park

Osh-Park is another PCB manufacture that uses community PCB orders to reduce cost for the manufacture and the consumer. The prices for standard two-layer PCB's run $5 per square inch for three copies, and for a standard four-layer PCB the cost will be $10 per square inch for three copies. OSH-Park also provides free shipping to anywhere around the world, and has a shipping time of about 12 to 14 days depending on the complexity of the design. The only real drawback is the return time associated with shipping.

4.8.2.4 PCB123

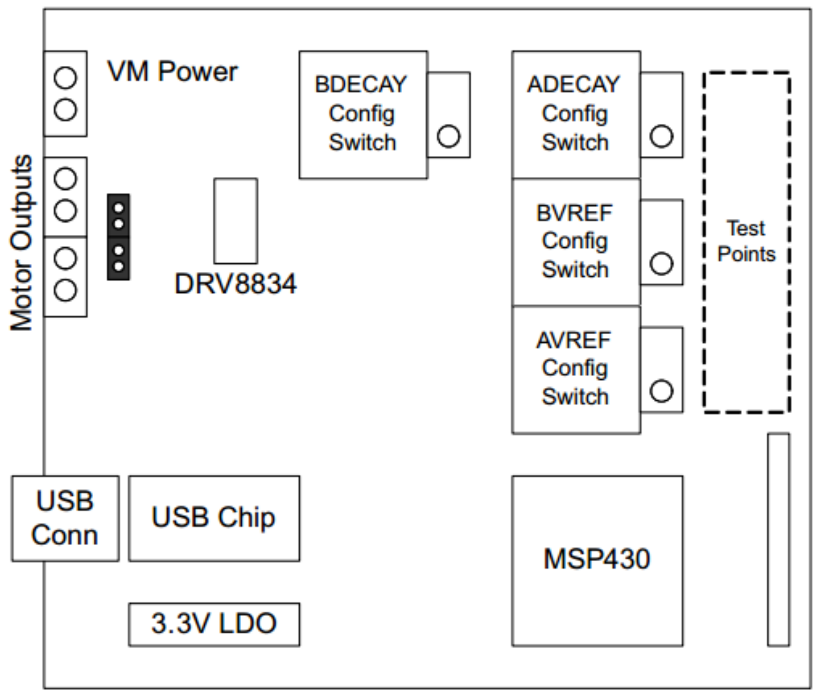
Sunshine circuits (PCB123) is another manufacture being considered for our PCB development. Offered on sunstones website PCB 123 V3 Design Suite is a reliable and trusted design software, recognized and utilized by companies such as: GE, Intel, MIT Artificial Intelligence Laboratory, Google, Cicso, HP, Honeywell, Motorola, US Naval Research, Texas Instruments and many others. With a library of over seven-hundred and fifty thousand parts PCB123 will allow us to utilize any part that is currently on the market; preventing us from any restrictions due to library restrictions. Another great resource that PCB123 provides is their free design for manufacturability review and design rule check, which ensures that the design provided is guaranteed to create a buildable working design. This is the ideal manufacture for the PCB design we would want to implement, however, there is a drawback. The unit price per circuit is very pricey (only for two-layer boards, and will increase even more for anything higher) and will only drop when purchased in large quantities. This is without a doubt the best manufacture, but the limiting factor of our budget constraints will be the determinant of whether or not we go through them.

4.8.2.5 4PCB

Lastly, 4PCB is another manufacture of PCB's from Advanced Circuits. As recommended by Dr. Richie, 4PCB offers great deals for students and even provides sponsorships. The base price for students for a two-layer PCB is $33 each, for a four-layer PCB is $66, and they provide free PCB software layout that is very notable. Another key feature is the PCB file check; this file check provides a free design file report that will notify the designer of any problems that may occur when manufacturing the design. This is a great resource just like PCB123 has; however, 4PCB provides its services at a lower price.

Summary

After evaluating the different manufactures of PCB's, they all have their values and disadvantages, but 4PCB has the ideal resources and a reasonable price that allows us to stay within our budget and also provides us the luxury of using Eagle CAD software that we already have obtained and familiarized ourselves with.



4.9 RS-232 Serial Connection

With the use of the SICK LMS-200 LIDAR sensor, communication between the BeagleBone Black and the LIDAR is necessary. Since the data interface for the SICK LIDAR is through serial RS-232 or RS-422 communication, we will need to add that capability to the BeagleBone. The simplest way in adding that feature is by connecting a RS-232 cape that enables communication from the LIDAR system to the BeagleBone.

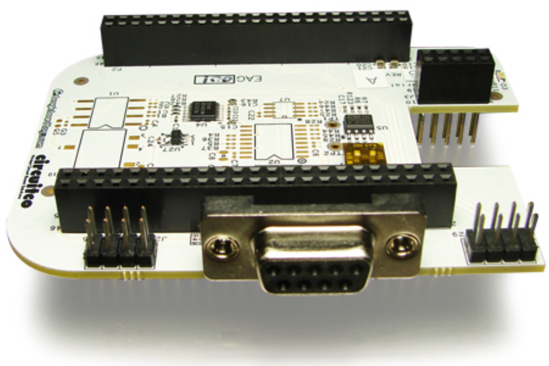


Figure 53: MCM Electronics RS-232 connection (permission pending)

For data exchange in measuring tasks, the LMS is equipped with a serial RS-232/ RS-422 interface. By setting a jumper cable, the RS-232 can be enabled. The default setting is RS-232. The figure below shows pin assignment from the LMS LIDAR system to the BeagleBone.

LMS			PC	
Signal designation	PIN No.		PIN No.	Signal designation
Not connected	1		1	NC
RxD	2		2	RxD
TXD	3		3	TXD
Not connected	4		4	Not connected
GND	5		5	GND
Not connected	6		6	Not connected
Not connected	7		7	Not connected
Not connected	8		8	Not connected
Not connected	9		9	Not connected

Figure 54: Pin Assignment from LMS to BeagleBone Black

4.10 Ultrasonic Sensor Selection

To ensure that the UGV will autonomously navigate its set path, we've decided to add in a HC-SR04 Ultrasonic sensor to the front of the vehicle. Extreme brightness in an outdoor environment may alter the accuracy of the laser range finder. Therefore, using the ultrasonic sensor and the LIDAR system it will help ensure that anything in its path will be noticed. Since the LMS-200 was built for indoor use (but can be used outside), we need to make sure that the obstacle avoidance system will work properly. Since the HC-SR04 uses low operating voltages we will directly connected the ultrasonic sensor to the BeagleBone. We will use the ultrasonic data to work harmoniously with the LIDAR information to maximize the performance of the obstacle avoidance system.

4.11 Database Selection

To first describe the database system, it must be known what the database will be communicating with. The database will be hosted locally on the single-board computer, and handled by the Linux operating system (OS) on that onboard computer. The database will be communicating with the OS, which will then be handled in one of two ways.

The first way that the database system will be used in the system is to track the location of mines when found. The metal detector will send off a flag when a mine is found. Once the onboard OS recognizes that flag the GPS location device will record the current position. This position will then determine a safe radius, which can be approximated using formulae. These formulae will be determined after testing.

The second way that the database system will be used in the system is to track the location of when the device turns. This will help in determining the clear path from start point to end point. Once the onboard OS recognizes a turning motion, a flag will be thrown. Once this flag is thrown, the GPS location device will record the current position. This position will be marked on the map, and later decided the clear path when the device reaches its end point.

These two pieces of data will be stored in separate tables as to maintain a schema that doesn't create problems. If there were one table, querying the database would become a nightmare. This would be especially bad since computational power onboard the device itself is extremely limited. This is also another reason that it is the smarter decision to send information that needs to be processed to the head node controller. Most of the information recorded into the database will be shipped to the head node, because the only use for the database on the device will be for obstacle avoidance.

The obstacle avoidance algorithm will highly depend on the GPS coordinates in the first table that was discussed, but not quite as much on the second table. This is another reason that two tables is a natural design choice, because the only information the obstacle avoidance algorithm needs in regards to the database system is the location of the mines. All other avoidance algorithm decision-making will be based on the LIDAR and sonar sensors.

The onboard OS will be supporting the current version of MySQL. MySQL is known to work well with Ubuntu 12.04, and this will be the operating system of choice for the single-board computer. It may not be the most minimal choice, but it is most definitely efficient. This is not due to the efficiency of the database management system itself, but due to our simple schema. So, it is sufficient to pick the database management that is easiest to implement within the current system. Since MySQL is one of the most well known database management systems for just about any system out there because of its compatibility with just about everything that can function as a computer.

This project will be implementing the Robot Operating System (ROS) as mentioned previously. The ROS also has compatibility with UTM coordinates in many of its API's and functionally this would make the most sense. With this in mind, it would make the most sense to store it as a UTM coordinate as this is what will be used most of the time.

On the rare occurrence that it needs to get converted to something other than a UTM coordinate, it would be converted one time, and then immediately stored in the appropriate row related to the original UTM coordinate. If it ever needed to be referred to as that data type again, it could just be referenced on the table to reduce computational complexity that much further.

In a large-scale application with a device that will be scouring a significant distance across the earth, it is not as simple to just simply calculate the distance as if the earth was flat. To account for this, there are formulas such as the haversine formula that takes into account the curvature of the earth in its calculation. Although probably not completely necessary for this project, it would be a design consideration even on the smaller scale for more accurate distance calculations. The haversine formula is as follows:

$$\text{haversine}\left(\frac{d}{r}\right) = \text{haversin}(\phi_2 - \phi_1) + \cos(\phi_1)\cos(\phi_2)\,\text{haversin}(\lambda_2 - \lambda_1)$$

Figure 55: Haversine Formula Between Two Coordinates

Where:

$$\text{haversin}(\theta) = \sin^2\left(\frac{\theta}{2}\right) = \frac{1-\cos(\theta)}{2}$$

And

$$\phi = latitude,$$
$$\theta = longitude,$$
$$d = distance\ between\ two\ points$$
$$r = radius\ of\ sphere$$

Because the simple database schema, we appear to not worry about latency of the database system. This is true to an extent. It is obviously not beneficial if the schema is relational at all. If there were any joins that were needed to learn something necessary for navigation, the latency of the database would be significantly more important. The computational complexity of the database schema starts to matter at that point. Since there will only exist the act of inserting and selecting, this is a non-issue for the application of this device

4.12 MCU Software Design

A fully autonomous unmanned ground vehicle is a challenge since it takes away the ability of the human operator planning and reasoning skills. Therefore, we are enabling the control of the UGV through a user in our main control unit. This will allow the operator to use reasoning, planning, and situational awareness when the UGV is in control. The main control unit will also provide a graphical user interface that receives a constant feed of the UGV hardware specifications, LIDAR point cloud, and localization of IEDs and mines discovered by the UGV.

4.12.1 MCU Software Requirements

The software requirements will be composed of processing the information from UGV and displaying live feedback to the human operator. The MCU will need to capture the data and display it through a graphical user interface. The graphical user interface will be written in C++ to utilize the QT framework, which is a cross-platform application and UI-framework.

Data from the sensors will be streamed through serial connection of the BeagleBone Black. Although, the LIDAR information will be parsed through the ROS interface, ultrasonic sensors, GPS data, and hardware data still needs to be processed in the main control unit. Therefore, it is necessary to implement a message protocol that will define the data structure. The message structure will consist of a header and footer. The header is the information that is placed before the actual data. The header will contain a small number of bytes about the information type and where the data came from. It will serve as the control link to differentiate the protocol elements on different devices. The actual data, which is also known as the payload will be attached to header. This will be the raw data from the sensors. The figure below shows how the information will be processed and sent from the main control unit and the unmanned ground vehicle.

