Autonomous Robotic Firefighter

(A.R.F.)

Group 15

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1.0 Executive Summary

A.R.F or "Autonomous Robotic Firefighter" is an autonomous or manually driven vehicle that utilizes proximity and flame detection sensors to navigate through a premade course that the group will build. The pre made course will have individual rooms and hallways to closely resemble real world situations. The course will be one story high and have different sources of fire located arbitrarily inside to represent a real fire situation that A.R.F will have to successfully located and suppress. As A.R.F navigates through the building it will use proximity sensors that will also be integrated with flame detection sensors that will constantly scan each area of the pre-made course for the detection of fire. A.R.F will avoid all obstacles present in the course and not repeat previously scanned areas. Once a flame source is located A.R.F will use its flame suppression mechanism to eliminate the located fire source. Once the fire source is suppressed A.R.F will continue to navigate through the course until another fire is then located. The entire process will also be monitored by a camera that will wirelessly communicate back to the human operator on a screen. Once A.R.F has finished suppressing all fire sources located inside of the course the human operator can then easily take control and navigate A.R.F out of the course or A.R.F will eventually through its navigation algorithm return to the starting position and exit where it will be turned off by the human operator. A.R.F will meet a low power consumption constraint while still be quick and efficient.

Currently technology has advanced to the point where un-maned vehicles, whether it be on the ground, in the air or in the water are being used more and more. This advancement is extremely beneficial in most every way because it reduced the chance of human error and loss of human life and endangerment. Autonomous vehicles can produce jobs for people in some areas while in others reduce employment in others but still benefit mankind as a result. Some un-maned vehicles are fully autonomous while others are fully manually driven. A.R.F will feature both types of un-maned vehicles which will allow it to quickly achieve its goal of locating and suppressing a fire source through its fully autonomous mode. If any problems occur that need to be manually fixed a human operator can at any time take full control of A.R.F and fix the opposing issue and then let A.R.F take control once again. The objectives of A.R.F in the real world would revolutionize the way fire situations were handled and assessed. No longer would human fire fighters be needed to endanger themselves by entering hazardous situations such as fire and deadly gasses. Instead a human operator can safely reside outside of the building while letting A.R.F do its job without the possibility of endangering more human lives. While A.R.F will be a low profile with a simplistic design that is scaled down from real world use the idea behind A.R.F of suppressing fires quickly and efficiently without introducing direct human contact with the fire and other dangerous situations will be a proof of concept that can lead the way for a scaled up realistic version that could be possibly massed produced and widely used.

2.0 Project Description

To make the fire-fighting robot successful, certain tasks need to be completed by the robot. Without these specific tasks, the robot would be useless. Since the design will be a scaled version of a full size model. The tasks will be scaled down to be able to prove the idea of the robot working.

The robot will need to be able to enter a maze type of course and go through searching for a fire source without human interaction. Once a fire source is found, the robot will need to be able to successfully extinguish the fire and keep searching the course for more fire. Once the entire course is covered and all fires extinguished then the robot can be manually removed via controller and with wireless camera system. The robot will be able to work manually and autonomous to give optimal use out the robots features. The following states the main objectives of the firefighting robot: Transmit video to allow firefighters to visually see what's going on inside the building, have an onboard fire extinguishing system, equipped with claw to remove possible dangerous material or even aid in a human exiting the area, would have the ability to be manually driven to the door of the building and switched to an autonomous state where all the fire fighter would have to do is monitor the process or go about another task helping in different aspects, go through course without human interaction and be able to navigate different terrains.

2.1 Motivation

Even though we live in a world where electronics are taking over, there are still places and fields where they are not quite as prevalent or not present in abundance. One of those fields is fire fighting. We always see on the news about houses or businesses catching fire putting human firefighters in dangerous positions to do their job to reduce the damage and also the possibility of saving lives while putting theirs on the line. How could technology help? UAVs. Firefighters could be able to use a UAV manually or autonomously to go into a building to scan for people, assess damages, and also assist in extinguishing the fire. The UAV would be equipped with sensors and video feedback so firefighters would know exactly what was going and know the severity of the situation, all the while they wouldn't be in harms way.

2.2 Goals and Objectives

2.2.1 Heat Detection

The goal of the vehicle is to distinguish a fire successfully. This main goal cannot be achieved without properly locating the fire. For this to work properly, testing will have only one flame at a time. It will be approximately the size of a tea candle, for scaling purposes. There will be at least three flame sensors mounted onto the chassis about six inches off of the ground. The flame sensors will continuously scan the surrounding area for certain wavelengths between the ranges of 700 to 900 nanometers. These are the approximate wavelengths of a flame. Once the flame is detected by one the flame sensors, the autonomous vehicle will then accurately pinpoint the flame and stop approximately six inches from it. This ensures that the vehicle itself does not catch on fire. Once the flame is suppressed, the autonomous vehicle will turn back around and back to the spot instantly before the flame was detected and continue searching for flames. The same process is repeated every time a flame is detected. The heat detection system will be light weight and low in power consumption. The size of each component and electronic system must be considered individually and as a whole in order to have a complete working system.

2.2.2 Collision Avoidance

The Goal of the vehicle is to distinguish a fire successfully. This main goal cannot be achieved if the vehicle does not properly avoid collision with obstacles that may be present in the vehicles path of travel. The vehicle will be low to the ground and mainly have the wall as an obstacle and not random items such as loose items you would find in a home like shoes, clothes, trash etc. With walls being the main obstacle in mind the characteristics of a wall must be considered. A wall is flat, large, solid, non-reflective and always present. The objective for collision avoidance is to design, test and implement and system that will ensure the vehicle will not collide with any obstacles. The vehicle will need to have a quick and accurate response when an obstacle is detected. The vehicle cannot over compensate when detecting an obstacle which means the system must be a stable closed loop system that will adjust itself as needed back to a steady state system every instance an object is detected by the system. If the system is overdamped and the vehicle begins to overcorrect causing high oscillations it will considerably slow the vehicle because it will appear to be zig-zagging to correct the vehicles path instead of appearing to maintain a straight line. The collision avoidance system must also have short delays between adjustments. If the vehicle pauses to long between adjustments it will take longer than needed to navigate as well as appear to be stuttering which make the overall design appear unprofessional and inefficient. The collision avoidance system will be light weight and low in power consumption to maintain an ideal design that is beneficial to the overall design of the vehicle. Power consumption and size of each component and electronic system must be considered individually and as a whole in order to have a complete working system.

2.2.3 Power/Size Constraints

The needs for power and size constraints are important to the robots functionality and overall usefulness. If there are no size or power caps the robot can be too robust and have wasteful functionality. If the robot is too big it can be cumbersome and not able to do its job properly. If too small it may not be able to keep up with its expectations well enough. The following table 2.2.4 shows all the main constraints to the power and size constraints that the fire-fighting robot will need to be designed and built to.

Power and Size Constraints

Max Overall Dimensions	18x17x10in	Will include all external sensors, electronics, and fire extinguishing mechanics.
Max Overall weight	15lbs	Will include all mechanics, electronics, and any extras need to finish the project.
Min Carrying Capabilities	30lbs	This will cover any possible scenarios where the robot will need to carry external hardware or other objects.
Min Run Time	30min	This will ensure that the robot has plenty of time to get the job done.
Max Battery Dimensions	573,547mm^3	Max dimensions to keep used space down to a minimum.
Min Battery Capacity	4000mAh	To help aid in an extended run time.
Min Continuous Current Usage	20A	To give overhead for the electronics.

Table 2.2.4: Power Size Constraints

The fire-fighting robot that is being made is to be a scaled down version of what could be considered a real life robot. Factors in size, functionalities, and power are all things that need to be taken in to consideration. A real life robot would be rather large and strenuous to meet certain build constraints and time frame. Therefore as a group the decision to make a scaled version was found to be crucial. Scaling down means more obvious changes like size and expectations but however some changes cannot be made like functionality and power. Power on any scale is always a concern. You want the robot to be able to do its task continuously for more than just a test purpose. Power can also be its overall functionality as well. The fire-fighting robot may come across terrain that is more strenuous than normal concrete or grass. The robot will be expected to go up a slope of at least 37 degrees and be able to go over reasonable size bumps and dips. In the real world the robot would have to be able to fit into certain scenarios like through doors and/or windows. Since ours will not be a true sized model we will set the size constraint to 2cubic foot of space needed. This will be the overall size needed to store all the electronics and mechanics that will need to be used to complete the task of putting out a fire. The overall weight of the robot will need to be less than 15 pounds and be able to carry additional 30 pounds when needed. With the large carrying capabilities of this robot the battery needs to be up to the current needs. A battery of at least 20 continuous amps use will be needed, as well as a capacity of 4000 milliamp hours. This should give the robot a run time of at least 30 minutes.

2.3 Realistic Design Constraints

It is possible that the autonomous firefighting robot could put people out of a job. If the robot goes into a burning building, there might not be a need for as many fire fighters to personally go into the building. On the other hand, this autonomous firefighting robot could also create jobs. If the robot needs to be switched to first person view, somebody would then have to drive it. Drivers would need to be hired to ensure proper suppression. Depending on how large the fire is, the robot could potentially put the fire out faster than a firefighter. If the robot can find the fire first, it will have no problem suppressing the flame. On the other hand, if the flame is too big, the robot will definitely need help from a firefighter.

There are a number of environmental constraints on this autonomous firefighting robot. First are the batteries; they will all be LIPO batteries so they cannot just simply be put in the garbage. The proper way to dispose of a LIPO battery would be to take it to an accredited place that will dispose of it properly for you such as Best Buy. The next environmental constraint would be the printed circuit board. The printed circuit board being used will have lead in it, which obviously is not good for the environment and will need to be disposed of properly. The best way to do this, since there are no regulations of the disposing of lead, is to take it to the nearest landfill and dispose of the lead in a specific section of the landfill. Another environmental constraint of this robot is the wheels. The wheels on this robot are non-degradable plastic. While there are no regulations on disposing plastic, it should be either recycled or taken to the nearest landfill and put into the plastic section. Some social constraints would be complaints from people being concerned about the robot. Some people might feel as if it is not a sure thing, and the success rate might not be as high. Some political constraints would be any laws regarding the handling of robots and fires.

Some ethical constraints of this robot are if the robot does not work or if the robot malfunctions and potentially hurts an innocent bystander. These are always issues with anything that is being used autonomously or anything electrical for that matter. Malfunctions will always occur, and there’s no way to stop it. The best way to keep the robot in top shape is to service it regularly and put it through multiple tests regularly. A big safety constraint of this robot is any being potentially getting hurt because of the robot. An example of that would be if an innocent person accidentally stepped in front of the robot while the robot was trying to suppress the flame, it could cause injury to the person. Another example would be if the robot accidentally ran over someone’s foot or maybe a small animal. A speaker and a flashing light could be put on the robot to ensure that people could hear and see the robot properly.

A manufacturability constraint for this robot is to ensure that it is easily duplicated. If this robot is in demand, there will need to be a high turnover rate. The robot will need to be made quickly so that multiple fire stations can use this robot. Some sustainability constraints of this robot are the lifetime of the robot, withstanding high temperatures and needs to be able to serviced easily. The robot needs to last at least a few years, to keep costs down and also so more robots don't need to be manufactured. The robot would need to be able to withstand high temperatures so it can easily go through hot buildings and get close to a flame without melting or being damaged. The robot needs to have maintenance done to it to ensure that it is always working at its best.

3.0 Research

3.1 Related Projects

Looking through past projects to compare the fire-fighting robot to others, there was one that had the same idea as this project. HeatSeekr was presented in the summer semester of 2013. While reading and researching their design, it was clear how this robot had to differ from HeatSeekr. HeatSeekr was an autonomous robot but rather than being completely unassisted, it used a line on the ground and followed it till the robot "found" a fire source. Once the robot found the fire source it started spraying water in a sweeping motion to extinguish the flame.

To improve on HeatSeekr's design, the fire-fighting robot will have a full autonomous feature, where the robot will be only assisted by the sensors on it and based off of its surrounds navigate a designated course. While in the course, the robot will use sensors mounted on it to find a fire source and go up to the source and extinguish the flame.