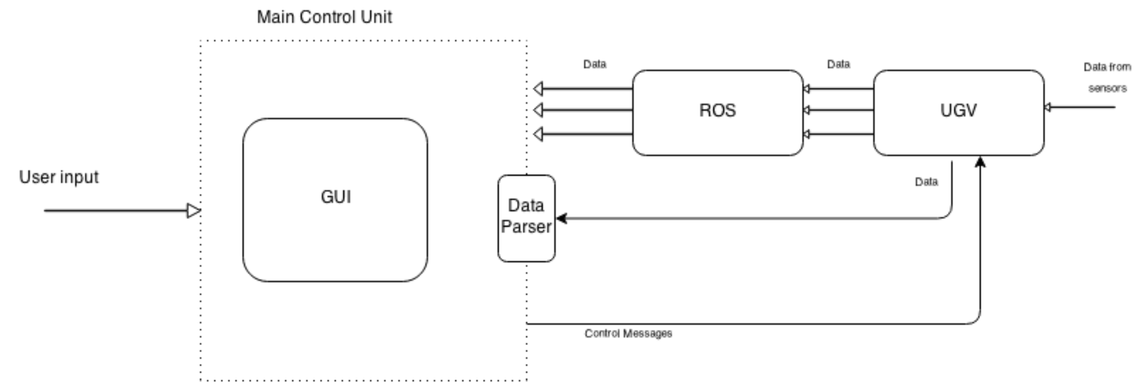


Figure 56: Software architecture paradigm

4.12.2 MCU GUI Interface

As described in the previous section, the main control unit GUI interface will be designed using the C++ Qt5 framework. Qt and the supporting tools are developed as an open source project governed by a meritocratic model. Qt can be used under open source or commercial terms. This section will give more detail on what are the necessary requirements for the MCU GUI interface.

Requirements:

- Receive and display live information of the UGV
- Display LIDAR point cloud
- Display located IEDs

Specifications:

- Will use Google Maps API to display the current location of the UGV and located IEDs and mines
- Librviz will be utilized to display ROS RVIZ in our custom GUI interface
- Allow user input waypoint capabilities by using ROS Navigation
- Display messages published to each topic using rostopic echo /topic_name

The Figure below shows what the GUI interface will look like.

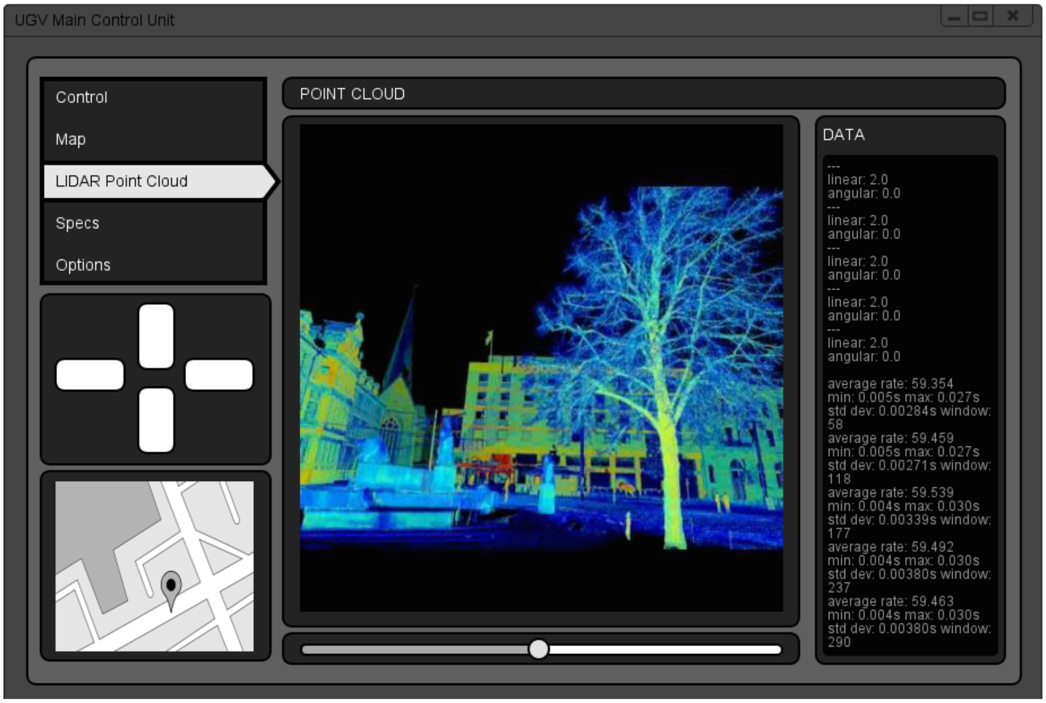


Figure 57: MCU GUI Interface (Point Cloud picture permission pending)

ROS RVIZ

In order to meet the requirements, the MCU will need to be considered the master node in the Robot Operating System. The ROS Master node provides naming and registration services to the rest of the nodes in the ROS system (see UGV node diagram in section 5.2.4 for a detailed visualization of the entire system). The ROS Master is able to track publishers and subscribers to topics and the services as well. The role of the Master node is to enable individual ROS nodes to locate one another. Once these nodes are enabled and located each other, they are able to communicate with one another using peer-to–peer communication.

An example of the peer-to-peer communication is illustrated in the figure below. The master node contains two nodes connected; a LIDAR node and an Image Viewer. A typical sequence of events would start similar to part a in the diagram below. The LIDAR node will notify the master node that it will publish the LIDAR information on the topic “images”. Next, the camera publishes the data into the “images” topic, but there is nothing subscribed to that topic yet so no data is actually sent. In order for the Image Viewer to receive the information from the LIDAR node the image viewer needs to subscribe to the topic “images” and check if there’s any images there. Part c shows that the topic “images” has both a publisher and a subscriber. The master node notifies the LIDAR node and the Image Viewer about each other’s existence so that they can start transferring data to one another.

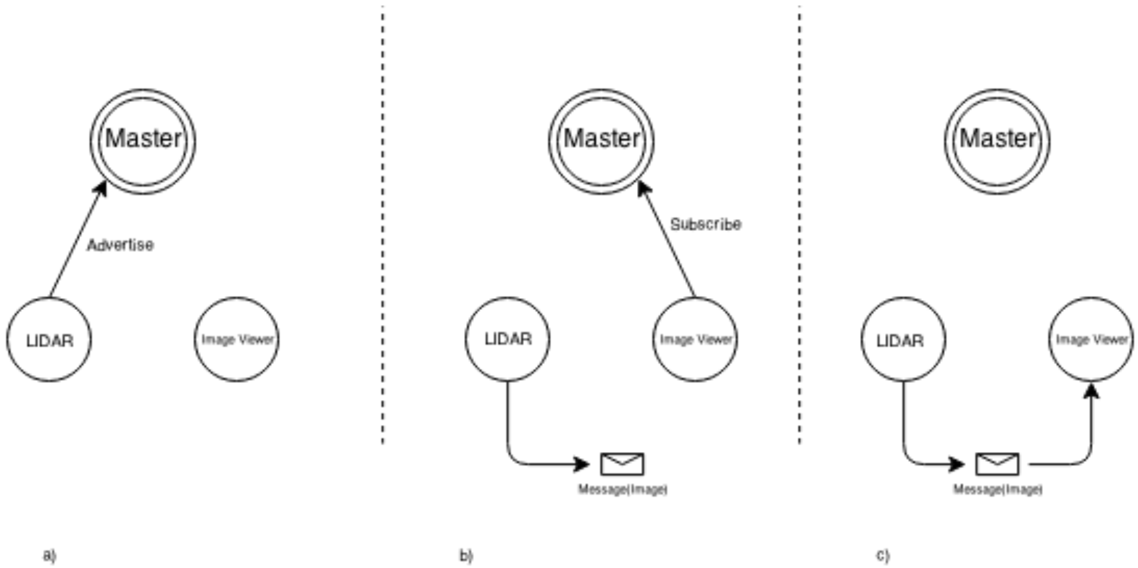


Figure 58: ROS Master Service Node example

This same concept will apply to the LIDAR data and the ROS visualization (RVIZ) tool. RVIZ will be incorporated into the MCU GUI system utilizing librviz library from the ROS API. RVIZ functionality can be accessed within an application by linking against librviz.so. Below is the header file that helps initialize RVIZ QApplication.

```
#ifndef MYVIZ_H
#define MYVIZ_H

#include <QWidget>

class MyViz: public QWidget
{
Q_OBJECT
public:
  MyViz( QWidget* parent = 0 );
  virtual ~MyViz();


private Q_SLOTS:
  void setThickness( int thickness_percent );
  void setCellSize( int cell_size_percent );


private:
  rviz::VisualizationManager* manager_;
  rviz::RenderPanel* render_panel_;
```

```
  rviz::Display* grid_;
};

#endif
```

Initializing the “MyViz” is simple. In order to display RVIZ application, ROS needs to be initialized, QApplication needs to be created, MyViz top-level widget needs to be created and shown, and Qt event loop needs to be run.

Google Maps and Latitude

To utilize Google Maps in QT, the Google API will be used. The Google Maps JavaScript v3 API allows for websites and programs to integrate with Google Latitude, enabling users to update and read their current location and their location history. The API feature includes: creating and tuning map, creating place marks (markers), getting current location, inserting current location, getting history of location, and going to a specific address.

In our application, we will be utilizing the Google Maps API to receive the current location of the UGV and place markers to all the located IEDs and mines in the area. This will give the human operator situational awareness of what’s going on the field.

Parsing Data

Although most of the data coming from the UGV will be receiving from the Robot Operative System, there is some information from several sensors that will be streamed into the main control unit through TCP/IP or UDP connection and will need to be parsed.

As the figure below shows, when new data is received through the stream the data is parsed to receive the header information. With several conditional statements the data can be placed into the right buffer. This is where the GUI interface program will have individual threads to receive the information in each buffer. The information in the buffer will be processed and used into the GUI interface.

Figure 59: Data Parsing

Some of the information received from the UGV will come from the ROS such as the LIDAR data. In order to receive the information, we will need to subscribe to the specific node needed. The subscribe method invokes a call to the ROS master node, which keeps a registry of who is publishing and subscribing the information (section 5.2 talks more about the ROS architecture). Now that the information is being received from the master node, we are able to pass any of the needed information into GUI software.

Navigation

For the navigation of the robot, we will use two different techniques. Using user input and waypoints. The ROS navigation stack provides a point-to-point navigation by default. In order to use the navigation stack we will need the point cloud from the LIDAR data and odometry information. The odometry information will be coming from the GPS module to estimate the change in position over time. With the use of the Simultaneous Localization and Mapping (SLAM) algorithm and the odometry data, we can combine the information to help set waypoints for the UGV.

In concept the navigation stack is fairly simple. It takes in the odometry and sensor streams and outputs the speed of the mobile robot. The system will need to be running ROS, have a “tf” package in use, and the ability to publish sensor data using the correct message type in order for the navigation stack to be in use. The “tf” package gives the robot the ability to publish information about the relationship between coordinate frames. It defines offsets in terms of both translation and rotation between coordinate frames.

With the use of the point cloud information, we can provide the navigation stack a map environment. With all the combined information, we are able to have the navigation stack configured. Using RVIZ we can use the navigation stack to send goals to the robot.

The second technique of controlling the UGV is by user input. We will add in the capabilities of having full control through Wi-Fi connection.

5 Design Summary of Hardware and Software

5.1 Hardware Architecture Summary

Since the Unmanned Ground Vehicle needs an operating system to run functionalities such as the Robot Operative System, the BeagleBone was incorporated into the design. Not only will ROS help in the display of LIDAR information, but also will help in passing messages throughout the system. As the figure below shows, the BeagleBone will be the main computer for the UGV. Using the sensors that are directly attached to it, the UGV will be able to decide in what is its best option to complete the given task.

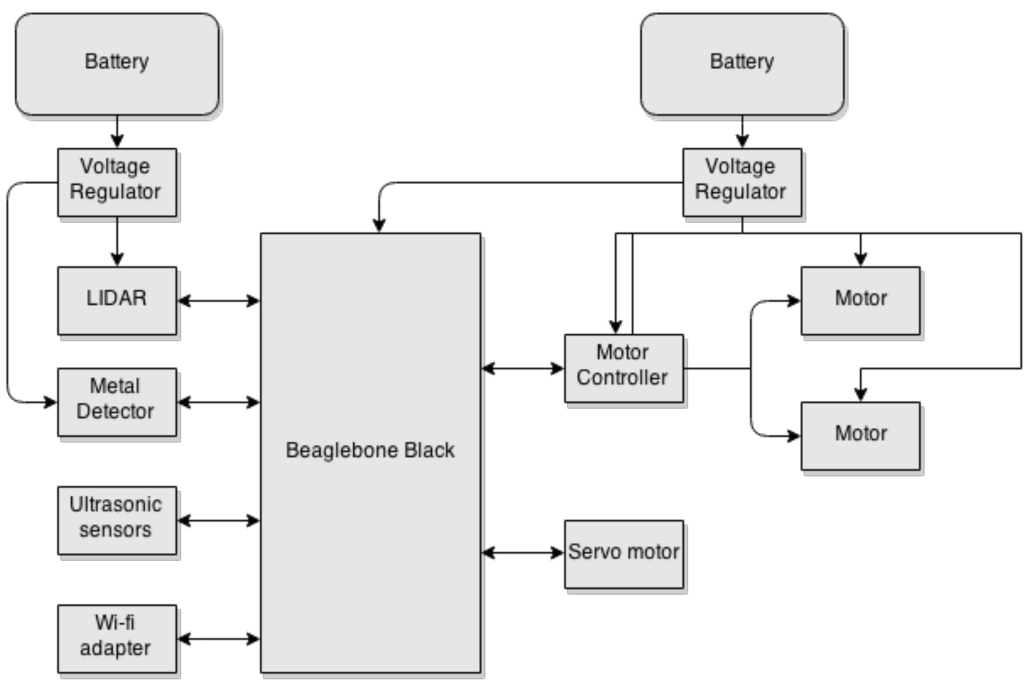


Figure 60: Hardware Architecture Flowchart

When designing the hardware architecture design, the Beagle Bone Black served as the brain of the architecture. Since the micro-computer has all the capabilities needed to run and operate the system, we designed each sub-system around the Beagle Bone Black. The LIDAR, metal detection, ultra-sonic sensors, and Wi-Fi adapter will all be directly controlled from the beagle bone. Then, we will have a separate motor controller PCB that will have the functions for the two DC motors, using an MSP430 CPU and an H-bridge IC.

The LIDAR system will communicate with the Beagle Bone Black with the help of the RS232 cape. This will provide the mapping and localization of the immediate setting, which will be displayed through the main control unit (computer). This will serve as our obstacle detection as well, through the SLAM and A* algorithm. The algorithms will allow the platform to redirect its pathway when an obstacle is detected.

The metal detection system is the lead detector for our project. The system will continuously run, by having a sweeping motion that will be located on the front of the platform. The pan and tilt system will have the metal detector placed 2.5 to 5 cm above the ground and will move in a sweeping motion that will clear the pathway for our vehicle. The metal detection will have a serial communication system that will relay signals to the Beagle Bone Black when any metal or IED's are detected, then the Beagle Bone will use its AI navigation to tell the motor to change its current path and find a clear path to its desired destination.

The Wi-Fi adapter will communicate the Beagle Bone Black with the main control unit (MCU) using AdHoc wireless network. This eliminates the need for a router and it will create a one-to-one communication network, which will allow us to receive and send information at prescribed intervals. This allows the LIDAR and other systems to have a direct communication to the Beagle Bone Black.

Also, as noticed there will be two power supplies integration systems that will power each side independently. This design selection was implemented due to the wide range of required supply voltage and for efficiency purposes. More information is described in section 4.

We have also included a PCB design for our motor controls using a MSP430 microcontroller; the flow chart of the motor controller is shown below in Figure 61. The MSP430 will contain the logic implemented to create a PWM to send control signals to the H-bridge circuit. The reason we included the MSP430 CPU is because the CPU had the capabilities of controlling the logic of the h-bridge and most importantly control the pulse width modulation sent to the DC motors. The serial communication from the motor controller to the Beagle Bone Black will be done by the UART. The beagle bone will essentially be the middle-man for the navigation of the platform. Furthermore, the Beagle Bone Black will contain the AI algorithm for the directional patterns (includes obstacle detection, and metal detection deterrence), and communicate the movements to the motor controller to move the given direction. The Beagle Bone is needed not only because of the communication of the obstacle deterrence, but most importantly because the artificial intelligence cannot be stored on the limited memory space located on the MSP430 CPU. So the UART connections will be essential to ensure that the system functions properly.

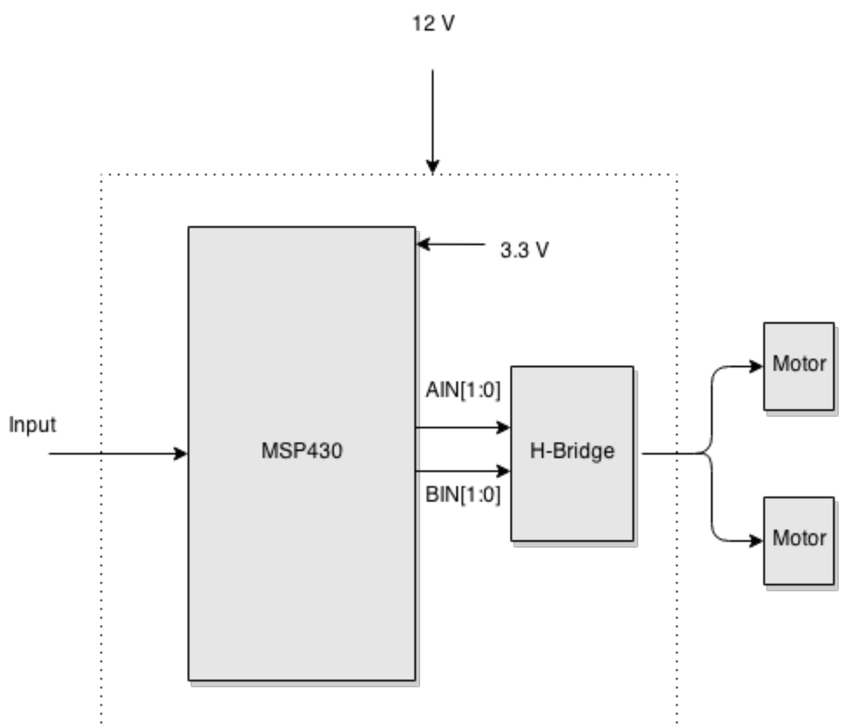


Figure 61: Motor Controller Flowchart

5.2 Software Architecture Summary

In ROS, many nodes spread between different tiers within the entire architecture handle computation that each has their own individual roles. The head node will be the controller, and where most of the computationally complex calculations will be handled. For example, the head node at runtime will handle LIDAR image processing and GPS path development. This head node will be a Linux based computer that will communicate directly with the next node, which would be the device itself.

From this point, the device itself handles all computation. There will need to be an obstacle avoidance algorithm programmed into the single-board computer which will then determine its course of action based on a searching algorithm that then makes decision based on its current location and the surrounding area if mines have been found or not.

On the next node are the different sensors and the motor controls. These sensors will provide accurate information based on the current location of the device from the GPS module, presence or lack of presence of a mine based on the metal detector, whether or not there is an obstacle in front of the device based on the LIDAR module, and this information would be used to tell each wheel motor to move.

From this node level, the device will then be communicating some of the information received from the sensors to the head node computer where more computationally complex issues can be handled as stated above.

5.2.2 Main Control Unit Software Architecture

The software architecture for the main control unit is simple. Since the MCU will be the master node for the ROS system, it will receive all the information from the UGV. The provided information from the ROS system will be used in the Main Control unit GUI system. The information that is streamed in from the TCP/IP connection will provide the necessary data for the user through the GUI interface.

The connection between the Main Control Unit and the UGV is essential. Without the data being streamed in, the user will not have any interactions with the mobile robot. Therefore, a lot of time will be spent during the integration and testing to make sure the MCU and UGV environment is communicating correctly.

The MCU will be housed within Linux's architecture to better pair with the single-board computer's Linux architecture. There will be communication between the MCU and the device itself, but the MCU can run independently of the device. The MCU will be doing its own computation based on information received from the device, however. So, even though it can run on its own, it depends on current information to compute the most accurate path and keep up to date with the current location of known mines.

5.2.3 Robot Operating System (ROS)

The Robot Operating System is a collection of frameworks for writing robot software. The framework is aimed to simplify the task of creating complex and robust robot behavior across a variety of platforms.

Creating a general-purpose robot software is extremely difficult. By implementing the Robot Operating System, the user is given services such as hardware abstraction, low-level device control, message-passing between processing, and package management. ROS package application includes perception, motion understanding, motion tracking, control, face recognition, planning, grasping, and much more.

ROS is also available on ARM processors. Although the use of ROS on the ARM processor is still in experimental mode, they currently show a stable support in the mobile robot community. Installing ROS on the UbuntuARM allows the necessary tools in developing a mobile robot. Some may think that the BeagleBone Black does not contain the necessary processing power to run a complex robot, but in reality this small single-board computer contains great potential. The board does contain an ARM processor so it is limited by its architecture and power capabilities in compared to PC. But ROS can use complex tools such as receiving and sending LIDAR information, perception with the use of cameras and lasers, and storing information into a point cloud.

ROS allows the ability of code reuse and hardware abstraction. All major functionalities are broken up into numerous nodes that allow communication with each other using messages. Each node typically runs as separate processes and sends the information into a “Master” node. The Master node takes the information and send the information accordingly to the location where it is needed.

Nodes are processes that perform different computation. Nodes are able to communicate with one another using the Parameter Server, RPC services, and streaming topics. ROS topics are the named bused over which nodes exchange messages. Usually messages are transported using TCP or UDP packets. Inside those messages is a simple data structure that comprises of the typed fields.

The UGVMD will heavily utilize the location and mapping tools found in the ROS. The 3D visualization tool that will be utilized is RVIZ. This tool lets user to subscribe to various topics such as odometry, map, laser sensors, etc., and visualize the data on the screen. Since we will be utilizing a LIDAR sensor, this will allow us to visualize the point cloud. The LIDAR data will be processes to create a spatial model of the environment surroundings. With the LIDAR data and the data from the GPS module we have substantial information for the localization and navigation.

Once the information from the mapping and localization is processed, the navigation can be easily achieved. ROS also includes packages that uses localization and provides move commands to the robot so it can safely navigate its environment without colliding with stationary or moving objects. The package utilizes the A* search algorithm for finding an efficient process of finding a path between points.

The figure below shows the ROS architecture for the UGVMD Robot. The single-board computer receives information from the different nodes and processes the information in order to complete its task. LIDAR information is sent from the BeagleBone Black to a remote computer. The LIDAR information is processed via on the remote computer and displayed. The user is able to see the LIDARs point cloud using the RVIZ, which is the 3D visualization tool found in ROS.