3.2 Chassis

A robots chassis is the main foundation to the functionality of the robot. A poorly planned chassis will rid the robot of issues and overall render it a failure. To keep the robot working properly, the chassis needs to be able to keep the robot going and be reasonable. The fire-fighting robot does not have to be huge and robust, but it also cannot be wimpy either. A solid middle ground will need to be chosen for it's best functionality. The robot needs to have a base roughly a square foot with wheels or tracks to give it mobility. The robot needs to be able to traverse multiple terrains and be able to go up and over obstacles.

When choosing a chassis for a robot many options arise and many different applications need to be sorted. Smaller robots may only need two wheels and a bearing to achieve its goal where a large robot may need tracks for weight and speed. For the application of our fire-fighting robot a mixture of small size and large carrying capability is needed. There will be no turning wheels or joints in the drivetrain so a tank style approach will be taken. Research narrows down the choice between four different robot chassis that will work best for a fire-fighting robot. All four robot chassis considered are from servocity.com.

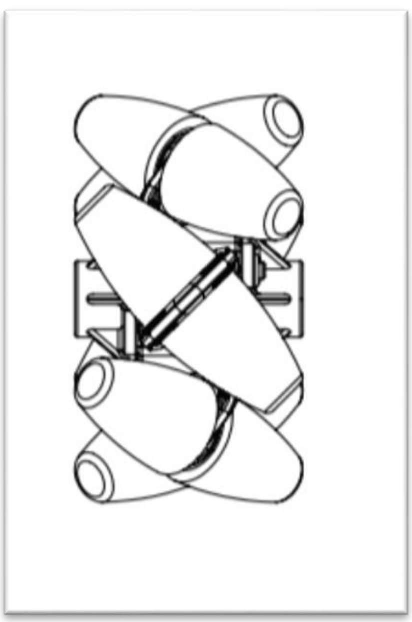
Robot Chassis	Agent 390	Warden	Half-Pint Rover	Scout
Pros	Heavy duty, powerful, traction from tracks, turning radius, all metal framing	Heavy duty, powerful, good for off-road terrain, solid ABS frame with ample electronic placement	Small in size, doesn’t need powerful ESCs, solid ABS frame with electronic storage, cheap, easy replacement	Heavy duty, good size frame, powerful, good for off-road terrain, low center of gravity, good turning radius, good price point
Cons	Very large, expensive, lack of electronic placement,	Top heavy, longer than wide, may have difficulty turning	Low weight carrying capabilities, not a lot of storage	Lack of electronic placement
Dimensions	18” x 16.42”	8.5” x 6.5”	8” x 8”	7.5” x 10.5”
Weight	8.3 lbs	4.05 lbs	1.27 lbs	3.35 lbs
Included Parts	Chassis, motors, wheels, tracks	Chassis, motors, wheels, tires	Chassis, motors, wheels, tires	Chassis, motors, wheels, tires
Price	$389.99	$149.99	$22.49	$127.49
Style	Tracks	4WD	4WD	4WD
Wheel Size	60T Hub Pulley1.5” wide track	4.3”	2.55”	4.3”
Wheel Type	Rubber toothed tracks	Rubber off-road RC tires	Rubber plain RC tires	Rubber off-road RC tires
Motor Specs				
Rated Load	4.5 kgf-cm	1.6 kgf-cm	800 gf-cm	0.6 kgf-cm
Output Power	13W	2.7W		3.2W
Max stall Current	20A @ 12VDC	4.9A @ 12VDC	250mA	4.9A @ 12VDC
# of Motors	2	4	4	4
Voltage	6~12VDC	3~12VDC	4.5V	3~12VDC

Table 3.2: Comparison of Chassis

3.2.1 Mecanum Wheels

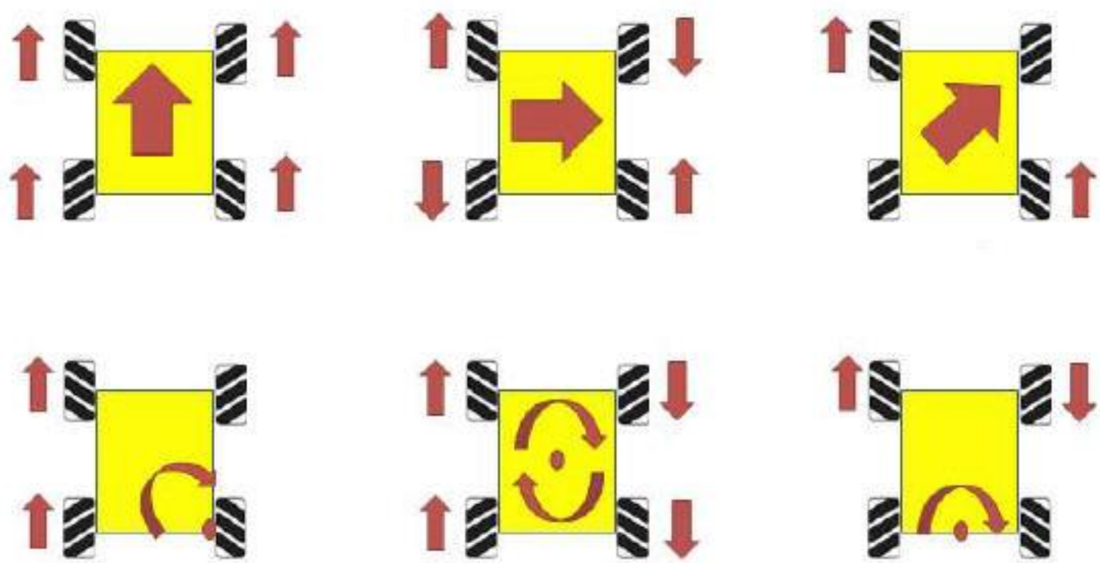
When trying to decide what form of wheel would be best, many come to mind. Tracks, mud-tires, street-tires, and even basic gear wheels are all options when making a robot. Certain large robots that carry large quantities of weight or supplies may not be able to use tires, or they might be in an environment where tires can flatten or aren't feasible. Therefore tracks are the best option. However, for smaller robots load might not be a huge concern but maneuverability may be more important. A Swedish inventor came across the use of angled wheels on a larger wheel could give the user massive maneuverability with also ease of use. This wheel was a Mecanum wheel.

Mecanum wheels allow for maximum maneuverability in tight areas and have endless possibilities. These wheels can move forward and reverse like normal wheels, but they also can go directly to either side. To achieve this sideways movement the wheels are equipped with a series of rollers set to an offset of 45 degrees on the revolving axis parallel to the main revolving axis of the wheel as seen in Figure 3.2.1a.



(Figure 3.2.1a, approval pending)

Operate a robot equipped with Mecanum wheels is fairly simple and much like a vehicle like a tank. For the Mecanum wheels to work, four wheels are required with four individual motors that spin individually from the others. To move forward, all four wheels rotate in the same direction, same with reverse just opposite direction. Spinning each side in opposite directions, the robot will spin about its center axis. To move laterally, wheels at one diagonal, spin in the opposite direction to those on the other diagonal. The description of directional use can be seen in Figure 3.2.1b.



(Figure 3.2.1b)

(Photo is from humanoid-robotics product page, approval pending.)

Getting mecanum wheels to run properly also takes extra steps, more so than more traditional tracks or tires. Rollers on mecanum wheels need constant lubrication to insure free and equal movement through out all for wheels and with the amount of rollers on each wheel, doing so can be quite tiresome. Next, making sure that each wheel is moving at the same speed to ensure direction the user wants the robot to go. This can be done through the use of motor or wheel encoders to track the speed and position of each motor or wheel. This added piece of hardware takes a significant increase in software programing and can lead to more possible bugs or errors in the main software code. Lastly, mecanum wheels require the load of the robot be evenly distributed across each 4 wheels. This requires an extra step in planning and building and also removes the ability to carry surplus cargo or items.

3.2.2 Tank Tracks

When you think of tracks you think tanks. Tanks are known for being very large and heavy. They go through some of the most treacherous terrains and doing so with ease. The use of tracks in robots can be useful for some of the same reason and then some. Tracks are simple; they have plenty of traction; make maneuverability easy; and can go over most obstacles given the robot has the suspension to do so. In large-scale equivalent of a fire-fighting robot, tracks are used for the sheer size of the robot and the ease of making it move. No wheels to turn and no separate drivetrain. Tracks are made up of a series of wheels on a suspension system that ride within a system of plates and toothed tracks. Most tanks have one main drive wheel that spins the tracks therefore propelling the vehicle. With the way the drive system is designed, tracks can offer high clearance and the offer the ability to have high traction in instances where climbing high grades is necessary.

When researching what method of moving the robot, observing the pros and cons were the best way to see if tracks were better for this robot. Compared with the old school technology of the wheel shows the advantages and disadvantages of both.

	Wheels	**Tracks**
Advantages	Low fabrication costs Speed Maneuverability Lightweight Simplicity Materials	Power efficiency Traction Maneuverability of terrain Ground effect Load capabilities
Disadvantages	Obstacle circumvention	Low speed Less maneuverability Lifespan Repair ease

Table 3.2.2: Advantages and Disadvantages of Tracks and Wheels

When using tracks on a robot you gain power efficiency. Compared with wheels tracks boast high performance and enhanced traction control systems. In rough conditions including sandy, slippery, or frozen, tracks have proven that their traction is beyond all. When operating in rough terrain, tracks can maintain a better position, because of its long tracked drivetrain, it can go over mild obstacles where wheels would be caught up or even stuck. With tracks, the pressure of the load is spread out over more area than a conventional wheel, giving tracks less of an impact to the terrain it is in. this gives tracked robots the ability to carry a higher load than most other ways of travel. Even though the suitability of tracks is higher, there are a few downfalls to consider. Due to the increase of ground contact, friction makes for a lower top speed and also a decrease in maneuverability. Tracks are made up of multiple treads and links, which can break easily causing a short life span and increased difficulty for repairing.

3.2.3 Discrete Components

With any project, the question of how to design and build it arises. Will the team build all parts from scratch? Building the fire-fighting robot from scratch is possible but difficult. Table 3.2.3 show the necessary parts that would be needed to accomplish this task. Even once the parts are in possession a lot of work and resources will be needed to build the robot. Saws will be needed to cut the material into pieces to assemble and drills to pair all parts together. Even taking time and resources serious problem can arise that could hinder the overall functionality of the robot. Parts can be misaligned and mismatched. Parts can may not hold up the full ability of the robot and not be able to complete its task.

In this project price of materials are crucial. If the parts need to build a chassis where bought separately, then accounting for the time to build the price could exceed what is allotted in the budget. Most chassis kits come precut, predrilled, and with extra parts that can aid in its assembly. Places like ServoCity sell kits for a reasonable price, and include extra items that otherwise would need to be bought separately. These items include motors, wheels and tires. Another benefit to buying a predetermined kit is all the items are made for a specific reason. The motors that are included in the kits from ServoCity are already predetermined and specific to that robots functionality. This takes the guess work and testing out of choosing motors and making sure they will do the job in the project.

Item	Price / Quantity	Description
ABS plastic sheet	\$9.99 / 4	15” x 15” This will compose the main body parts of the chassis and hold the motors and all electronics.
Aluminum railing	\$5.99 / 4	The railing would go in between the pieces of the ABS to hold the chassis together.
Motor mounts	\$4.99 / 4	Holds the motors to the main frame of the chassis.
Fasteners	\$20 / misc.	The fasteners will bind all parts and pieces together and give the robot its rigidity.

Table 3.2.3: Comparison of Discrete Components

3.3 Motors

Any vehicle weather it is electric, gas or any other type of fuel propelled, has motors that drive the vehicle in a chosen direction. For the vehicle being used, electric motors will be the type of motors being selected. Electric motors have to be the type used due to the small scale of the vehicle being built, most likely around a foot or two in length and width. When choosing the correct type of electric motor multiple factors must be considered. The amount of power required to drive the motors must be low enough for the power system being designed to handle. The torque of the motors must be a constraint or else the vehicle will either accelerate to quickly or not quickly enough. The cost will be another constraint to be followed when choosing the correct motor for the vehicle. There are numerous types of electric motors to be researched that each have their own characteristics for different uses. Electric motors that will be researched include brushless in runner, brushless out-runner, brushed, continuous servos and stepper.