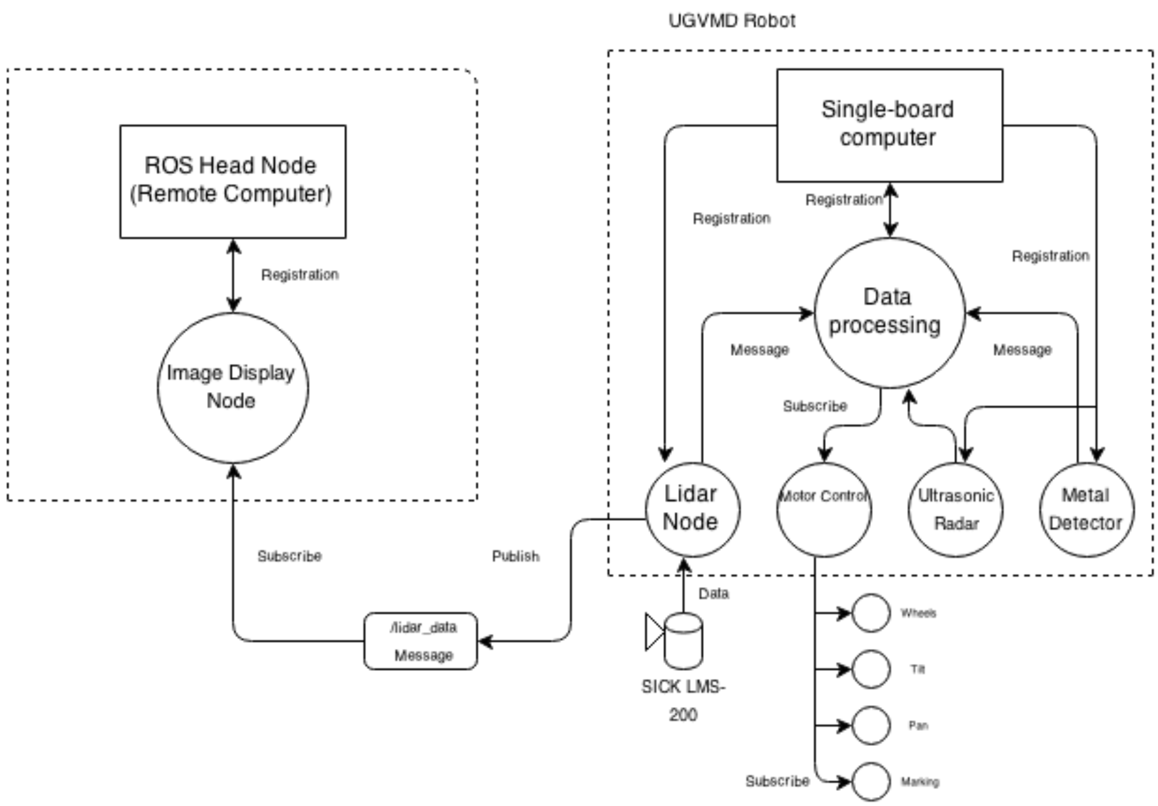


Figure 62: Robot Node Diagram

6 Project Prototype Testing

6.1 Hardware Specific Testing

6.1.1 Detection System

UUT (Unit under test): Detection System

Objective: To ensure that the detection system detects metal objects buried in the ground within a reasonable depth, to make sure that no false readings are obtained, to compare the effectiveness of the built detection system, and to ensure that the proper signal is being sent to the microcomputer.

Equipment:
- DD coil assembly
- Donated metal detector
- Two 3lbs metal weights
- Two Metal washers (0.75" diameter)
- Multi-meter

Test Procedure:

For testing purposes only, two 3lbs metal weights and 2 metal washers are to be buried in the ground, at different depths, in order to test the detection ability and to compare the effectiveness of the system. The donated metal detector will then be tested to make sure that the objects are detectable and to record the effectiveness of it, these measurements will be used to determine the effectiveness of the built detection system.

Initially, only the DD coil system will be tested, this will be done by removing the coil system from the donated detector, and replacing them with the DD coil system, before the test begins, measurements of the current through the coils will be measured to make sure the ideal current is flowing through the coils, then the detector will be used to locate the buried objects at the same distance and sweeping speed to make sure the least amount of variables are affecting the system. The data will be gathered and compared to the donated metal detector's results.

If the results are not within reasonable detection standards the coil assembly should be altered and re-tested until it becomes reasonably effective compared to the initial results of the donated metal detector, if the problem is the current flowing through the coils, the circuit will be modified until the right current is achieved and the system will be re-tested.

Once effective readings are acquired, the effectiveness of the differential reading will be tested, this is done by putting a metal object right in the middle of both coils, if the detector is not giving an alert, it is working properly.

The next thing to be tested, is the ability to filter false reading, this is done by testing the system in different types of soil, and finally, the circuit from the donated metal detector will be taken off the detector and carefully modified so that the signal from the alert can be sent to the microcomputer instead of a speaker, this test will be completed once the microcomputer is able to read and recognize the signal from the detection system.

Expected Results:

The DD coil assembly should be able to work with minor alterations, and work nearly as effective as the donated metal detector, even though the modification of the circuit, might not be easy, once achieved, a clear reading of the alert coming from the detection system should be able to be used by the microcomputer in order to make a decision on what is needed to be done.

6.1.2 Drive System

UUT (Unit under test): Drive System

Objective: To ensure that the motors are working properly, and are capable of driving the whole system smoothly and accurately through different types of terrain, also to ensure that the track system is sturdy enough and will not break in the middle of an operation.

Equipment:

- Platform with integrated drive system
- Weight scale
- Metal weights
- Donated metal detector
- Motor Controllers
- Multi-meter

Test Procedure:

Making sure that the chassis and drive system are properly put together, the motors will be connected to a set of motor controllers connected to a normal RC controller, this will be used to test the system in its simplest form, once all directional motions, different turning speeds, turning in place and sudden stops have been tested, and full mobility has been achieved, the vehicle will be weighted, and extra weight will be added until it reaches the previously estimated weight of the vehicle. This will be done to make sure that the motors will work once the vehicle is fully assembled, and also to test the current draw and make sure it is not going above desired amperage.

The vehicle will also be tested with the donated metal detector attached, to test the stability and sturdiness of it moving through different terrains with the detection system sticking out in front of it, the vehicle will also go through some strenuous maneuvers, to make sure that the tracks will not break under normal operational conditions.

NOTE: The donated metal detector will be used to prevent the built detection system from getting damaged.

Expected Results:

The vehicle should be able to drive the entire weight of the completely assembled vehicle plus more, and it should be able to do so accurately and sturdily, through any type of terrain.

6.1.3 Pan and Tilt System

UUT (Unit under test): Pan and Tilt

Objective: To ensure that the servo motor and the linear actuator are working properly, making sure that the servo motor and pan system are rotating the detection system at the required speed, and the linear actuator is capable of changing the height of the detection system in order to achieve optimal detection capabilities under different situations.

Equipment:
- Servo motor
- Pan system
- Linear actuator
- Donated metal detector
- Motor Controllers

Test Procedure:

Making sure that the detector, servo, pan system and linear actuator are properly put together, the servo motor and the linear actuator will be connected to a set of motor controllers connected to a normal RC controller, this will be used to test the system in its simplest form, slowly moving the servo and linear actuator to make sure the desired mobility is working.

The servo will then be programmed to sweep the detector at the desired speed for optimal detection, multiple readings of the time taken will be collected, to ensure that it is sweeping at the desired speed, and also to make sure that the sweeping speed is constant and not changing.

The linear actuator will also be tested to make sure that it can slowly and smoothly move the arm of the detector and keep it at the required height for optimal detection, once again, multiple readings will be take in order to make sure that it is working properly.

NOTE: The donated metal detector will be used to prevent the built detection system from getting damaged.

Expected Results:

The servo, pan system and linear actuator should be able to handle the weight and the speed and height specifications in order to keep the detection system at the optimal detection operation.

6.1.4 Obstacle Avoidance

UUT (Unit under test): SICK LMS-200 LIDAR for obstacle avoidance

Objective: To ensure that SICK LIDAR systems communication with the BeagleBone Black through serial connection is fully functional. Also, the information is being sent from the BeagleBone to the Main Control Unit.

Equipment:

- MCU (Computer)
- Single-board computer (Beagle Bone Black)
- RS-232 Cape
- SICK LMS-200 LIDAR System

Test Procedure:

During the testing of LIDAR system we will ensure that all connections necessary to the BeagleBone Black are placed correctly on the board. Once the power supply is connected and the BeagleBone is powered on we will setup the UART for the communication between the two devices.

When the UART connection is established we will interface with the device at 9600 Baud. A LMS status request will be sent from the BeagleBone to the LIDAR system by sending the following hexadecimal code:

02 00 01 00 31 15 12

If the connection is not establish follow the flowchart below:

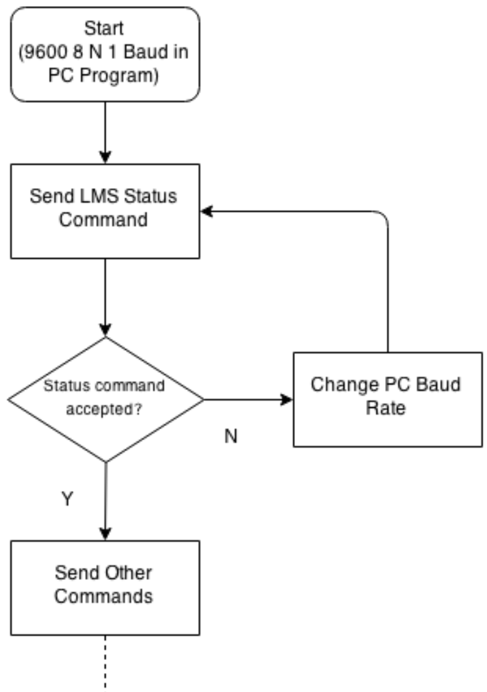


Figure 63: LMS Test Flowchart

Expected Results:

When the LMS is powered on, the yellow and red indicators are active until the start-up procedure has been completed. When only either the green or the red indicator is active, the unit is ready for communications. When the Baud rate is establish with the BeagleBone, a LMS start-up message is provided. We should see something similar to the following:

02 80 17 00 90 4C 4D 53 32 30 30 3B 33 30 31 30 36 33 3B 56 30 32 2E 31 30 20 10 72 D0

6.1.7 Power Supply

UUT (Unit under test): Power Supply PCB's

Objective: To ensure that the power supply PCB's supply the correct power to its individual sub-systems.

Equipment:

- Integrated Power Supply PCB
- Battery Charger
- Batteries
    - 11.1 V 3300 mah LiPo (x2)
    - 14.8 V 5200 mah LiPo (x2)
- Parallel T-Plug Battery Harness
- Series T-Plug Battery Harness
- Multi-meter

Test Procedure:

Preliminary Checks:
Before conducting any tests to the circuit, make sure that all 4 battery packs are fully charged. Also, in accordance with their datasheets, make sure that the test is being conducted in nominal operating conditions. Lastly, before moving forward with the testing procedure, check to see that the battery pack and leads are not corroded or worn down in any form. If any of these issues are presented, please resolve the issues before proceeding to the following steps.

Battery Preparations:
For the two 11.1 V 3300 mah LiPo batteries, use the parallel T-plug to connect both batteries in parallel. Then, for the two 14.8 V 5200 mah LiPo batteries, use the series T-plug to connect them in series.

Testing:
Begin by placing the battery source in their labeled terminals, making sure the polarity is correctly placed in the screw in terminals. For the first sub-system you will connect the parallel 11.1 V batteries to the SYS1 terminals. Once the leads are connected to the terminal, use the multimeter to read the voltage across the terminal, you should have an output of 11.1 V and current reading of 6.6 A.

Repeat the same procedure done for the 11.1 V batteries, but this time use the 14.8 V batteries connected in series. Also, be sure to connect the leads to the labeled screw terminal called SYS2. Once connected measure the voltage and current across the terminal, and you should obtain a reading of 29.6 V and 5.2 A.

Now that the input voltage and current values are correct, it is time to test the voltage regulator outputs to ensure that, if and when the components are connected, the correct output is obtained.

We will first begin with sub-system 1, once the 11.1 V battery is connected, using the multimeter test the output voltage of the 5 V regulator by placing the positive terminal on pin 1 of the voltage regulator (reference lm2678 for data sheet), and the negative to ground. You should obtain a reading of 5 V and 5 A.

Next, we will conduct the same tests for sub-system 2. We will start by analyzing the 24 V regulators, using the same method as before. Place the positive lead of the multimeter on the positive pin and the negative to ground. (reference datasheet 3012fd) The output voltage should measure 24 V and current 250 mA. If the output voltage gives an incorrect reading measure R1 and R2 resistor values and make sure the ratio from R2:R1 is 18.35. If this is not correct reference the data sheet to determine accepted R values.

Expected Results:

Voltage Regulator Outputs

Sub-System	**Max Voltage Required**	**Total Current Needed**
SYS1 (Beagle Bone Black, and Motor Control)	5 V for BBB and Motor Controller	5000 mA
SYS2 (LIDAR, and two DC motors)	24 V for LIDAR and 12 V for DCM	4250 mA

Our expected result should match the design specifications shown in the table above.

6.1.8 Motor Controller Testing

UUT (Unit under test): PCB: Motor Controller for DC Motors

Objective:

To ensure that all motor functions and communication from the Beagle Bone Black to the PCB are fully functional. Also, to properly get the desired speed and output from the motors that will move the platform.

Equipment:

- MCU (Computer)
- Single-board computer (Beagle Bone Black)
- Motor Controller (PCB)
    - Contains: H-Bridge, msp430_2553
- Multi-meter

Test Procedure:

During the testing of PCB1 we will ensure that all connections to supply the PCB are placed correctly on the breadboard. Once powered on the user will check the each connection to the motor to ensure that it is receiving the correct supply voltage using a multi-meter.

Then run the software on the motor controller and verify the correct outputs for all range of motions: forward, reverse, and stall (stop). This will be done by applying the digital signals to the xin1 and xin2 pins of the h-bridge in the correct form as described in the research portion of this report. Once the motors are functioning correctly, vary the duty cycle of the pulse width module on the h-bridge to ensure that the motor runs accordingly. For example, at 100% duty cycle the motor should be receiving the max current and be running at full speed and max torque.

Expected Results:

The input voltage entering the motors is within the 2 amp limit when initially turned on. After varying the duty cycle the dc motor reaches its max current capacity and is running at max speed/torque.

6.2 Software Specific Testing

6.2.1 Detection Interface

UUT (Unit under test): SICK LMS-200 Connection with Robot Operative System RVIZ

Objective:

To ensure that SICK LIDAR systems communication with the Main Control Unit is fully functional. Data will be sent through TCP/IP connection and will viewed using ROS RVIZ, therefore connection needs to be establish for a proper vehicle.

Equipment:

- MCU (Computer)
- Single-board computer (Beagle Bone Black)
- RS-232 Cape
- SICK LMS-200 LIDAR System
- Cross-over cable or null modem cable

Test Procedure:

Start the procedure by getting the dependencies and compiling the driver and rviz.

```
rosdep install sicktoolbox_wrapper rviz
rosmake sicktoolbox_wrapper rviz
```

When that is established, we make sure that the SICK Laser Scanner is plugged in via serial port. Keep in mind that the RS232 TX and RX lines on the SICK LMS200 are reversed. A cross-over cable is needed for the data connection to work properly. Next, make sure that the sicklms node will be able to access the SICK laser scanner. Start by listing the permissions of the SICK connection.

```
ls –l /dev/ttyO1
```

If the file permission does not show "rw", the file needs to be configured properly using the following command.

```
sudo chmod a+rw /dev/ttyO1
```

In a new terminal run "roscore". Set the ROS parameters for the SICK LIDAR. Run "rosrun sicktoolbox_wrapper sick lms" in a another terminal. Set the parameters using the following parameters.

```
rosrun sicktoolbox_wrapper sicklms _port:=/dev/XXX _baud:=9600
```

To see if all the data is being processed, run "rosrun rviz rviz" in a new terminal.

Expected Results:

When the LMS is powered on, the yellow and red indicators are active until the start-up procedure has been completed. When running the sicklms node, we should see the following text in the terminal *"*** Attempting to initialize the Sick LMS...*" Connection is being established with the SICK rangefinder. When RVIZ is run, we should se the laser scan of the vicinity. If no information is being displayed check to see there is connection with the laser rangefinder.

6.2.2 GPS Interface

UUT (Unit under test): GPS Functionality

Objective:

The objective in the application of GPS is to ensure that the device is regularly recording GPS location at prescribed intervals, and storing the received information properly to the database.

Equipment:
- MCU (Computer)
- Single-board computer (Beagle Bone Black)
- GPS Unit
- Simulation Software

Test Procedure:

To specifically test the GPS, and ensure that it is working, the device will have to be walked around and ensure that the device is detecting movement. This test will have to be done physically, as there is not any practical way to test the GPS device programmatically. It must also be made sure that the device is logging the correct GPS data into the database. Otherwise, no decisions can be made off of the GPS coordinates.

Expected Results:

It is expected that the device will accurate pull data from satellites and correctly store this information to the database without false data. This will allow the path generation to be accurate and usable.

6.2.3 Database Interface

UUT (Unit under test): Database Functionality

Objective:

The objective in the application of database functionality is to make sure that the database is storing correct data, and is able to be queried without much processing time.

Equipment:
- MCU (Computer)
- Single-board computer (Beagle Bone Black)
- MySQL Database
- Simulation Software

Test Procedure:

When testing the database, it is important to know whether or not the database is affecting the ability to path find. Luckily, this can be simulated before the device is completely built. Using a simulated map and clever programming, a simulation could be run that shows whether or not the GPS coordinates are being logged into the database at appropriate times. This would be the best way to test the device before it gets assembled.

Once built, the same checks will need to be made, but will be handled in the physical realm instead of in a simulated one. Ideally, the tests have the same results that they do in the simulation. This may not happen, and slight adjustments may need to be made from that point.

Expected Results:

The database should store this information in a form that will be able to be queried in such a way that will allow the Obstacle Avoidance algorithm to properly function.

6.2.4 Obstacle Avoidance Interface

UUT (Unit under test): Obstacle Avoidance Algorithm

Objective:

The device will avoid predetermined points that are known in software development and testing, but will be found in real time when not in a simulation.

Equipment:

- MCU (Computer)
- Single-board computer (Beagle Bone Black)
- Simulation Software

Test Procedure:

Going along the lines of the simulation similar to the database simulation, pre programmed obstacles can be put on the simulated map. The actual device would require finding these obstacles at run time, but the idea behind it is the same. From there, the simulation would show whether or not the algorithm behind the obstacle avoidance is working correctly or not. Should it work properly in the simulation, it would only be assumed that it would work properly in the physical realm. However, in the physical realm, it will have to detect obstacles with LIDAR. The only thing that changes between the simulation and the real world application is the type of input that is being received.

Expected Results:

The simulated robot will properly avoid the locations of obstacles without running into the obstacles.

6.2.5 Ultrasonic Interface

UUT (Unit under test): Ultrasonic sensors connection with the BeagleBone Black.

Objective: To ensure that the ultrasonic sensors are sending valid information through serial communication of the BeagleBone Black. Data will be streaming through the UART interface.

Equipment:

- MCU (Computer)
- Single-board computer (Beagle Bone Black)
- Ultrasonic sensor

Test Procedure: During the testing of Ultrasonic sensor system we will ensure that all connections necessary to the BeagleBone Black are placed correctly on the board. Through the UART interface verify that there is data being sent from the UART0. Run:

```
cat /dev/ttyO1
```

Using some sort of flat surface (paper, cardboard, book) stand 5 feet away from the sensor. Measure the results from the UART interface. Now test the sensor with out being in front of the sensor. Measure the results from the UART interface.

Expected Results: When the connection is established with the ultrasonic sensor, we should see random streams of information. Make sure the information is valid by viewing the distance between close objects and objects that are far.

6.2.6 GUI Display Testing

UUT (Unit under test): Valid information is being received and displayed by the MCU GUI system

Objective: To ensure that valid information in being received by the MCU GUI software and valid information is being displayed to the operator.

Equipment:

- MCU (Computer)
- Single-board computer (Beagle Bone Black)
- Ultrasonic sensor
- RS-232 Cape
- SICK LMS-200 LIDAR System
- GPS Module

Test Procedure:

During the GUI System testing we will ensure that all connections for the necessary peripherals are correct. Power on the BeagleBone and start all the peripherals. Start the MCU application and establish a connection with the unmanned ground vehicle. Navigate each section of the GUI system (Map, LIDAR Point Cloud, etc).

Expected Results:

When the connection is established with the BeagleBone, we should see random streams of information on the right side of the MCU GUI System. In the map section, a correct location should be displayed on the screen. In the LIDAR Point Cloud, RVIZ should display the point cloud coming from the SICK LMS-200 Laser Range Finder.

6.2.7 Path Finding Interface

UUT (Unit under test): Path Finding Algorithm

Objective:

The objective of the path finding algorithm is to determine a path based on information found in real time.

Equipment:

- MCU (Computer)
- Single-board computer (Beagle Bone Black)

Test Procedure:

Path finding will work similarly to the obstacle avoidance simulation except will be checking to make sure that a clear path can be found with known locations of mines. The only difference between the simulation and the real world application is that the location of mines will not be known at run time. Which, consequently, shows why an algorithm like Dijkstra's or Prim's wouldn't be ideal, and an algorithm like A* would be more ideal for a situation like this one.

Expected Results:

The algorithm will develop a safe path by traversing the map with known mine locations, and then relay that information back to the MCU.

6.2.8 Integration Testing

UUT (Unit under test): Obstacle Avoidance Integration Testing

Objective: To ensure that the obstacle avoidance system is behaving correctly when there is an obstruction in its path.

Equipment:
- MCU (Computer)
- Single-board computer (Beagle Bone Black)
- Ultrasonic sensor
- RS-232 Cape
- SICK LMS-200 LIDAR System
- GPS Module
- Platform

Test Procedure:

During the obstacle avoidance integration testing we will ensure that all connections for the necessary peripheral sensors are correct. Power on the UGV and start and the Main Control Unit. Establish a connection with the UGV through the MCU. When the connection is established, set a path for the UGV that contains an obstruction through the main control unit. Measure the results from the experiment.

Expected Results:
The user should tell when the connection is established with the UGV through the GUI interface. When the set path is established, a route should be displayed through RVIZ. The UGV should start moving towards the direction of the

waypoints. When the UGV is confronted with the obstruction it should find the best path to the ending point.

UUT (Unit under test): Software Integration Testing

Objective: To ensure that the Main Control Unit, ROS and UGV is sending and receiving the right information.

Equipment:

- MCU (Computer)
- Single-board computer (Beagle Bone Black)
- Ultrasonic sensor
- RS-232 Cape
- SICK LMS-200 LIDAR System
- GPS Module
- Platform
- Wireshark packet analyzer program

Test Procedure:

During the obstacle avoidance integration testing we will ensure that all connections for the necessary peripheral sensors are correct. Power on the UGV and start and the Main Control Unit. Establish a connection with the UGV through the MCU. Open Wireshark in the main control unit. Start SICK LMS LIDAR system through the main control unit. Since the UGV is active, GPS data should be coming into the MCU. Give the UGV a waypoint.

Expected Results:

The user should tell when the connection is established with the UGV through the GUI interface. When the LIDAR connection is established, TCP/IP data should appear in the Wireshark program. If no information is being processed, make sure there is connection from the Main Control Unit and the UGV through the ROS interface. On the Wireshark program, record any data from the TCP Protocol. Information should be from the communication of the MCU and the UGV.

Simulators

In an ideal situation, a custom application would be developed to do software testing of the device itself. Since this could potentially take more development time than necessary in and of itself, it would be beneficial to find a program that already does this and either modify its capabilities if it is open sourced or find a well suited program that would suit the needs of this project. There are a million robot simulators out there, but a few examples would be *MOBS – Mobile Robot Simulator* from the University of Western Australia, *Gazebo* from gazeboism.org, and *Simbad 3d Robot Simulator* are all perfect examples of potential simulators.