3.3.1 Brushless

A brushless motor is a DC electric synchronous motor that is powered by a DC source through an integrated inverter. This produced an AC electric signal to drive the motor. This also allows the motor to act as a generator when spinning the motor and treating it as the source instead of the load. Brushless motors have stationary electromagnets and have permanent magnets on the spinning portion of the motor that when spun create an electric field. Brushless motors are 3 phase and have three wires as the input. One is labeled as the positive and one as the ground even though there is no real positive and negative side of a brushless motor, the third wire is used for feedback. If any two wires are switched the motor will then spin in the opposite direction. The advantages of using a brushless motor are that no brushes or commutator wear out. No maintenance is needed for cleaning the brushes. Brushless motors are more efficient than due to the lack of friction caused by the brushes which results in a longer battery lifetime per charge. Brushless motors also have a higher power to weight ratio.

3.3.1.1 Brushless in-runner and Brushless out-Runner

A brushless in-runner motor has the permanent magnets positioned on the inside of the electromagnets. An out runner brushless motor has the permanent magnets on the outside of the electromagnets. When deciding which type to choose one must consider that the faster a motor spins the more efficient it is. In runner motors turn much faster than out runner motors and therefore are more efficient. In-runner brushless motors require that a speed reducing gearbox is used between the motors shaft and what it is driving. Since a gear must be used the output speed and torque can easily be calibrated mechanically. The biggest downside of using an in runner is that there are more parts that can fail. A gear can be stripped or broken much easier than the metal shaft of an out-runner motor.

3.3.2 Brushed

A brushed motor has rotating portion called the armature. It consists of the poles, terminals and the commutator. The poles are copper wires wound around a piece of metal that form an electromagnet. The poles are attached to the armature. Terminals are a point at which the copper wire of a pole attaches. Commutator is a switch on the armature that reverses the current to the poles every half rotation so that the magnetic fields of each will always maintain rotation. A brushed motor has brushes inside. The brushes are tabs in the motor cap that are wired to the battery and make contact with the plates on the commutator as the armature rotates. The outer shell of the motor has magnets that are permanent and each has a different polarity. The brushes make contact with the plates of the commutator when the motor rotates. When the brushes make contact with the plates a particular pole is charged. After a pole becomes charged it is attracted to one of the magnets in the inside of the motor and repelled by another. This creates a repeating process that causes the motor to spin and keep spinning as long as a voltage is applied. The biggest disadvantages to using brushed motors are that they wear out more quickly and are less efficient due to the friction of the brushes. They are easier to use than brushless motors for people who are not familiar with electric motors and are generally cheaper.

3.3.3 Continuous Servos

A normal servo is simply a geared down motor that has a limited range. Most servos use some form a PWM to determine the amount of degrees to rotate. A continuous servo is the same as a normal servo except that there are no limitations on how many degrees the motor can rotate. This type of motor is extremely useful when exact and precise movements are needed. The downside to using a continuous servo as a motor to drive a vehicle is that they are generally quite slow and not all that powerful. For applications that do not need quick speeds and instead need to focus on extremely accurate movements and a steady pace this is the best option. Most electric motors can only be given a command to go forward, reverse and stop with a variable speed. Continuous servos can be programed using pulse width modulation to rotate 90 degrees and then negative 180 degrees which is great of a predetermined path or a vehicle that has outstanding artificial intelligence (AI).

3.3.4 Stepper Motor

Stepper motors are similar servos since they have the ability to make discrete mechanical movements with precision. Unlike a servo that has most likely 90 increments between 0 and 90 degrees a stepper motor may only have half that many increments. A stepper motor is by definition an electromechanical device which converts electrical pulses into discrete mechanical movements. When electrical command pulses are applied the shaft of the stepper motor rotates in discrete step increments. Stepper motors have many advantages over other electric motors. The rotation angle of the motor is proportional to the input pulse. The motor has full torque instantly from rest. The precision of the motor and repeatability of movement is usually accurate within 3-5 percent of a step and the error that does occur is not cumulative from one step to the next. Stepper motors also respond to digital input pulses with means it uses an open loop control that in return makes the motor simpler and cost less. A wide range or rotational speeds can be used as well. The biggest shortcoming of a stepper motor is that it cannot be operated easily at extremely high speeds.

3.3.5 Type of Electric Motor Chosen

The type of electric motors chosen for the vehicle is brushless electric DC motors. The choice was determined by the team for multiple reasons. Brushed motors are easy to use, can be low in torque without expensive parts. Brushed motors only need 2 wires, a positive and a negative. Brushed motors were also the most affordable while still meeting the requirements. There are a large variety of brushed motors to choose from and more research will be conducted before a final choice can be made.

3.3.5.1 RC4WD 540 Crawler Brushed Motor (35T)

The RC4WD540 Crawler (45T) is a brushed motor built to be used with either a LIPO or NiMH battery. This model has an effective operating voltage of 7.2 volts and the max current is 4.62 amps. The RC4WD540 offers a high torque magnet and rotor that will ensure it can move the vehicle as needed. At 7.2 volts the motor will work well with a 2 cell LIPO battery without issue. The shaft has a length of 11mm and a diameter of 3.1 mm. The lengths of the motor’s dimensions are 50mm*36mm with an outer diameter of 3.2mm. Refer to Fig. 3.3.5.3 for more information.

3.3.5.2 RC4WD 540 Crawler Brushed Motor (45T)

The RC4WD540 Crawler (45T) is a brushed motor built to be used with either a LIPO or NiMH battery. This model has an effective operating voltage of 7.2 volts and the max current is 4.29 amps. The RC4WD540 offers a high torque magnet and rotor that will ensure it can move the vehicle as needed. At 7.2 volts the motor will work well with a 2 cell LIPO battery without issue. The shaft has a length of 11mm and a diameter of 3.1 mm. The lengths of the motor’s dimensions are 50mm*36mm with an outer diameter of 3.2mm. Refer to Fig. 3.3.5.3 for more information.

3.3.5.3 C13-L19 Samarium Cobalt

The C13-L19 Samarium Cobalt is a brushed motor built to be used with either a LIPO or NiMH battery. This model has an effective operating voltage of 6-24 volts and the max current is 1.8 amps. The RC4WD540 offers a high torque magnet and rotor that will ensure it can move the vehicle as needed. At 6-24 volts the motor will work well with a 2 cell LIPO battery without issue. Refer to Fig. 3.3.5.3 for more information.

3.3.5.4 HK Shanhai Brush Motor

The HK Shanhai Brush Motor is a brushed motor built to be used with either a LIPO or NiMH battery. This model has an effective operating voltage of 8-30 volts and the max current is 40 amps. The HK Shanhai Brush Motor offers a high torque magnet and rotor that will ensure that it can move the vehicle as needed. At 8-30 volts, the motor will work well with a 2 cell LIPO battery without issue. Refer to Fig. 3.3.5.3 for more information.

3.3.5.5 Motor Comparison Chart

A chart is used to compare all motors researched in a way that makes it easy to make the best choice when deciding on the best motor controller for the vehicle. The chart below in figure 3.3.5.3 displays the model name, the voltage, maximum current output in Amps, the torque, the speed in RPM and cost. The voltage is an important characteristic because power consumption is vital to any electrical system, especially an autonomous system that relies solely on non-human input. If voltage consumption is too high, the battery life will be shortened and therefore results in a shorter operating time. If there is more battery lifetime, this creates more time for the vehicle to achieve the goal of fire suppression. The max current rating is important to know because the motor controller selection is solely based off of max current that the motor pulls. High torque is important because this ensures that the vehicle no matter what load it carries is able to effectively move its payload where it needs to go. If a motor is chosen with a torque that is too low and the pay load is too heavy, the motor will have a much higher risk of stalling. This also is a negative effect because when a motor stalls, it will usually pull its maximum current which the motor can only do so long before burning out. Usually when a system has high torque, a negative side effect is that speed is generally reduced. This negative side effect needs to be taken into consideration; meaning that a motor with a balanced torque and speed must be chosen that will satisfy the needs of a vehicle. The speed is an important factor because if the vehicle is too slow, realistically the fire will not be able to detected and suppressed in a timely manner. The faster the speed is the better up until a certain pinch off point. At this pinch off point, the coding becomes too difficult with the hardware being used to effectively function. The price column may not be a huge factor for some but for this project the budget is a main factor when making all decisions and will help decide on major components used. Refer to figure 3.3.5.3 for the complete details of all of the motors compared.

Type	Voltage	Max current	Torque	Speed	Cost
RC4WD 540 Crawler Brushed Motor (35T)	7.2 v	4.62 amps	High Torque	10400 RPM	$9.99
RC4WD 540 Crawler Brushed Motor (45T)	7.2	4.29	High Torque	8100 RPM	$9.99
C13-L19 Samarium Cobalt	6-24	1.8	High Torque	2875 RPM	$30.00
HK Shanhai Brush Motor	8-30	40	High Torque	10000RPM	$28.88

Figure 3.3.5.3 Comparison Chart for Motors

3.4 Batteries and power

From the research of necessary parts including motors (speed controllers), sensors, and microcontrollers, we gather that we will need certain power demands. Voltage, current, capacity, weight, size, and safety all become factors in finding the right power sources and distribution. When considering the load that the robot will be consuming, we have to take in consideration what each piece of the project will be drawing current and how much. The following table shows each piece with the power demands each need.

Part	# of pieces	Voltage(V)	Current Cons(mA)
Motors(ESC)	2	12	10000
Sensors	10	5	30

Microcontroller	1	9	1000
Fire Sup. System	1	12	1000
Total mA			22300

Table 3.4: Comparison of Batteries and Power

With the data from the different parts, we see that we will need a power source that can handle at least 23 amps. The following shows the types of batteries that were considered in the planning of our robot, each would include a description of the battery along with the pros and cons that were considered in the choosing of what would be used.

3.4.1 NiCd (Nickel Cadmium)

Invented in 1899, NiCd or nickel cadmium batteries used to be a top choice in electronic needs. In 1946 consumer production was released to the population of America. They replaced the recently popular lead acid batteries, which had more maintenance and where a “wet” cell. The make up of a NiCd uses nickel oxide hydroxide and metallic cadmium as electrodes. NiCd batteries come in individual cells with a voltage of 1.2v and ranging in sizes from AA to D sized cells. With the AA size cells you see a current of 1.8A and the D sized with a current of 3.5A. Thus giving NiCd batteries a perfect market for smaller electronics specifically radios, phones, and RC hobbies.

With the needed specifications for our project, multiple cells in parallel and series would be needed to meet the voltage and current needs. With the multiple cells we would need to set aside a fair amount of valuable space for the cells. Also the weight of the amount of cells needed would be too high for the application that we are using them for.

Pros:
Economical; Dependable; Resists mistreatment; can have high discharge, that up to 10C; can be used over wide temperature range: -20C to +60C
Cons:
Hefty; can 'die' rapidly and unexpectedly; Requires discharging for long life; Memory effect; Toxic.

3.4.2 NiMH (nickel metal Hydride)

NiMH came out to consumers in the late 1980’s. Filling the majority of the market, NiMH batteries were most companies top choice for power solutions, as late as 2008 more than two million hybrid cars around the world were outfitted with the batteries. Proving more reliable and safe to the previous go to NiCd batteries that had a reputation for toxic chemicals and mishaps. In Japan, 22% of portable rechargeable batteries sold in 2010 were NiMH. With the release of Lithium Ion and Lithium Ion Polymer batteries, the markets for NiMH batteries have diminished greatly. However this did not keep us from not considering them for this project, from their popularity decreasing so has their prices.

NiMH batteries are predominately found mostly in RC hobbies for their durability and wide variety of usages. For the correct voltage needed, a NiMH battery pack with 10 cells, because they are 1.2v (nominal voltage 1.5v charged) cells linked together in series to give the needed voltage at the terminals. Typical NiMH 12v battery packs range from 1000mah to around 2000mah with current maxing out at around 30amps. With the capacity being low, multiple packs would need to be added for a practical capacity to achieve the robots duration that is pleasing to the consumer and engineers working with the system. Also boasting a 500–2000 cycle longevity makes for an ease of robot maintenance.

Pros:
High overhead capacity; Energy concentration up to two times that of a NiCd
Cons:
Reduced low temperature performance; can be damaged if charged in low temps; Can not deliver high load; Same weight as normal NiCad's; Low cycle lifespan; Can require separate charger; has memory effect.

3.4.3 Lithium-Ion

For many years, NiCd had been the only available battery suitable for consumer electronics. Much like NiMH batteries, lithium-ion batteries emerged in the early 1990s, fighting back and forth to gain consumers acceptance. Today, lithium-ion is the fastest growing and most promising battery chemistry. Lithium-ion is a low maintenance battery, which is an advantage that other battery chemistries cannot boast. With the entrance of this battery so departed the era of batteries having to have scheduled charging cycles and batteries having discharge memory. With this new technology batteries no longer had to be fully discharged so the user wouldn't destroy the longevity of the batteries life. With the new lithium-ion cells being more stable, little harm would be caused in the event of the batteries internals being exposed.

With the new and ever evolving technology of lithium-ion cells the boastedpromising numbers for what we needed for our project. Lithuium-ion cells can be found in many modern electronics including power tools, laptop power cells, electronic-cigarette uses, and many other applications. The cells that would be applicable to the robot would be the 18650 version of the cells. With the size being 18mm by 65mm (diameter x height), space would not be an issue, considering each cell has a nominal voltage of 3.7v (4.2v fully charged) and high current capabilities. High-end Lithium-ion cells like Samsung and Sony boast amperage ratings of 25A and 30A respectfully.

Pros:
No discharge is needed for storage; 50% lighter than the older NiCd; No memory effect; Environmentally friendly; Lightweight; generally smaller than other equivalent batteries.
Cons:
Expense; Can be dangerous when safety are not taken in charging or discharging.

3.4.4 Lithium Ion Polymer

Much like its older brother, lithium-ion battery is a lithium-based battery but instead of being in a sealed spherical, LiPo batteries have a lithium-ion wet cell incased in polymer pouch. The theoretical reasoning for the pouch was the need for a thin battery that was also “flexible.” The science for a flexible battery has still not been completely mastered as of yet. With the similarities to the lithium-ion batteries LiPos have been the go to battery for most RC enthusiasts when it come to their power needs. Applications such as quadcopters, robots, electric scaled vehicles, and even normal day-to-day cars are just some of the ones these batteries are put to the test in.

LiPos have independent cells or “pouches” that are assembled in a series format to give the user the voltage they need. With our need in mind we will need a 3 cell LiPo battery with a high amperage limit and capacity. Since the battery is a pouch format verse a metal tube housing, the weight of the units have decreased significantly, making them more applicable to more devices. In 2013, some LiPo batteries are boasting an impressive 1.3Ah rating, offering 45C continuous discharge with 90C burst. With a bigger packaging, rating of 4.5Ah and 70C to 140C of discharge, which is incredible given the size of the battery.

Pros:
No discharge is needed for storage; 50% lighter than the older NiCd; No memory effect; Environmentally friendly; Lightweight; generally smaller than other equivalent batteries.
Cons:
Expense; Can be dangerous when safety are not taken in charging or discharging.

3.4.5 Battery safety

With any electronics project, safety is always most important followed by functionality and need. When working with batteries of any type special precautions must be taken. For our design we will be using a LiPo battery talked about earlier. If mishandled wrong they can be dangerous if not deadly.

First step in making the project as safe as possible is making sure the battery can handle the current being pulled by the motors, MCU, and other accessories. Our fire fighting robot will need at least 22.3 amps if everything is pulling power at the same time. Trying to maximize capacity goes hand in had with the current output. Discharge of a LiPo is shown in a C rating for each battery. We will be using a LiPo with a 5000mAh capacity so the robot will have plenty of time to achieve its goal and then some. To calculate the C rating we will need to have we follow this formula:

$$C_{rating} = \frac{cont.\,discharge}{capacity\ in\ ah}$$

Using this formula a C rating of at least 5C, which will discharge 23 amps safely. To give us a little headroom we will be choosing a LiPo with around 20C so if in the future we or the user want to add more features there is room in the power department for the upgrade.

Second step in making the project as safe as possible is making sure the environment the battery is placed in is proper for the specs of a LiPo. The battery needs to be placed in a position where it will be secure and not deformed. LiPo batteries are incased in a pouch that if misplaced, can be punctured and start a fire releasing harmful gases and liquids. At a certain point LiPos have been known to explode. Temperature is the next spec that needs to follow strictly. LiPo batteries have an operating temperature of -20c to 60c (-4F to 140F). Considering that our project is a fire fighting robot we will need to keep an eye on this spec. Ways to help is thermo shielding and also using a sensor internally to keep an eye on the temperature as the battery discharges.

Third and final step in making the project as safe as possible is making sure that the charging of the robot is done in a manner that doesn't stress the battery. When charging a LiPo battery, a charge of 1C-2C is recommended. Same formula as discharge, depending on the capacity the charge and discharge are proportional. We will be getting a 5000mah LiPo so we will recommend charging the fire fighting robot at 5 amps or less for the best longevity of the cells.

3.4.6 Distribution of Power

With as many parts and accessories that will need power comes an issue that many projects have to face, power management. Power management includes distributing voltages to different devices and also making sure that any wire routing is done in such a way that is considered safe and orderly. Organization is key to making an efficient and effective robot. Many simple methods of distributing power can be hazardous and messy with wires going everywhere. Wiring that is just thrown into a box for the robot can make life quite hard. Wires need to be run in a safe path that will not cause shorts or issues that could end badly by harming parts of fragile equipment and also human injuries. The best method for distributing power will be the use of barrier strips. They are simple but very effective in making a clean robot and assessing issues with power if any were to come up. Barrier strips can handle amperages upwards of 20-60 amps, which in our case is perfect. Barrier strips come in many different sizes, which is perfect for our use where a barrier strip will be the central hub between our battery, electronics, sensors, monitors, and other accessories.

3.4.7 Voltage regulation

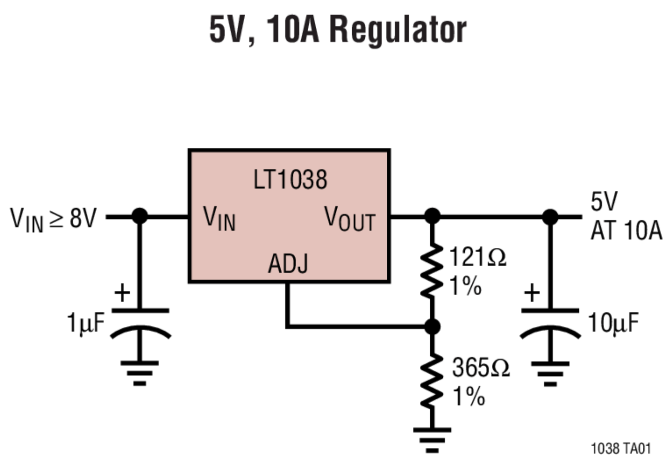
With any type of electronic project, the need of different voltages is crucial. In our robot we have at least three separate voltages that will be needed. Our main MCU will need a voltage 9 volts for it run optimally, our multiple sensors will need a voltage of 5 volts, and our motor controllers/ motors will need 12 volts. Since we will be using a 12 volt LiPo battery, the motors will be ran directly off the battery so that they can draw their individual high currents directly from the source to help with voltage drop and losses. However for the MCU and sensors we will not be able to run them off the battery. Voltage regulation will help us be able to run separate voltages without harming the chips and other important pieces of our system

3.4.7.1Linear voltage Regulators

Liner voltage regulators have plenty of uses as they are small, easy to implement, they are cheap, and will work in many lo powered devices. However, due to the way they regulate power they are exceptionally inefficient. In our robot we will want as little power loss as we can possibly achieve so that the more important aspects of the robot can have a higher capacity to draw from. The current needed for the lower voltages aren't high but he wasted power would still be relevant.

Power wasted = $(V_{in} – V_{out}) * I_{load}$

If we implemented a linear regulator we would have a power loss of 7 watts just from our sensors. Over the duration of the robot doing its job, a substantial battery capacity would be loss to a part of the robot that would normally pull less than a .2watts at 5 volts. Refer to the picture below for a schematic.



(Figure 3.4.7.1 Switching Voltage Regulators.)

Unlike a linear regulator, a switching regulator is more complex than just mount a part to a board and running three wires using your stepped down voltage. A switching regulator uses a complex arrangement of parts to give a user a more efficient power step down or even a step up regulator. By rapidly switching the input on and off , it charges either an inductor or a capacitor depending on circuit , given a set duty cycle to achieve the desired average voltage. With this method power is not dissipated, but stored in the active devices, giving a high efficiency rating.

In our project we will be using 2 separate regulators to power our multiple devices and accessories. We do not want a high power loss so we will be implementing switching regulators to give us less power loss in these components. We will be implementing two Texas Instruments LM2576T-ADJ components to achieve our desired voltages. The

LM2576T-ADJ also carries a 3A limit, which will give plenty of overhead for our sensors and monitors. Refer to the picture below for a schematic.

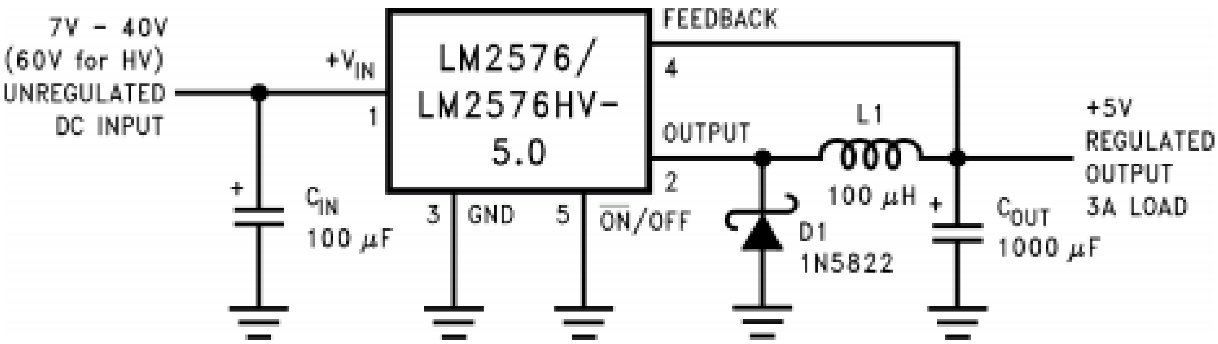


Figure 3.4.7.2.: Switching Regulator

3.5 Motor Controller

Brushed motors will be used for the vehicles means of propulsion and therefore will require a motor controller that will effectively supply power. A Brushed motor needs to use a motor controller that is compatible. There are multiple types of motor controllers available for use such as electronic speed controllers (ESC). An ESC is an electronic circuit that is intended to vary an electric motor's speed, its dynamic brake if one exists and its direction. An ESC uses pulse width modulation to vary the speed of motor. The longer the pulse width is the more power is supplied and the faster the motor will spin. The slower the pulse width the slower the motor will spin. Only two wires are connected from the output of the ESC to the brushed motor and the input of the ESC that is connected to the microcontroller has three wires. One for the input voltage, one for ground and the last wire is used for the input signal given by the microcontroller that controls the how many times per second the ESC will pulse to control the speed of the motor. There are other motor controller options such as a multioutput ESC which is usually a PCB that has multiple ESCs connected together that will generally connect all grounds and voltages together but still have multiple signal wires. The motors that are chosen for this vehicle are moderate in torque which requires the motor controller to be able to handle an adequate amount of current. 30 amps should safely handle and motors used. The motor controller should also be able to use a 2-3 cell LIPO battery as an input voltage source

3.5.1 Hobby Wing Wp-1625-BRUSHED

The Hobby Wing Wp-1625 is a brushed electronic speed controller that uses pulse width modulation to vary the speed of a DC brushed motor. The Wp-1625 is water proof and dustproof allowing it to be used in most all conditions. This ESC has the ability to drive brushed motors in either the forward or reverse direction as well as braking the motor. A built in BEC outputs a current of 1 AMP and a voltage of 5 volts which allows easy power distribution without having to using the microcontroller or the battery source to connect more components. The continuous output current is 25 amps in both the forward and reverse directions and also has a 100 amp peak current for both directions. 2-3 cell LIPO batteries may be used or 5-9 cell NiMH batteries. The PWM frequency is 1 kHz. The dimensions measure 1.3 x 0.9 x 0.6 inches and weighs 23.5 grams.

3.5.2 Hobby Wing Wp-1060-BRUSHED

The Hobby Wing Wp-1060 is a brushed electronic speed controller that uses pulse width modulation to vary the speed of a DC brushed motor. The Wp-1060 is water proof and dustproof allowing it to be used in most all conditions. This ESC has the ability to drive brushed motors in either the forward or reverse direction as well as braking the motor. A built in BEC outputs a current of 2 AMPs and a voltage of 5 volts which allows easy power distribution without having to using the microcontroller or the battery source to connect more components. The continuous output current is 60 amps in forward direction and 30 amps in the reverse direction. The peak current for the forward direction is 360 amps and 180 amps for the reverse direction. 2-3 cell LIPO batteries may be used or 5-9 cell NiMH batteries. The PWM frequency is 1 kHz. The dimensions measure 36.5 x 32 x 18 mm and weighs 73 grams.