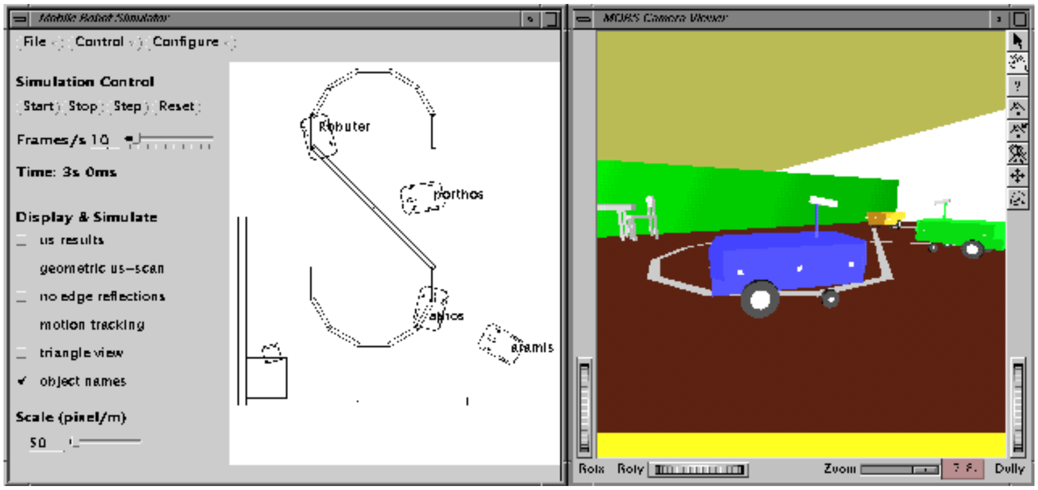


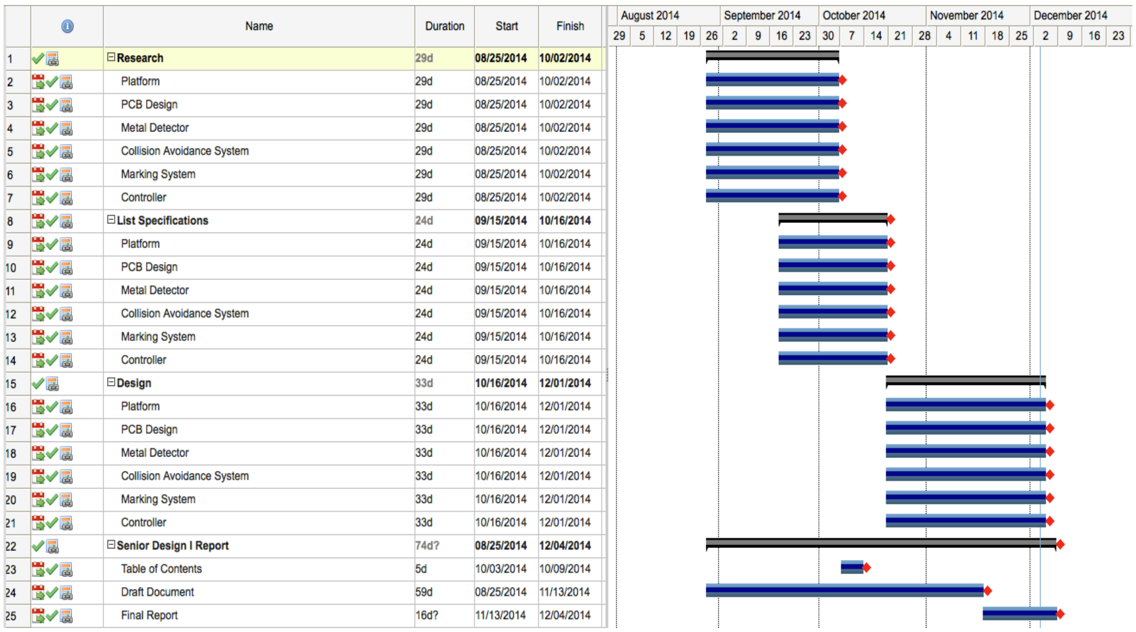
Figure 64: Potential Robot Simulation Program (Permission Pending)

7 Financial Agenda

7.1 Project Milestones

To ensure that the projective objectives are being met, a project milestone was designed using Gantter. Project scheduling is essential to maximize performance in the team, therefore a project timeline was designed for Senior Design I and II. The overall schedule for both the semesters are shown in the tables below. Senior Design I was mostly focused on researching, designing and documentation of the overall project. Senior Design II will be devoted to the construction of the unmanned ground vehicle, integration and testing of the entire system.

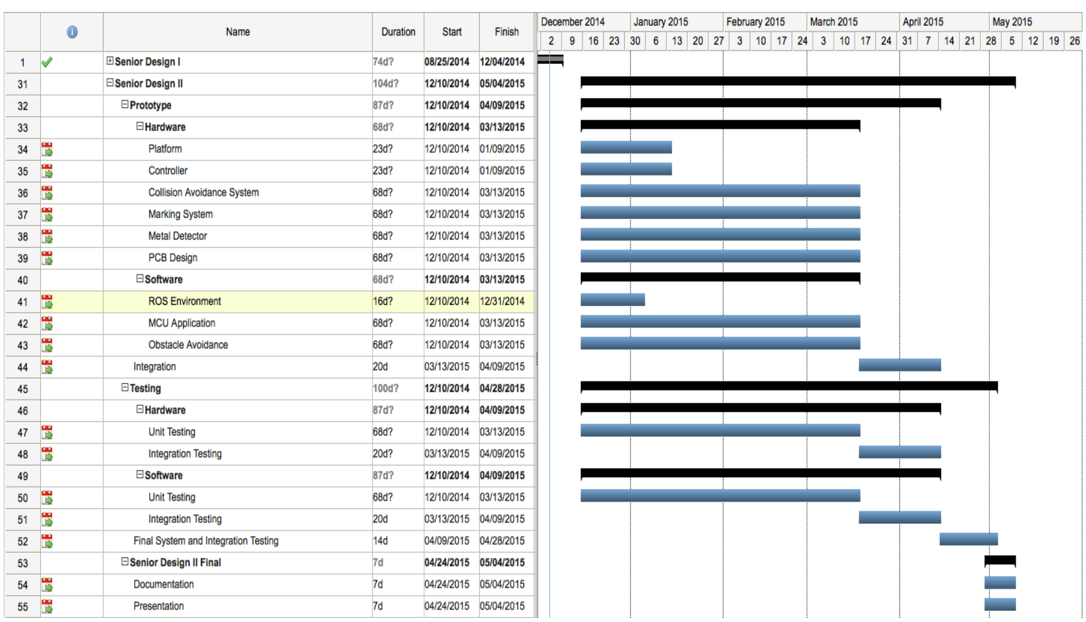
7.1.1 Senior Design I Milestones



	Name	Duration	Start	Finish
1	**Research**	29d	**08/25/2014**	**10/02/2014**
2	Platform	29d	08/25/2014	10/02/2014
3	PCB Design	29d	08/25/2014	10/02/2014
4	Metal Detector	29d	08/25/2014	10/02/2014
5	Collision Avoidance System	29d	08/25/2014	10/02/2014
6	Marking System	29d	08/25/2014	10/02/2014
7	Controller	29d	08/25/2014	10/02/2014
8	**List Specifications**	24d	**09/15/2014**	**10/16/2014**
9	Platform	24d	09/15/2014	10/16/2014
10	PCB Design	24d	09/15/2014	10/16/2014
11	Metal Detector	24d	09/15/2014	10/16/2014
12	Collision Avoidance System	24d	09/15/2014	10/16/2014
13	Marking System	24d	09/15/2014	10/16/2014
14	Controller	24d	09/15/2014	10/16/2014
15	**Design**	33d	**10/16/2014**	**12/01/2014**
16	Platform	33d	10/16/2014	12/01/2014
17	PCB Design	33d	10/16/2014	12/01/2014
18	Metal Detector	33d	10/16/2014	12/01/2014
19	Collision Avoidance System	33d	10/16/2014	12/01/2014
20	Marking System	33d	10/16/2014	12/01/2014
21	Controller	33d	10/16/2014	12/01/2014
22	**Senior Design I Report**	74d?	**08/25/2014**	**12/04/2014**
23	Table of Contents	5d	10/03/2014	10/09/2014
24	Draft Document	59d	08/25/2014	11/13/2014
25	Final Report	16d?	11/13/2014	12/04/2014

Figure 65: Senior Design I Milestones

7.1.2 Senior Design II Milestones



	Name	Duration	Start	Finish
1	**Senior Design I**	74d?	**08/25/2014**	**12/04/2014**
31	**Senior Design II**	104d?	**12/10/2014**	**05/04/2015**
32	**Prototype**	87d?	**12/10/2014**	**04/09/2015**
33	**Hardware**	68d?	**12/10/2014**	**03/13/2015**
34	Platform	23d?	12/10/2014	01/09/2015
35	Controller	23d?	12/10/2014	01/09/2015
36	Collision Avoidance System	68d?	12/10/2014	03/13/2015
37	Marking System	68d?	12/10/2014	03/13/2015
38	Metal Detector	68d?	12/10/2014	03/13/2015
39	PCB Design	68d?	12/10/2014	03/13/2015
40	**Software**	68d?	**12/10/2014**	**03/13/2015**
41	ROS Environment	16d?	12/10/2014	12/31/2014
42	MCU Application	68d?	12/10/2014	03/13/2015
43	Obstacle Avoidance	68d?	12/10/2014	03/13/2015
44	Integration	20d	03/13/2015	04/09/2015
45	**Testing**	100d?	**12/10/2014**	**04/28/2015**
46	**Hardware**	87d?	**12/10/2014**	**04/09/2015**
47	Unit Testing	68d?	12/10/2014	03/13/2015
48	Integration Testing	20d?	03/13/2015	04/09/2015
49	**Software**	87d?	**12/10/2014**	**04/09/2015**
50	Unit Testing	68d?	12/10/2014	03/13/2015
51	Integration Testing	20d	03/13/2015	04/09/2015
52	Final System and Integration Testing	14d	04/09/2015	04/28/2015
53	**Senior Design II Final**	7d	**04/24/2015**	**05/04/2015**
54	Documentation	7d	04/24/2015	05/04/2015
55	Presentation	7d	04/24/2015	05/04/2015

Figure 66: Senior Design II Milestones

7.2 Bill of Materials

Project Section	Cost Per Unit	Amount	Total Cost
Platform			
Acrylic sheet (48" x 24" x 0.25")	50.80	2.00	101.60
Acrylic Rod	3.68	7.00	25.76
Conveyor Belt for tracks	11.40	2.00	22.80
12T Drive Sprocket	15.25	4.00	61.00
Center Wheels (4PKG)	2.95	2.00	5.90
Idler Wheels (2PKG)	3.95	2.00	7.90
DC motor & Gear Assembly	59.99	2.00	119.98
Servo (S3515)	29.99	1.00	29.99
Pan System (DDP 115)	39.99	1.00	39.99
Servo Connector Wires	1.42	4.00	5.68
Acrylic cement (Weld-On #3)	12.00	1.00	12.00
Linear Actuator for tilt	41.35	1.00	41.35
Platform Total			473.95
Detection System			
Copper wire for coils	9.95	1.00	9.95
Acrylic Rod (Detector arm)	3.68	1.00	3.68
Acrylic sheet (48" x 24" x 0.1")	23.60	1.00	23.60
Mounts for Dtetion system	7.65	2.00	15.30
Detector Circuit	20.00	1.00	20.00
Detection System Total			72.53
Obstacle Avoidance			
Adafruit Ultimate GPS Breakout	$39.99	1	$39.99
USB WiFi Module w/ Antenna	$19.95	1	$19.95
BeagleBone Black v3	$55.00	1	$55.00
SICK LMS-200	$379.99	1	$379.99
HC-SR04	$4.39	1	$4.39
Bus Pirate v4	$37.15	1	$37.15
Bus Pirate v4 Probe Kit	$4.99	1	$4.99
Serial RS-232 BeagleBone Cape	$29.99	1	$29.99
11.1 V 3300mah LiPo	$36.95	2	$73.90
14.8V 5200 mah LiPo	$69.95	2	$139.90
Parallel T-Plug Battery Harness	$3.95	1	$3.95
Series T-Plug Battery Harness	$3.95	1	$3.95
Tenergy 1-4 Cells Li-PO	$19.99	1	$19.99
24 V Regulator	$2.93	1	$2.93
12 V Regulator	$0.82	1	$0.82
5 V Regulator	$5.70	1	$5.70
DRV8834	$2.89	1	$2.89

Express PCB	$51.00	1	$51.00
Obstacle Avoidance Total			$876.48
Overall Total			$1,422.96

8 Conclusion

In conclusion to our senior design 1 report, we as a group learned how implement and design a project. Between working with the Beagle Bone Black and learning how to communicate with the peripheral sensors, we developed an extensive understanding on how our system will be built and tested.

In regards to next semester we will ensure that we continue to meet our milestones and ensure we take advantage of our prolonged winter break. We feel confident that with the research and design conducted throughout the semester we will be on track to complete the project on its expected date.

9 Appendices

9.1 Bibliography

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- Rohitbd

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from the english wikipedia: A simple zener voltage regulator. Image created by Rohitbd.