3.5.3 Hobby Wing Wp-860-DUAL-BRUSHED

The Hobby Wing Wp-1060 is a brushed electronic speed controller that uses pulse width modulation to vary the speed of a DC brushed motor. The Wp-1060 is water proof and dustproof allowing it to be used in most all conditions. This ESC has the ability to drive brushed motors in either the forward or reverse direction as well as braking the motor. A built in BEC outputs a current of 3 AMPs and a voltage of 5 volts which allows easy power distribution without having to using the microcontroller or the battery source to connect more components. The continuous output current is 60 amps in forward direction and 30 amps in the reverse direction. The peak current for the forward direction is 360 amps and 180 amps for the reverse direction. 2-4 cell LIPO batteries may be used or 5-12 cell NiMH batteries. The PWM frequency is 1 kHz. The dimensions measure 46.5*34*28.5 mm and weighs 39 grams.

3.5.4 Turnigy 20A BRUSHED ESC

The Turnigy 20A Brushed ESC is a brushed electronic speed controller that uses pulse width modulation to vary the speed of a DC brushed motor. The Turnigy 20A esc is not water proof and will have to housed inside of a location away from the elements if there is any water exposure. A built in BEC outputs a current of 1 amp and a voltage of 5 volts which allows easy power distribution without having to using the microcontroller or the battery source to connect more components. The continuous output current is 20 amps in forward direction. The peak current for the forward direction is 25 amps. 2-3 cell LIPO batteries may be used or 4-10 cell NiMH batteries. The dimensions measure 45.*21*8 mm and weighs 17 grams. This ESC does not support reverse but does support forward and reverse direction. This ESC is very cheap and affordable but with no ability for the ESC to drive motors in reverse may hinder the vehicle unless a design can be created that will allow the vehicle to only use forward direction.

3.5.5 HobbyKing X-Car 45A ESC

The HobbyKing X-car 45A ESC is a brushed electronic speed controller that uses pulse width modulation to vary the speed of a DC brushed motor. The HobbyKing X-Car is water proof and dustproof allowing it to be used in most all conditions. This ESC has the ability to drive brushed motors in either the forward or reverse direction as well as braking the motor. A built in BEC outputs a current of 2 AMPs and a voltage of 5.6 volts which allows easy power distribution without having to using the microcontroller or the battery source to connect more components. The continuous output current is 45 amps in forward direction and 45 amps in the reverse direction. The peak current for the forward direction is 320 amps and 320 amps for the reverse direction both for 10 seconds max without causing damage to the motor controller. 2-3 cell LIPO batteries may be used or 5-6 cell NiMH batteries. The PWM frequency is 1 kHz. The dimensions measure 38*28*22 mm and weighs 40 grams. This electronic speed controller also features a low voltage cut-off for use with lipoly batteries. This feature is peace of mind since there is no need to worry about the LIPO batteries being drained too low which will ruin the battery unlike other batteries such as lead acid or NiMH. The voltage cutoff is roughly 3.1 volts, if a LIPO battery drains below 3 volts damage may occur.

3.5.6 105906SC-15wp Waterproof ESC

The 105906SC-15wp is a brushed electronic speed controller that uses pulse width modulation to vary the speed of a DC brushed motor. The 105906SC-15wp is water proof and dustproof allowing it to be used in most all conditions. This ESC has the ability to drive brushed motors in either the forward or reverse direction as well as braking the motor. A built in BEC outputs a current of 2 AMPs and a voltage of 5 volts which allows easy power distribution without having to using the microcontroller or the battery source to connect more components. The continuous output current is 200 amps in forward direction and 100 amps in the reverse direction. The PWM frequency is 1 KHz. The dimensions measure 1.3 * .94 * 1.08” inches and weighs 50 grams. This ESC also has a temperature cutoff for protection if the ESC becomes too hot. This ESC will quit working before any components fail.

3.5.7 9SIA2V51428281 New Egg 320 amp ESC

The *9SIA2V51428281*is a brushed electronic speed controller that uses pulse width modulation to vary the speed of a DC brushed motor. The *9SIA2V51428281* is not water proof or dustproof limiting the uses and environmental conditions this ESC can be used in. This ESC has the ability to drive brushed motors in either the forward or reverse direction as well as braking the motor. A built in BEC outputs a current of 2 AMPs and a voltage of 5.6 volts which allows easy power distribution without having to using the microcontroller or the battery source to connect more components. The continuous output current is 320 amps in forward direction and 240 amps in the reverse direction and the Brake has a peak output current of 250 Amps. The PWM frequency is 1.5 KHz. The dimensions measure 34 x 34 x 30 mm and weighs 47 grams. This ESC also has a temperature cutoff for protection if the ESC becomes too hot. This ESC will quit working before any components fail.

3.5.8 Motor Controller Comparison Chart

A chart is used to compare all motor controllers researched in a way that makes it easy to make the best choice when deciding on the best motor controller for the vehicle. The chart below in figure 3.5.3 displays the model name, continuous current output in Amps, Peak current output, Voltage range and price. Continuous current output is an important characteristic because it is what current the motor controller can safely output to the motors constantly. If the motors required more current than what the motor controller outputs the vehicle will not be able operate correctly. Peak current output is the highest current that can be outputted by the motor controller at any instantaneous time. This specification is important because if the motor stalls it will have what is known as a stall current. A stall current is when a motor shaft is denied the ability to rotate by external forces which in return causes the motor to pull a very high current. If the motor controller cannot handle this stall current then the controller may fail and no longer work. Voltage range is needed to help users know what type of battery or power system they will need to pair with the motor controller for the controller to function correctly and safely. The price column may not be a huge factor for some but for this project the budget is a main factor when making all decisions and will help decide on major components used. A comparison of each motor controller researched is shown below in figure 3.5.3.

Model Name	**Continuous Current Output (Amps)**	**Peak Current Output**	**Voltage Range**	**Price**
Hobby Wing Wp-1625-BRUSHED	25 Forward 25 Reverse	100 Forward 100 Reverse	2-3S LIPO 5-9S NiMH	$18.49

Hobby Wing Wp-1060-BRUSHED	60 Forward 30 Reverse	360 Forward 180 Reverse	2-3S LIPO 5-9S NiMH	$22.80
Hobby Wing WP-860-DUAL-BRUSHED	60 Forward 30 Reverse	360 Forward 180 Reverse	2-4S LIPO 5-12S NiMH	$31.49
Turnigy20A BRUSHED ESC	20 Forward	25 Forward	2-3S LIPO 5-10 NiMH	$4.95
HobbyKing X-Car 45A ESC	45 Forward 45 Reverse	320 Forward 320 Reverse	2S LIPO 5-6 NiMH	$20.95
105906SC-15wp	200 Forward 100 Reverse	N/A Forward N/A Reverse	2S LIPO 4-6 NiMH	$41.50
Newegg320 amp ESC	320 Forward 240 Reverse	N/A Forward N/A Reverse	1-2S LIPO 4-6 NiMH	$15.96

Fig.3.5.3: Motor Controller Comparison Chart

3.6 Microcontroller (MCU)

In this project it is important to weigh some key features in the decision as to which microcontroller would be most effective in this design. Within the Specifications section of this document, it can be seen that the maximum number of proximity sensors to be used in this design is 4 and the maximum number of flame sensors to be used is 5. This is vital information because it determines how many General Purpose Input/Output (GPIO) pins will be needed for this design. The amount of current that each of these device’s signal pins pulls is also information that would need to be considered when choosing the correct MCU. If the MCU is trying to source too much current, it is very possible that the controller could shut down or even heat up to the point of breaking permanently. These metrics as well as others will be considered further in this section to determine the proper MCU for this particular application.

3.6.1 Important Metrics

Before entering comparison between different MCU brands, this section will outline metrics based off the Specifications section of this document. These metrics along with others will ultimately guide the decision as to which microcontroller would be most beneficial to this project.

3.6.1.1 GPIO Designation

GPIO pins will be used as control signals to relay power or supply direct to a subsystem, whether that subsystem is range finding, flame sensing, fire suppression, or motor control. Referring to the Proximity Sensor section of this document, it can be shown that most proximity sensors will use 4 or less pins; 2 for power and 2 for signal. GPIO pins will not be used for power, so it can be assumed that every proximity sensor will need 2 GPIO pins. Referring to the Flame Sensor section, it can also be found that on average a flame sensor uses 3 pins; 2 will again be for power and 1 will be an analog output that encodes the intensity of flame signature that the sensor is detecting. Using just this information, it can be shown that a total of 13 GPIO pins will be needed, just for robust control of the sensing system.

This number can be specified even further by knowing a little bit more about the types of sensors that will be used in this application. Usually, as seen in the Proximity Sensor section of this document, these sensors utilize a sort of “ping” and “echo” scheme; bouncing some form of energy with a known speed off of an object and timing the response. The “ping” pin would need to be a digital pin in order to get higher resolution timing. It would also make sense that the echo pin be of the same type for the same reason. Now referring to the Flame Sensor section of this document, it can be seen that the flame sensor operates very similarly to a solar cell (with some filtering and amplification). This means that the signal pin will be an analog voltage that should be proportional to the intensity of energy (of a certain frequency profile). The applicable portion of this information as it pertains to this section is that these will be *analog* pins. Now it can be shown that of these 13 GPIO pins, at most 8 will be digital and 5 will be analog. To be even more specific, 4 will be digital inputs, 4 will be digital outputs, and 5 will be analog inputs.

Referring now to the Fire Suppression section of this document, it can be seen that when using the fan to extinguish fires there will also need to be a digital pin reserved to relay (or possible supply power to) this subsystem. An example of our groups idea to relay power from the microcontroller to a subsystem is given in figure 1 of the Fire Suppression section of this document.Whether or not the MCU will supply power to the fan or simply relay power through a MOSFET or similar transistor will be decided based on power consumption of the fan chosen as well as consumption of the proximity sensors. Other than the power supplied, the fire suppression system does not have any other specifications to meet (such as switching speed) and so, one standard digital output pin will be sufficient for this system.

The last set of GPIO pins needed to be accounted for are those of the motor control system. At this point the exact scheme of motor control has not officially been decided, so because of this, it is difficult to say with exact certainty what type of GPIO configuration will be needed. Although, there will most likely be two sets of motors acting independently that will either be controlled by 2 Electronic Speed Controls (ESC) or by some sort of integrated chassis/motor controller package. Either of these choices could be controlled using two digital output pins with Pulse Width Modulation (PWM) capability. If, for example, the motor controller requires analog inputs to each of the motors to determine the speed; the PWM signal could simply be filtered using a capacitor, leaving an analog signal. Using all the information given so far in this section, it can be shown that the microcontroller pin designation must satisfy the table given below.

	Digital Inputs	Digital Outputs	Analog Inputs
Number Needed	4	7	5
Total Estimated Current (without MOSFET relaying)	NA	<200mA (Based on estimated sensor/ESC specs)	NA
Number of pins needing PWM capability	NA	2	NA

Table 3.6.1.1.1: Necessary GPIO pins

Lastly, it would be favorable that the microcontroller have more an excess of pins (including the pins listed in Table 1). It is possible that extra features, such as manual remote control be integrated into this design. If this is the case, having the exact amount of pins listed above will not suffice.

3.6.1.2 Software

Since the exact amount of space needed to execute this code has not yet been established (because the code has yet to be written) the specification calls for a generous amount of 256kB of space. The reason for this amount of space is the code will most likely be written in a high level language that possibly utilizes large libraries (more info in the Algorithms section). The high level language will be used because of the depth of code necessary for this project to work and the fact that all of the members of this group are hardware based engineers and not software. Due to these facts, it would be favorable to use a microcontroller that has a design environment in a C-based language and has a collection of open source libraries.

3.6.1.3 Energy Consumption

As outlined in the Specifications section of this document, battery life should exceed 20 minutes of continued use. Due to this specification, energy consumption will be one of the metrics considered when comparing microcontrollers below. Although, because a microcontroller should consume much less energy that some of the other subsystems (such as the motors), this requirement will not be held in as high importance as the GPIO Designation outlined in the above section.