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Description	Principle of the intersective pulse width modulation (PWM). Created with maxima.
Date	29 May 2011, 00:42 (UTC)
Source	• Pwm.png
Author	• Pwm.png: CyrilB • derivative work: Krishnavedala (talk)

This image was created with gnuplot.

Source Code

This is a *retouched picture*, which means that it has been digitally altered from its original version. Modifications: *vector image*. The original can be viewed here: **Pwm.png**. Modifications made by Krishnavedala.

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tantos <andras@tantosonline.com>
Wed 12/3/2014 9:42 AM
Inbox

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To: jpalomo27;

Javier,

Thanks for contacting me, and of course you have my permission to use the diagrams. All I ask you is to put the source of the images on the documentation.

Thanks,
Andras Tantos

On 12/2/2014 1:30 PM, jpalomo27 wrote:

Good Afternoon,

My name is Javier Palomo, an Electrical Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

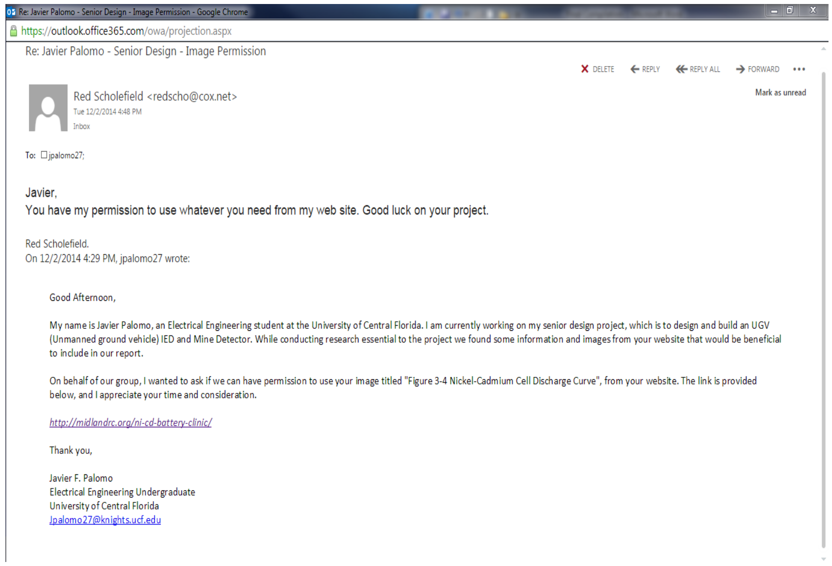
On behalf of our group, I wanted to ask if we can have permission to use your images that describe the static operation of an H-Bridge, from your website. The link is provided below, and I appreciate your time and consideration.

http://www.modularcircuits.com/blog/articles/h-bridge-secrets/h-bridges-the-basics/

Thank you,

Javier F. Palomo
Electrical Engineering Undergraduate
University of Central Florida
Jpalomo27@knights.ucf.edu

- Midland RC



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Inbox

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To: jpalomo27;

Javier,
You have my permission to use whatever you need from my web site. Good luck on your project.

Red Scholefield.
On 12/2/2014 4:29 PM, jpalomo27 wrote:

Good Afternoon,

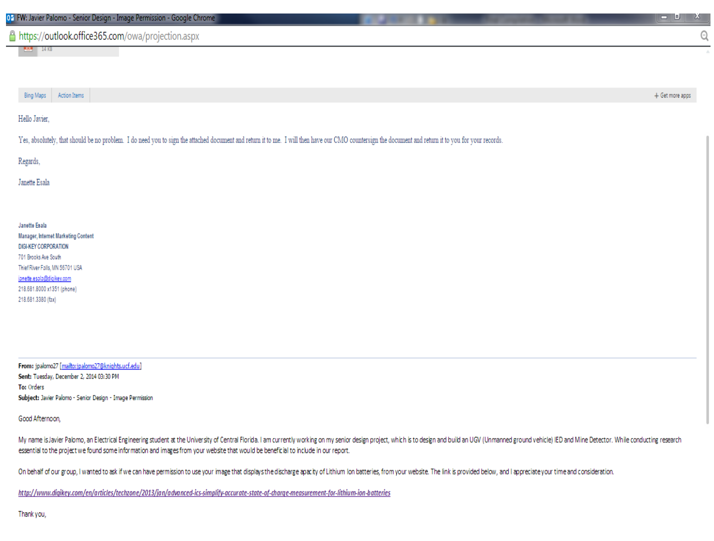
My name is Javier Palomo, an Electrical Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use your image titled "Figure 3-4 Nickel-Cadmium Cell Discharge Curve", from your website. The link is provided below, and I appreciate your time and consideration.

http://midlandrc.org/ni-cd-battery-clinic/

Thank you,

Javier F. Palomo
Electrical Engineering Undergraduate
University of Central Florida
Jpalomo27@knights.ucf.edu



FW: Javier Palomo - Senior Design - Image Permission - Google Chrome

https://outlook.office365.com/owa/projection.aspx

Bing Maps | Action Items | + Get more apps

Hello Javier,

Yes, absolutely, that should be no problem. I do need you to sign the attached document and return it to me. I will then have our CMO countersign the document and return it to you for your records.

Regards,

Janette Esala

Janette Esala
Manager, Internet Marketing Content
DIGI-KEY CORPORATION
701 Brooks Ave South
Thief River Falls, MN 56701 USA
janette.esala@digikey.com
218.681.8000 x1351 (phone)
218.681.3380 (fax)

From: jpalomo27 [mailto:jpalomo27@knights.ucf.edu]
Sent: Tuesday, December 2, 2014 03:30 PM
To: Orders
Subject: Javier Palomo - Senior Design - Image Permission

Good Afternoon,

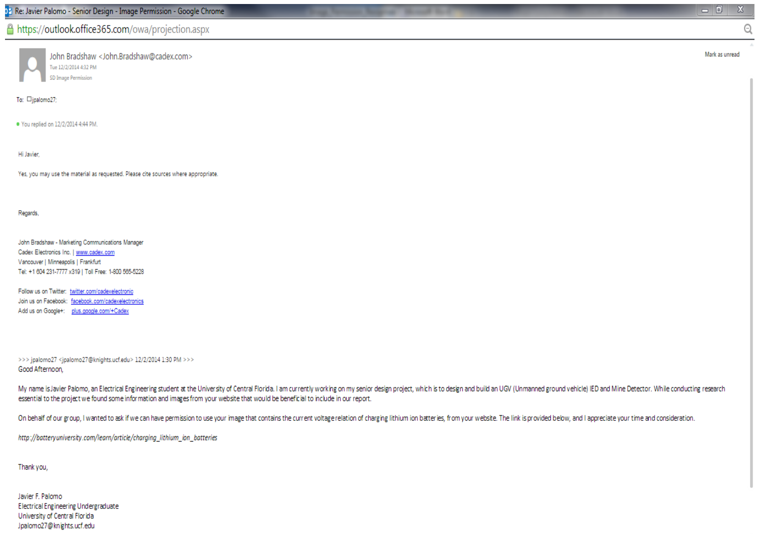
My name is Javier Palomo, an Electrical Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use your image that displays the discharge apacity of Lithium Ion batteries, from your website. The link is provided below, and I appreciate your time and consideration.

http://www.digikey.com/en/articles/techzone/2013/jan/advanced-ics-simplify-accurate-state-of-charge-measurement-for-lithium-ion-batteries

Thank you,

Javier F. Palomo



Re: Javier Palomo - Senior Design - Image Permission - Google Chrome

https://outlook.office365.com/owa/projection.aspx

John Bradshaw <John.Bradshaw@cadex.com>
Tue 12/2/2014 4:32 PM
SD Image Permission

Mark as unread

To: jpalomo27;

You replied on 12/2/2014 4:44 PM.

Hi Javier,

Yes, you may use the material as requested. Please cite sources where appropriate.

Regards,

John Bradshaw - Marketing Communications Manager
Cadex Electronics Inc. | www.cadex.com
Vancouver | Minneapolis | Frankfurt
Tel: +1 604 231-7777 x319 | Toll Free: 1-800 565-5228

Follow us on Twitter: twitter.com/cadexelectronic
Join us on Facebook: facebook.com/cadexelectronics
Add us on Google+: plus.google.com/+Cadex

>>> jpalomo27 <jpalomo27@knights.ucf.edu> 12/2/2014 1:30 PM >>>
Good Afternoon,

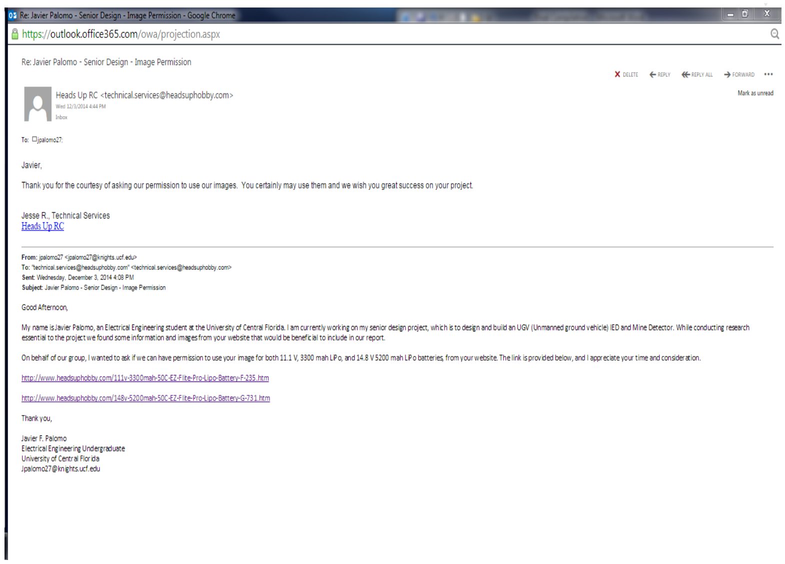
My name is Javier Palomo, an Electrical Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use your image that contains the current voltage relation of charging lithium ion batteries, from your website. The link is provided below, and I appreciate your time and consideration.

http://batteryuniversity.com/learn/article/charging_lithium_ion_batteries

Thank you,

Javier F. Palomo
Electrical Engineering Undergraduate
University of Central Florida
Jpalomo27@knights.ucf.edu



Re: Javier Palomo - Senior Design - Image Permission - Google Chrome

https://outlook.office365.com/owa/projection.aspx

Re: Javier Palomo - Senior Design - Image Permission

DELETE REPLY REPLY ALL FORWARD

Heads Up RC <technical.services@headsuphobby.com>
Wed 12/3/2014 4:44 PM
Inbox

Mark as unread

To: jpalomo27;

Javier,

Thank you for the courtesy of asking our permission to use our images. You certainly may use them and we wish you great success on your project.

Jesse R., Technical Services
Heads Up RC

From: jpalomo27 <jpalomo27@knights.ucf.edu>
To: "technical.services@headsuphobby.com" <technical.services@headsuphobby.com>
Sent: Wednesday, December 3, 2014 4:08 PM
Subject: Javier Palomo - Senior Design - Image Permission

Good Afternoon,

My name is Javier Palomo, an Electrical Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use your image for both 11.1 V, 3300 mah LiPo, and 14.8 V 5200 mah LiPo batteries, from your website. The link is provided below, and I appreciate your time and consideration.

http://www.headsuphobby.com/111v-3300mah-50C-EZ-Flite-Pro-Lipo-Battery-F-235.htm

http://www.headsuphobby.com/148v-5200mah-50C-EZ-Flite-Pro-Lipo-Battery-G-731.htm

Thank you,

Javier F. Palomo
Electrical Engineering Undergraduate
University of Central Florida
Jpalomo27@knights.ucf.edu

Permission Pending:

Ronald Hanifen - Senior Design - Image Permission

Thomas.Braunl@uwa.edu.au

Ronald Hanifen - Senior Design - Image Permission

Good Morning,

My name is Ronald Hanifen, a Computer Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use your image(s) "*mobs.gif*", from your website. The link is provided below, and I appreciate your time and consideration.

http://robotics.ee.uwa.edu.au/mobs/

Thank you,

Ronald L. Hanifen
Computer Engineering Undergraduate
University of Central Florida
rhanifen@knights.ucf.edu

Ronald Hanifen - Senior Design - Image Permission

Suzanne.thorpe@usu.edu

Ronald Hanifen - Senior Design - Image Permission

Good Morning,

My name is Ronald Hanifen, a Computer Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use your image(s) "*GPS Accuracy Diagram*", from your website. The link is provided below, and I appreciate your time and consideration.

https://extension.usu.edu/nasa/htm/on-target/gps-tutorial

Thank you,

Ronald L. Hanifen
Computer Engineering Undergraduate
University of Central Florida
rhanifen@knights.ucf.edu

Send

Ronald Hanifen - Senior Design - Image Permission

redblobgames@gmail.com

Ronald Hanifen - Senior Design - Image Permission

Good Morning,

My name is Ronald Hanifen, a Computer Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use your image(s) "*A* Algorithm Visualization*, from your website. The link is provided below, and I appreciate your time and consideration.

http://theory.stanford.edu/~amitp/GameProgramming/AStarComparison.html

Thank you,

Ronald L. Hanifen
Computer Engineering Undergraduate
University of Central Florida
rhanifen@knights.ucf.edu

Send

Ronald Hanifen - Senior Design - Image Permission

rcnarrendar@gmail.com

Ronald Hanifen - Senior Design - Image Permission

Good Morning,

My name is Ronald Hanifen, a Computer Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use one of your images, from your website. The link is provided below, and I appreciate your time and consideration.

http://www.slideshare.net/narrendar/ros-an-opensource-robotic-framework

Thank you,

Ronald L. Hanifen
Computer Engineering Undergraduate
University of Central Florida
rhanifen@knights.ucf.edu

Send

Ronald Hanifen - Senior Design - Image Permission

contact@jeromeabel.net

Ronald Hanifen - Senior Design - Image Permission

Good Morning,

My name is Ronald Hanifen, a Computer Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use your image(s) "*Network Ranges*", from your website. The link is provided below, and I appreciate your time and consideration.

http://www.jeromeabel.net

Thank you,

Ronald L. Hanifen
Computer Engineering Undergraduate
University of Central Florida
rhanifen@knights.ucf.edu

Send

Fill in the form fields below and click submit. Fields with an * are required.

Company	
Account Number	
First Name*	Josh
Last Name	Genao
Email Address*	jgenao622@knights.ucf.edu
Phone	
Message*	Good Afternoon/Morning, My name is Josh Genao an/a Electrical Engineering/Computer Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.
Reason to send Email*	To obtain an RA or to contact customer service.

Submit

Image Permission for Senior Design

support@robopeak.com

Image Permission for Senior Design

Good Afternoon/Morning,

My name is Josh Genao an/a Electrical Engineering/Computer Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use your image from your website of the RPLIDAR system.

Thank you,

Josh Genao
Electrical and Computer Engineering Undergraduate
University of Central Florida
Jgenao622@knights.ucf.edu

Your message

Good Afternoon/Morning,

My name is Josh Genao an/a Electrical Engineering/Computer Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use the image of LMS-200.

Thank you,

Josh Genao
Electrical and Computer Engineering Undergraduate
University of Central Florida
Jgenao622@knights.ucf.edu

Industry

Address

City , ZIP

Country

Phone

Fax

Function

e-Mail

jgenao622@knights.ucf.edu

Title

Senior Design Image Permission

First name

Josh

Last name

Genao

Company

Permission For Image Use

treasurereports@yahoo.com

Permission For Image Use

Good Afternoon,

My name is Hernan Carvajal, and I am an Electrical Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an Unmanned Ground Vehicle (UGV) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use your image titled "Using the Pulse Induction Underwater Metal Detector for Wading in Surf" from your website. The link is provided below, and we appreciate your time and consideration.

http://www.metaldetectingworld.com/beach_hunting_p10.shtml

Thank you,

--

Hernan Carvajal
Electrical Engineering Undergraduate
University of Central Florida
hernan.d.carvajal@gmail.com
(910) 478-7249

Permission to Use Image

webmaster@jmu.edu

Permission to Use Image

Good Afternoon,

My name is Hernan Carvajal, and I am an Electrical Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an Unmanned Ground Vehicle (UGV) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use one of your images on metal detection from your website. The link is provided below, and we appreciate your time and consideration.

http://www.jmu.edu/cisr/journal/2.1/bruschini.htm

Thank you,

--

Hernan Carvajal
Electrical Engineering Undergraduate
University of Central Florida
hernan.d.carvajal@gmail.com
(910) 478-7249

Send message to AutomationAtJacobs

AutomationAtJacobs

Good Afternoon/Morning,

My name is Josh Genao an/a Electrical Engineering/Computer Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our

Cancel | Send

Permission to Use Image

esimonton24@gmail.com

Permission to Use Image

Good Afternoon,

My name is Hernan Carvajal, and I am an Electrical Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an Unmanned Ground Vehicle (UGV) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use on of the images you posted on a forum, the image is of an RC car with a plastic chassis. The link is provided below, and we appreciate your time and consideration.

http://www.rcuniverse.com/forum/rc-car-general-discussions-179/5593595-anybody-interested-custom-parts-chassis-arms-motor-mounts-shock-towers-etc.html

Thank you,

--
Hernan Carvajal
Electrical Engineering Undergraduate
University of Central Florida
hernan.d.carvajal@gmail.com
(910) 478-7249

QinetiQ Capability of interest*

Robotics ▼

Enquiry *

Good Afternoon,

My name is Hernan Carvajal, and I am an Electrical Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an Unmanned Ground Vehicle (UGV) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use the image of the EOD Talon, in your website. The link is provided below, we really appreciate your time and consideration.

http://www.qinetiq.com/services-products/survivability/UGV/bomb-disposal-eod/Pages/talon.aspx

Thank you,

--
Hernan Carvajal
Electrical Engineering Undergraduate
University of Central Florida
hernan.d.carvajal@gmail.com
(910) 478-7249

Ask for Reprint Permission ▼

Hernan Carvajal

hernan.d.carvajal@gmail.com

I wanted to ask if I can have permission to use your images of "How VLF Metal Detector Works" and "How BFO Metal Detector Works" from your website. The links are provided below, I appreciate your time and consideration.

http://electronics.howstuffworks.com/gadgets/other-gadgets/metal-detector2.htm
http://electronics.howstuffworks.com/gadgets/other-gadgets/metal-detector5.htm

Hernan Carvajal

Permission to Use Images

marketing@servocity.com

Permission to Use Images

Good Afternoon,

My name is Hernan Carvajal, and I am an Electrical Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an Unmanned Ground Vehicle (UGV) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use on of the images of the DDP 115 Base Pan system, one of the images of the Digital Servo S3151, and one of the images of the Robotzone Gear Motor, in your website. The links are provided below, we really appreciate your time and consideration.

https://www.servocity.com/html/ddp155_base_pan.html#.VH-QUjHF-id
https://www.servocity.com/html/s3151_sport_ball_bearing.html#.VH-RKDHF-ic
https://www.servocity.com/html/robotzone_gear_motors.html#.VH-RcTHF-id

Thank you,

--
Hernan Carvajal
Electrical Engineering Undergraduate
University of Central Florida
hernan.d.carvajal@gmail.com
(910) 478-7249

Permission to Use Image

PMGroup.CFL@dot.gov

Permission to Use Image

Good Afternoon,

My name is Hernan Carvajal, and I am an Electrical Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an Unmanned Ground Vehicle (UGV) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use one of your images on GPR data from your website. The link is provided below, and we appreciate your time and consideration.

http://www.cflhd.gov/resources/agm/engApplications/SubsurfaceChartacter/634DetectUnexplodedOrdnance.cfm

Thank you,

--
Hernan Carvajal
Electrical Engineering Undergraduate
University of Central Florida
hernan.d.carvajal@gmail.com
(910) 478-7249

Permission to Use Image

To enquiries@wimborne.co.uk

Cc Bcc

Permission to Use Image

-- Good Afternoon,

My name is Hernan Carvajal, and I am an Electrical Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an Unmanned Ground Vehicle (UGV) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use the image of the block diagram of the detector, which was found in a publication of one of your magazines. The link is provided below, we really appreciate your time and consideration.

http://www.geotech1.com/pages/metdet/projects/twinloop/twinloop.pdf

Thank you,

Hernan Carvajal
Electrical Engineering Undergraduate
University of Central Florida
hernan.d.carvajal@gmail.com
(910) 478-7249

Javier Palomo - Senior Design - Image Permission - Google Chrome

https://outlook.office365.com/owa/projection.aspx

Javier Palomo - Senior Design - Image Permission

DELETE REPLY REPLY ALL FORWARD ...

Mark as unread

jpalomo27

Sent Items

To: kb1qqm@arrl.net;

Good Afternoon/Morning,

My name is Javier Palomo, an Electrical Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use your image that depicts a switching regulator and linear regulator, from your website. The link is provided below, and I appreciate your time and consideration.

http://www.rason.org/Projects/swregdes/swregdes.htm

Thank you,

Javier F. Palomo
Electrical Engineering Undergraduate
University of Central Florida
Jpalomo27@knights.ucf.edu

- Dprg.org

REPLY REPLY ALL FORWARD ...

Mark as unread

jpalomo27

Tue 12/2/2014 4:30 PM

To: info@dprg.org;

Good Afternoon,

My name is Javier Palomo, an Electrical Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use your image that depicts an h-bridge using relays, from your website. The link is provided below, and I appreciate your time and consideration.

http://www.dprg.org/tutorials/1998-04a/

Thank you,

Javier F. Palomo
Electrical Engineering Undergraduate
University of Central Florida
Jpalomo27@knights.ucf.edu

REPLY REPLY ALL FORWARD •••

jpalomo27
Tue 12/2/2014 4:30 PM

Mark as unread

To: alain.webdev@gmail.com;

Good Afternoon,

My name is Javier Palomo, an Electrical Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use your image that shows the current voltage relation of the charge stages of a Lithium-Polymer battery, from your website. The link is provided below, and I appreciate your time and consideration.

http://www.iphoneproguide.com/iphone-5-battery-review/

Thank you,

Javier F. Palomo
Electrical Engineering Undergraduate
University of Central Florida
Jpalomo27@knights.ucf.edu

---

jpalomo27
Wed 12/3/2014 4:10 PM

Mark as unrea

To: service@tenergy.com;

Good Afternoon,

My name is Javier Palomo, an Electrical Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial tc include in our report.

On behalf of our group, I wanted to ask if we can have permission to use your image of the LiPo Balance 1 A battery pack charger, from your website. The link is provided below, and I appreciate your time and consideration.

http://www.tenergy.com/01267?sc=59&category=38236

Thank you,

Javier F. Palomo
Electrical Engineering Undergraduate
University of Central Florida
Jpalomo27@knights.ucf.edu

REPLY REPLY ALL FORWARD •••

jpalomo27
Wed 12/3/2014 4:25 PM

Mark as unread

To: general@nteinc.com;

Good Afternoon,

My name is Javier Palomo, an Electrical Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use your image that displays the design of the external circuit for the NTE1936, from your website. The link is provided below, and I appreciate your time and consideration.

http://www.nteinc.com/specs/1900to1999/pdf/nte1936.pdf

Thank you,

Javier F. Palomo
Electrical Engineering Undergraduate
University of Central Florida

jpalomo27
Wed 12/3/2014 4:33 PM

Mark as unread

To: express@linear.com;

Good Afternoon,

My name is Javier Palomo, an Electrical Engineering student at the University of Central Florida. I am currently working on my senior design project, which is to design and build an UGV (Unmanned ground vehicle) IED and Mine Detector. While conducting research essential to the project we found some information and images from your website that would be beneficial to include in our report.

On behalf of our group, I wanted to ask if we can have permission to use your image that shows the application design of the LT3012 Low Dropout linear regulator , from your website. The link is provided below, and I appreciate your time and consideration.

http://cds.linear.com/docs/en/datasheet/3012fd.pdf

Thank you,

Javier F. Palomo
Electrical Engineering Undergraduate
University of Central Florida
Jpalomo27@knights.ucf.edu

-