3.6.2 MCU Comparison

The table below is used to compare various microcontrollers against each other based on the metrics that were outlined in the beginning of this section. This data will be used in final decision making as to which controller is best suited for this project. The table below has a full description of each MCU.

	MSP430FR5739	ATmega640	TMS320F28027	ATmega8
Cost (Not including shipping)	$3.70	$10.87	$7.11	$2.62
Number of digital GPIO	32	86	22	23
Number of Analog inputs	12	16	16	8
Number of hardware capable PWM channels	0	12	3	6
Program Memory Size (kB)	16	64	32	8
Input Voltage	2-3.6	2.7-5.5	3.3	4.5-5.5

Range (V)				

Table 3.6.2.1: Comparison between various MCU's

3.6.2.1 MSP430FR5739

Texas Instruments produces this line of microcontrollers that utilizes a 16-bit architecture and up to a 24Mhz clock. It comes in a variety of packages including a quad-flat no lead package and a small outline package. This chip provides 16kB of non-volatile FRAM memory and has 26 GPIO pins. One big drawback to this chip is its lack of resources available to it. With the time constraint put on this project, it is hard to justify using an MCU that does not provide adequate access to necessary tools such as timing library access. This controller provides a lot of control and would be excellent for a project with a more generous timeline, or possibly less software heavy project.

3.6.2.2 Atmel ATmega640

Atmel produces a variety of 8 bit microcontrollers that use little power, but are still very powerful. This chip became popularized when Adafruit, an Italian electronics company, began using this chip as the centerpiece to their Arduino development boards. These boards were originally created for graduate students at an Italian college, but have since been used in many prototyping applications. The point of all this is that because the ATmega line is so well known, there are many libraries available; making very large project such as this, much more possible. As mentioned in the Important Metrics section above, having a large toolbox of libraries and resources is important for this project.

The ATmega640 comes in a few different package options that will be discuss more in the PCB section of this document. This chip is capable of performing 135 hardware level instructions, many of which are done in just one clock cycle due to its efficient hardware architecture. It can perform 16 million instructions per second using a 16 Mhz clock and has 32 general purpose 8-bit registers. Probably the most important part of this chip is the fact that it provides 86 GPIO pins and has 12 of those pins capable of providing PWM output.

3.7 Printed Circuit Board

This section will be used to explore various options for PCB manufacturers based on price, required specifications, and explore the high level block diagram design options for both the wiring schematics as well as board layout options. There are currently two versions of the design at this time, but for the sake of simplicity, only one will be shown. The two design versions only differ by one system, the power supply and filtering. One idea is to include a power supply unit on the main PCB containing the MCU and another is to build a power supply or even use a separate pre-fabbed power supply design to regulate and filter power from the battery. Using this design is more likely as the current plan is to use a switch mode power supply, which according to multiple sources listed in this document can cause “ground-plane noise”. This ground-plane noise can cause bit errors on the MCU or possibly even temporary power loss. To avoid this, some sources suggest using a split ground-plane, while others suggest simply keeping the power regulation board separate from the MCU board. Keeping the power supply unit separate from the main PCB may be the most ideal case, but the more complicated design involves including the power supply unit on the same board as the MCU, so this will be shown below. If it can be shown that this design can work with the power supply unit, then it can easily be adapted to work without it on the board. This section will not be used as a source for final design plans, but rather explore the options available and start the decision process that will be used in the final design. These options will include device footprint options and how this will affect the final design, potential wiring schematics, device packaging as it pertains to board layout, and fabrication house limitations. With all of these factors being considered there will also be a decision as to which fabrication house to use to print the boards, and potentially which assembly house to use if difficult soldering is necessary. If there are any other alternatives to work being sent out of house, these will also be mentioned in the “Assembly Options” section below.

3.7.1 Specifications

This section will briefly outline a list of common specifications that will be used in determining a circuit board fabricator. These specifications will come from power and size specifications given elsewhere in this document. Some specifications that will be covered in this section include trace and via size, copper pad size, solder mask and copper overlap, and copper trace weight. Some of these figures will be obtained through constraints from certain systems within the design (as mentioned above) and some will be obtained from the IPC-2221 standards or their interpretations. These standards may be taken directly from the IPC release document or from interpretations given by references outlined in the corresponding section of this document. These interpretations could be suggested rules to be followed in order to remember the IPC standards easier or could also be custom web-based calculators that are coded using these standards. For instance the calculator shown below in figure 3.7.1.1 will be used to determine trace sizes based on current capacity of copper weight and heat restrictions. The current plan is to minimize the amount of money spent on this project, so unless absolutely necessary, a copper density/weight of 1 oz/ft will be used. Of course, in some cases this is not safe. This is why the calculator in figure 3.7.1.1 will be used to determine a size necessary. There is also a possibility of just using solid core wire instead of running traces on a board. This option also eliminates the possibility of overheating and will be explored in later stages of development.

Once copper weight and trace width have been determined, the next step is to determine the minimum spacing between traces that could be used as a function of the highest voltages used in the board design. Again, another calculator or table based off the IPC-2221 standards could be used to determine this distance and determine which PCB fabricator can meet these specifications. The first step to determine this is to first determine what the maximum voltage that will be on the PCB is. It is known that the highest voltage in this entire design is not to exceed 9 volts, so this will be used in the investigation. According to the same IPC-2221 standard, as long as no more than 15 volts are used, a trace center to center spacing of at least 5 mils or .13 mm. As a general rule according to *electronicdesign.com*, the “rule of 10” can be followed in most applications. This says that traces should be 10 mils from each other, or about .2 mm. They should also be pulled away from the edge of the board by 10 mils or more. It also states that vias should have a hole size finished to 10 mils surrounded by an additional 10 mils of pad. This project does not have a very strict constraint on size of the PCB and because of this, it will be easy to attain more than enough space between traces and other traces,

Inputs:

Current	10	Amps
Thickness	4	oz/ft^2 ▼

Optional Inputs:

Temperature Rise	10	Deg C ▼
Ambient Temperature	25	Deg C ▼
Trace Length	1	inch ▼

Results for Internal Layers:

Required Trace Width	184	mil ▼
Resistance	0.000685	Ohms
Voltage Drop	0.00685	Volts
Power Loss	0.0685	Watts

Results for External Layers in Air:

Required Trace Width	70.8	mil ▼
Resistance	0.00178	Ohms
Voltage Drop	0.0178	Volts
Power Loss	0.178	Watts

traces and the edge of the board, and traces and components.

Figure 3.7.1.1: Re-print permission requested from “Circuitcalculator.com”- screenshot of the tool used to choose trace width based off heat/copper weight restrictions.(approval pending)

As for the material of the insulation that will be used in this board, there is no real restriction besides budget. In most cases it would seem that, especially at lower frequencies, the increase in reliability versus the increase in cost is not worth going with a material other than FR-4. Other materials may be more reluctant to obtain water damage or possibly have a lower susceptibility to electromagnetic interference, but these attributes are not required by the overall specifications of this project.

The chosen fabrication company must also be able to produce double sided PCBs. This is necessary as some surface mount components may be utilized and will have a very small pitch. As there will not be much room to route traces off the MCU, it will be much easier to have the ability to run the trace through a via to another layer or, more than likely, the other side of the board. The ability to be able to produce a printed circuit board that contains features on both sides is pretty common, but adds a lot of design freedom. A full comprehensive list of desired fabrication specifications is listed in table 3.7.1.1 below.

Specification Type	Requirement
Insulator Material	FR-4
Trace Material	Copper
Minimum Trace Width	10 mils ~(.25 mm)
Minimum Trace Pitch	10 mils ~ (.25 mm)
Copper Weight Range	1-4 oz
Minimum Via Drill Size	10 mils
Ability to Print Multiple Layers	Yes
Electrical Testing	Yes
Cost	Lowest
Lead Time	Lowest

Table 3.7.1.1: Minimum requirements of PCB fabricators

3.7.2 High Level Schematics

This section will provide an overview of the proposed configuration of the printed circuit board from a high level perspective. This overview will be a simplified block diagram showing possible configurations and relationships between subsystems. An example of such a design can be shown in figure 3.7.2.1 below which shows each subsystem within the PCB as a blue rectangle, the PCB board limits as a green rectangle, and power/data flow is given by bold arrows. All corresponding data and power transfers as well as their sending and receiving subsystems have been labeled below. Directions of arrows pertains to the directional flow of power or data. The SPI port shown in the diagram will be explained later in more detail, but will be the main form of communication between the MCU and an external processor such as an external programmer.

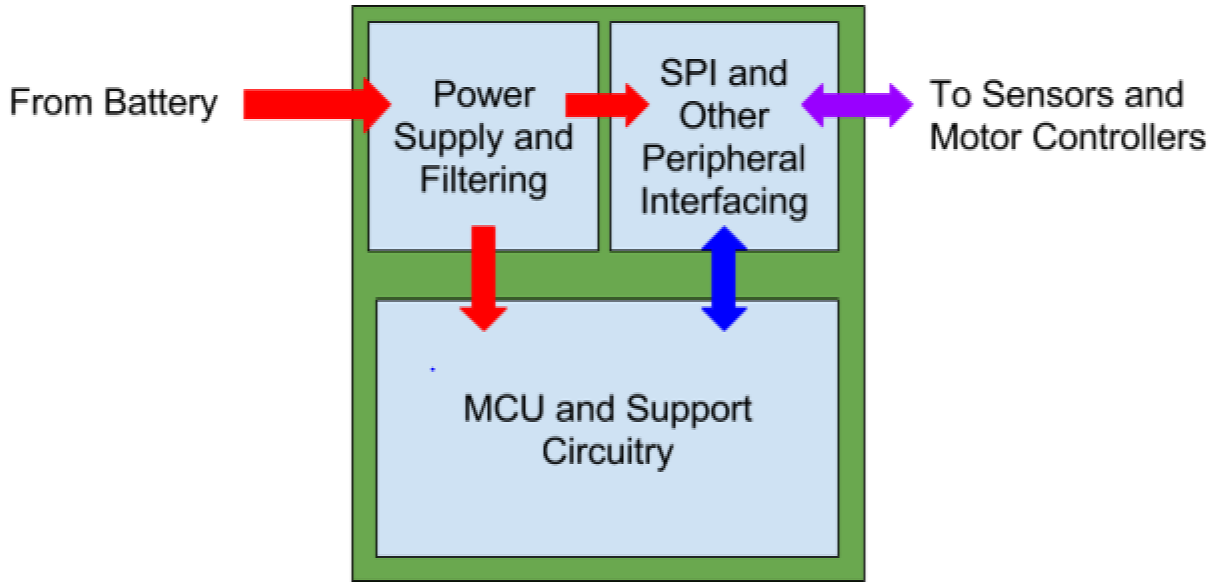


Figure 3.7.2.1: Full PCB overview design including integrated power supply unit. Note: Red arrows correspond to power flow, blue arrows correspond to signal, and purple corresponds to mixed power and signal. Arrows in image should not be treated as individual lines, but rather data and power buses.

It still has not been determined at this point whether or not the power supply and filtering unit will be integrated into the PCB as shown in figure 3.7.2.1 or if it will be its own seperate unit to lower ground-plane noise interference with the MCU. If it is decided that the power supply will be integrate into the main PCB design, it will be important to tune the switching frequency such that the frequency and its harmonics are not in interference with any of the sensor data rates or on-board crystal oscillator MCU support circuitry. If it is decided that the power section of the design will be separate from the MCU PCB, then most likely this section will be implemented on a perf-board.

Next the MCU section of the board will be explored in further detail. At this point in time, the current plan is to use an Atmega2560 microcontroller; but if the code and IO can be optimized enough, an Atmega328P or Atmega644 microcontroller will be used. This issue is explained more fully in the “Component Footprint Options” section of this document. Below a slightly lower level block diagram of the MCU section of the PCB can be seen with its connections. The external oscillator support circuitry that will be used will be shown in the final board layout, but will most likely consist of a 16 MHz quartz crystal in a DIP package connected to two 22 pF capacitors. This configuration was obtained from the Atmel datasheets. The connector that will be used for the sensor and motor controller section is still undecided, but it is ideal to keep a robust connection here. One idea is to use a D-sub connector that runs to a separate “peripheral breakout board”. This breakout board would simply be a PCB with traces that run from a D-sub connector to individual sensor connectors.

The SPI section is used to program the MCU in the case that the chip used is a surface mount component and cannot be put on a development board for programming. This also gives

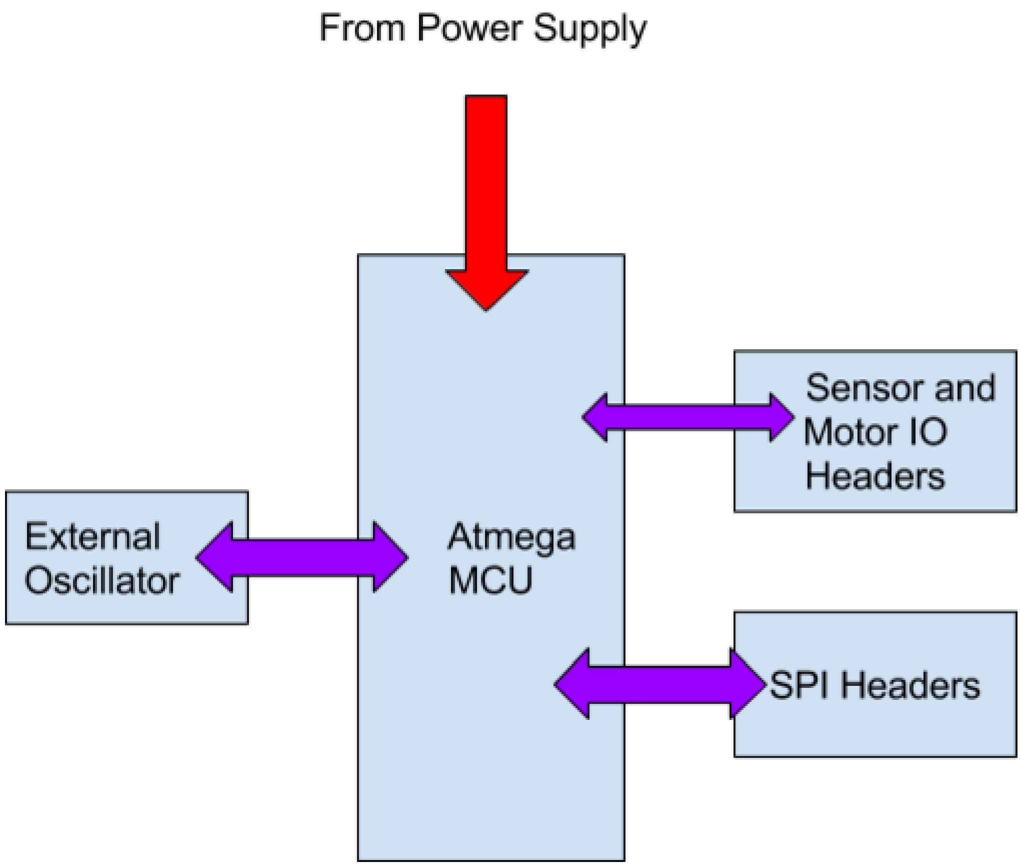


Figure 3.7.2.2: Microcontroller and peripheral mid-level overview. Again, red arrows correspond to power transfer, blue stands for signal, and purple for a mix of both.

additional support as an on board debugging unit for the microcontroller. It could help determine if there is a problem with the MCU or any other component on the PCB. This standard header will consist of 6 pins. There will be 5V and GND pins that will be used by an external programmer as a comparison to differentiate a logical “0” from “1”. Then there will be four other pins designated to communication. These four pins will come of the MCU and are labeled “MOSI”, “MISO”, “RESET”, “SCLK”. MOSI stands for “Master Out Slave In” and is used to send data from the external serial programmer to the MCU. On the other hand MISO or “Master In Slave Out” is used to send data from the MCU to the programmer, as the MCU in this situation is the slave. The RESET line is used to reset the MCU into a mode that allows for access to direct memory, allowing for bootloader uploading and direct non-volatile parameter editing. The line "SCLK" is simple a clock that syncs the master to the slave to improve data fidelity during transfers.

3.7.3 Component Footprint Options

This section will be used to describe the various packaging options for the components that are used at the lower level as described by sub-systems above. This list will not yet be a comprehensive bill of materials, but instead will be used to determine the proper foot-print configuration of each component put on the PCB. This information will be used when finalizing the board layout. The table below describes the minimum requirements.

Sub-Section	Part Name	Description	Common Footprint Options
Power Regulation/Filtering	LM2576HVT-5V	Switching Regulator	TO-220 TO-3
	67127000	Inductor	22x13 PC
	1N5822	Schottky Diode	DO-201AD
	511D107M075CG4D	Aluminum Capacitor	Radial
MCU and Support Circuitry	Atmega2560	MCU	TQFP QFN
	Atmega328P	MCU	PDIP TQFP
	Atmega644	MCU	PDIP QFN
	TBD	16 MHz Crystal Oscillator	HC49S
	TBD	22 pF Capacitor	Radial
Peripheral Interfacing	TBD	Sensor and Motor IO Pins	Unknown/ Through-hole
	N/A	Standard pitch Header Pins	Through-hole 1 mil pitch 2x3

Table 3.7.1.1: Minimum requirements of PCB fabricators

As seen in table 3.7.3.1, multiple options are still left open for the MCU, depending on the size of code needed and IO necessary as determined by testing. The ideal case from a manufacturing standpoint would be to use one of the options that allows for through-hole mounting rather than a form of surface mount. In this scenario, there would not be a need to send the board to an assembly house or worry about using a solder reflow oven. This would be the best case as solder reflow just introduces more unknowns and more potential problems. There are ways to create a solder reflow oven using a standard toaster, but it would be ideal to be able to avoid this situations at all cost.

3.7.4 PCB Fabrication House Comparison

Printed circuit board manufacturers will be compared to each other as well as the specifications that have been outlined in the above section. Based on all these metrics, a final PCB manufacturer will be determined in this section with a provided explanation as to why it was chosen.

3.7.4.1 Pentalogix

One benefit to Pentalogix is the fact that the company has been in business for over 30 years, making it seem to be reliable and efficient. The metric of company age was not considered in the specifications, but it good to consider as it can be directly related to less issues. It would seem the longer a company does business, the more it can be optimized and streamlined. This potentially saves the customer time in the end, but may require a higher cost. It would seem that Pentalogix uses FR-4 for their boards, copper for traces, and meets all of the minimum spacing requirements as defined in the above specifications section. The problem with this service so far is the fact that gerber files must be uploaded to determine a quote. There is also a lead time on simply obtaining a quote for the PCB fabrication. This option will still be explored once the board layout has been finished, but for now it seems that Pentalogix is targeted more towards industry professionals and not a group of individuals printing a single board.

3.7.4.2 3PCB

Unlike The previous company, Pentalogix, 3PCB seems to be targeted more towards single prototypes for the hobbyist or engineer. This means that prices are shown more easily up front, and are generally lower. After reviewing the PCB capabilities of the company, it would seem that they are able to meet every mechanical requirement as outlined above. As a direct comparison for PCB fabricators, a board size of 100x100mm will be used in pricing and lead time. After receiving a quote from the 3PCB website, this size board is estimated to cost $38 and take 5-8 days for total turnaround. This also is for

5 PCBs (not fitted with components), as this was the lowest amount available for the quote.

3.7.4.3 PCBWay

Very similar to 3PCB, PCBWay seems to be targeted more towards small production or prototype runs rather than full fledged production like Pentalogix. This fabricator also meets the specifications outlined above and quoted the same price as 3PCB at a slightly longer lead time (7-11 days). It also was not clear on the website whether or not a continuity check is included in this price. Because of this reason, it is more likely that 3PCB will be used in the final design.

3.7.4.4 Final Fabricator Selection

At this point, it makes the most sense to choose 3PCB as the fabricator for this PCB. The biggest reason for this is their quick turnaround time, cheap prices, precise mechanical tolerance, and free continuity checking for every board. This company caters much more heavily to small prototype runs rather than huge productions, which is favorable in this situation. The table given below (Table 3.7.4.4.1) will show a list of 3PCB capabilities as they compare to the specifications listed above.

Specification Type	3PCB Value	Spec Met (Y/N)
Insulator Material	FR-4	Y
Trace Material	Copper	Y
Minimum Trace Width	6 mils	Y
Minimum Trace Pitch	6 mils	Y
Copper Weight Range	1,2	Y
Minimum Via Drill Size	11.8 mils	N
Ability to Print Multiple Layers	Yes	Y
Electrical Testing	Yes	Y
Cost	~$2.38/sq. in	Y
Lead Time	5-8 days	Y

Table 3.7.4.4.1: Final Fabricator Specifications

As seen above in table all specifications have been met except for the minimum via drill size. On the 3PCB website they claim to have drill sized between .3mm and 6.3mm, which is equivalent to 11.8 mils to 248 mils.

3.8 Wireless Receivers and Transmitters

Wireless transmitters and receivers are used to transmit and receive data through a radio frequency without the need of hardwired wires. Sending data from a controller to the microcontroller is necessary for the vehicle to be autonomous and also be controlled via human interface. Controlling the vehicle manually will usually be slower than using a smart autonomous system that eliminates human error but in a situation where an error occurs or an unexpected problem a human controller can take over using a controller that sends data through the transmitter to the receiver that controls everything on the vehicle. Another reason this manual mode is needed for this vehicle is when the fire has been suppressed the vehicle will not have an exit code but instead be able to be switched into manual mode and be driven out of the building by a human operator. This method of sending data increases the range in which data can be sent without any restrictions of obstacles obstructing the path whereas wired data paths cannot go through a wall or trees unless a hole is drilled through or the wires are redirected around the obstacle. There are many different frequencies that can be used for radio receivers such as 433 MHz, 315 MHz, 2.4 GHz and 5 GHz. Other frequencies can be used but the four listed are the most commonly used frequencies. Radio transmitters and receivers in the range of MHz that are also low power consumption models are not used for long distances because they are not capable of transmitting data more than about 100ft. 5GHz transmitters cannot transmit data as far as 2.4 GHz transmitters but have far less interference than 2.4GHz because not as many devices use the frequency of 5GHz. When using a video transmitter and receiver for data transfer and then also using a transmitter and receiver pair for video transfer conflicts can occur if the same radio frequency is used. With this in mind the group must take into consideration when choosing the wireless receiver and transmitter pairs for data and for video so that no conflicts occur or else the entire system cannot function correctly. The main characteristics to consider when researching possible candidate transmitter and receiver pairs are: the radio frequency, voltage and current consumption, range of transmission, size, delay time if available and cost. For the tests that will be conducted extremely long range transmitter and receiver pairs will be first priority but still considered. The power consumption will ideally be less than a watt and the size will be ideally less than 2x2x2 inches. Cost for most transmitter and receiver pairs are quite expensive and will not be able to be purchased for low price but more in the range of $100 dollars for the pair will be the target price.

3.8.1 433 MHz RF Transmitter Module Receiver Module

This Transmitter Receiver pair uses a radio frequency of 433 MHz to wirelessly send and receive data. This transmitter receiver is sold without a controller to easily connect to the transmitter meaning either a controller will have to be built or a microcontroller will be connected to the transmitter. The range of this transmitter receiver pair is only about 100 feet without any obstructions. This short range is due to the radio frequency band it uses. Any transmitter receiver pair that uses a frequency in the Mega Hertz range with such a low power consumption will only be about a 100 feet too at most half a mile which will limit the use of this pair and most likely not be able to transmit very well or at all through walls and obstacles. The voltage range for the receiver is 3.3 – 6 volts. The more voltage applied up to 6 volts will increase the receiving power. The input voltage for the transmitter is 3-12 volts. The higher the input voltage up to 12 volts for the transmitter the further the data can be transmitted. The transmitter uses 4 pins. One pin for the ground, one pin for power, one pin for obtaining data from an input and one pin for transmitting the data to the receiver. The receiver has three pins. One pin for ground, one pin for input power and one pin for receiving data. The transmitter has a working current of 20 to 28 milliamps. The working temperature range for the transmitter is -10 degrees to 120 degrees Fahrenheit. The transmission power is 25mW. The transmission speed is 10 kbps. This slow transmission speed is a characteristic that has the ability to greatly inhibit the functionality of this transmitter receiver pair. If the data transfer rate is too slow the vehicle will not receive the data in time to react to the command given by the transmitter and will cause the vehicle to stutter and have poor controllability. The operating current for the receiver is 4 milliamps and the operating temperature is -10 degrees to 120 degrees Fahrenheit.

3.8.2 2 pcs nRF24L01+ 2.4GHz Wireless Transceiver

This Transmitter Receiver pair uses a radio frequency of 2.4 GHz to wirelessly send and receive data. This transmitter receiver is sold without a controller to easily connect to the transmitter meaning either a controller will have to be built or a microcontroller will be connected to the transmitter. The range of this transmitter receiver pair is about 1262 feet without any obstructions. The voltage range for the transmitter and receiver are both 1.9-3.6 volts which is supported directly by most microcontrollers and easily powered by a one cell LIPO battery. The data rate is variable between three options. The lowest data rate available is 250 kbps and the highest data rate is 2Mbps. Depending on how much data needs to be transmitted either the lower or the higher data rate can be selected but will use more current at the higher data rate. The transmitter uses 11.3 milliamps and the receiver uses 13.5 milliamps both at 2Mbps. When in standby both transmitter and receiver use only 26 micro amps. The module includes an interrupt request pin which can be used to wake the host microcontroller from sleep when the module receives a transmission providing great power conservation in battery devices. Both the transmitter and receiver measure in at 1.1 x 0.6 x 0.5 inches and with a combined weight weigh 0.3 ounces.

3.8.3 315 MHz RF transmitter and receiver

This Transmitter Receiver pair uses a radio frequency of 315 MHz to wirelessly send and receive data. This transmitter receiver is sold without a controller to easily connect to the transmitter meaning either a controller will have to be built or a microcontroller will be connected to the transmitter. The range of this transmitter receiver pair is about 30 – 150 feet without any obstructions. This short range is due to the radio frequency band it uses and most likely will not be able to transmit very well or at all through walls and obstacles.

The voltage range for the receiver is 3.3 – 6 volts. The more voltage applied up to 6 volts will increase the receiving power. The input voltage for the transmitter and receiver is 3.3-12 volts. The higher the input voltage up to 12 volts for the transmitter and receiver the further the data can be transmitted and received. The transmitter uses 4 pins. One pin for the ground, one pin for power, one pin for obtaining data from an input and one pin for transmitting the data to the receiver. The receiver has three pins. One pin for ground, one pin for input power and one pin for receiving data. The transmitter and receiver have a working current of 4 milliamps. The transmission power is 10mW. The transmission speed is 4 kbps. This slow transmission speed is a characteristic that has the ability to greatly inhibit the functionality of this transmitter receiver pair. If the data transfer rate is too slow the vehicle will not receive the data in time to react to the command given by the transmitter and will cause the vehicle to stutter and have poor controllability. The price for this pair is only $6.69 .the transmitter and receiver measures 30 x 14 x 7 mm each.

3.8.4 Spektrum DSM2 AR6200 6 Channel Receiver

This component is a 6 Channel DSM2 2.4 GHz Receiver that is used with remote control devices such as remote control cars, airplanes, helicopters and boats. This receiver is a spektrum brand. Since this receiver is used only with remote control devices and it is spektrum brand it can work with a spektrum transmitter module that also uses DSM2. The spektrum transmitter and receiver are bound to one another by simply shorting the signal pin labeled batt/bind on the receiver and then using a remote control that has the spektrum transmitter in it to locate the receiver. The Spektrum transmitter module costs usually around $50-$75. DSM2 is based on CDMA (code division multiple access. This means that the signal is spread out over a wider frequency and that each transmitter/receiver pair uses its own coding scheme for the signal. This is meant so that even if two stations are transmitting on the same frequency the respective signals can be isolated by the receivers. The Spektrum module transmitter is directly plugged into a remote control. The remote controller is sometimes but not always sold separately. The range of the receiver is around 10,000-15,000 feet but can be extended slightly depending if the user plugs a range booster into the receiver. This receiver also features a failsafe that is activated when connection with the transmitter is lost. What this failsafe entails is that a PWM of a certain value is sent by the receiver to the microcontroller that can then be mapped to perform a certain action. For the vehicle this failsafe will stop the motors so that the vehicle does not collide with any obstacles and cause potential damage. There are 6 channels on this receiver which means that up to 6 different signal lines can be sent to the microcontroller. This means no more and no less than 6 different values will be transmitted to the microcontroller. In normal remote control devices the receiver would be connected directly to motors and servos and directly control them but for the vehicles system those same signal wires that would normally go to motors and servos will be plugged into input/output pins on the microcontroller. These signal wires will be able to feed data to the microcontroller and then be mapped to control the electronic speed controllers that will drive the motors as well as any other components that need to be controlled. The dimensions of this receiver is 1.19 x 1.03 x 0.48 inches and weighs 0.35

ounces. The price of this receiver is $79. The input voltage for the Spektrum DSM2 AR6200 6 channel receiver is 9-12.6 volts.

3.8.5 Spektrum DSM2 AR400 4Channel Receiver

This component is a 4 Channel DSM2 2.4 GHz Receiver that is used with remote control devices such as remote control cars, airplanes, helicopters and boats. This receiver is a spektrum brand. Since this receiver is used only with remote control devices and it is spektrum brand it can work with a spektrum transmitter module that also uses DSM2. The spektrum transmitter and receiver are bound to one another by simply shorting the signal pin labeled batt/bind on the receiver and then using a remote control that has the spektrum transmitter in it to locate the receiver. The Spektrum transmitter module costs usually around $50-$75. The range of the receiver is around 10,000-15,000feet but can be extended slightly depending if the user plugs a range booster into the receiver. There are 4 channels on this receiver which means that up to 4 different signal lines can be sent to the microcontroller. This means no more and no less than 4 different values will be transmitted to the microcontroller. In normal remote control devices the receiver would be connected directly to motors and servos and directly control them but for the vehicles system those same signal wires that would normally go to motors and servos will be plugged into input/output pins on the microcontroller. These signal wires will be able to feed data to the microcontroller and then be mapped to control the electronic speed controllers that will drive the motors as well as any other components that need to be controlled. This receiver also features a failsafe that is activated when connection with the transmitter is lost. What this failsafe entails is that a PWM of a certain value is sent by the receiver to the microcontroller that can then be mapped to perform a certain action. For the vehicle this failsafe will stop the motors so that the vehicle does not collide with any obstacles and cause potential damage. The dimensions of this receiver is 1.2 x .7 x 0.4 inches and weighs 0.2 ounces. The price for this Spektrum Ar400 DSM2 receiver is $29.99. the input voltage for the Spektrum Ar400 DSM2 4 channel receiver is 9-12.6 volts.

3.8.6 Orange Rx R615X DSM2/DSMX 6CH 2.4 GHz Receiver

This component is a 6 Channel DSM2/DSMX 2.4 GHz Receiver that is used with remote control devices such as remote control cars, airplanes, helicopters and boats. This Receiver is compatible with all DSM2/DSMX 2.4 GHz Air transmitters. This receiver features both the DSM2 and the DSMX modulations. In section 3.8.4 DSM2 was explained that it is a certain type of modulation that the signal is encoded with and for DSMX the same thing applies. Certain transmitters use DSM2 or DSMX and some use both. This particular receiver will work with any transmitter which makes this receiver a perfect candidate for the vehicle since any transmitter will work regardless of the type of modulation the transmitter uses. This receiver also features a failsafe that is activated when connection with the transmitter is lost. What this failsafe entails is that a PWM of a certain value is sent by the receiver to the microcontroller that can then be mapped to perform a certain action. For the vehicle this failsafe will stop the motors so that the vehicle does not collide with any obstacles and cause potential damage. There are 6 channels on this receiver which means that up to 6 different signal lines can be sent to the microcontroller. This means no more and no less than 6 different values will be transmitted to the microcontroller. This receiver is bounded to the transmitter the same way as every other remote control receiver and transmitter which allows each connection. The dimensions of this receiver is 19.5 x 30 x 10mm without the case and 43 x 22 x 13mm with the protective case that comes with the receiver board when purchased. The receiver weighs 3.7 grams without the protective case and 9.8 grams with the protective case. The range for this receiver is about 10,000- 14,000 feet. The voltage input for the orange R615X 6 channel receiver is 3.7-9.6 volts.

3.8.7 Lemon Rx DSM2 8 Channel Receiver

This component is an 8 Channel DSM2 2.4 GHz Receiver that is used with remote control devices such as remote control cars, airplanes, helicopters and boats. This Receiver is compatible with all DSM2 transmitter modules. The DSMA2 transmitter and receiver are bound to one another by simply shorting the signal pin labeled batt/bind on the receiver and then using a remote control that has the transmitter in it to locate the receiver. There are 8 channels on this receiver which means that up to 8 different signal lines can be sent to the microcontroller. This means no more than 8 different values will be transmitted to the microcontroller. These values transmitted to the microcontroller can then be mapped through coding to control the motors to go forwards, backwards and stop the motors using pulse width modulation. With this receiver having 8 channels at its disposal the amount of functionality available is more than that of most other receivers that have 4 or 6 channels to use. The range of the receiver is around 9,000-12,000feet but can be extended slightly depending if the user plugs a range booster into the receiver. The input voltage for the 8 channel lemon receiver is 3.45-7.2 volts. The dimensions for the lemon receiver weighs 25 x 18 x 11mm. The lemon receiver weighs 12 grams. This receiver also features a failsafe that is activated when connection with the transmitter is lost. What this failsafe entails is that a PWM of a certain value is sent by the receiver to the microcontroller that can then be mapped to perform a certain action. For the vehicle this failsafe will stop the motors so that the vehicle does not collide with any obstacles and cause potential damage. The 8 channel Lemon receiver costs $16.50

3.8.8 Transmitter/Receiver Comparison Chart

A chart is used to compare all transmitter/receiver pairs researched in a way that makes it easy to make the best choice when deciding on the best pair for the vehicle. The chart below in figure 3.8.8 displays the model name, the frequency, the range in feet, the receiver voltage, the transmitter voltage, failsafe and the price. When comparing transmitter/receiver pairs the frequency at which the two components communicate is an important characteristic. The frequency usually depicts how long of a range the transmitter/receiver pair can communicate with one another. If the range is too short then the human operator will lose control of the vehicle and therefor lead to causing possible damage to the vehicle. The receiver voltage will be a factor that must be included in the vehicles power system and integrated correctly. The transmitter voltage will be powered by the remote control and therefor is not an important factor because it is a completely separate power system that will not affect the vehicle directly or indirectly. A failsafe is quite an important characteristic for a transmitter/receiver pair to have. This gives peace of mind to the human operator. With a failsafe in place if connection is lost from the transmitter the receiver will send a pulse width modulation that will be coded to stop the motors and safely allow the vehicle to stay in place until the connection is regained. The price for the transmitter/receiver pair will most likely be one of the more expensive costs for the vehicles design.

Model Name	Frequency	Range (Feet)	Receiver Voltage (Volts)	Transmitter voltage (Volts)	Failsafe	Price
433 MHz RF Transmitter Module Receiver Module	433MHz	100	3.3-6	3-12	NO	$17.22
2pcs nRF24L01+ 2.4GHz Wireless Transceiver	2.4GHz	262	1.9-3.6	1.9-3.6	NO	$6.48
315 MHz RF transmitter and receiver	315 MHz	30-150	3.3-12	3.3-12	NO	$6.69

DSM2 AR6200 6Channel Receiver	2.4 GHz DSM2	10,000-15,000	3.5-9.6	9-12.6	YES	Receiver: $79.99 Transmitter:$50.00
DSM2 AR400 4Channel Receiver	2.4 GHz DSM2	10,000-15,000	3.5-9.6	9-12.6	YES	Receiver: $29.99 Transmitter: $50.00
Orange Rx R615X DSM2/DSMX 6CH 2.4 GHz Receiver	2.4 GHz DSM2/DSMX	10,000-14,000	3.7-9.6	9-12.6	YES	Receiver: $15.00 Transmitter: $50.00
Lemon Rx DSM2 8 channel receiver	2.4 GHz DSM2	9,000-12,000	3.45-7.2	9-12.6	YES	Receiver: $16.50 Transmitter: $50.00

Fig. 3.8.8: Transmitter Receiver Comparison Chart

3.9 Proximity Sensors

Effectively finding a route through a building without collisions is one of the most essential functions the vehicle must achieve. To meet this need the team assessed multiple methods of object detection to find the one that will provide the highest accuracy and functionality while still considering cost. Some methods discussed include RADAR, Ultrasonic, IR and computer imaging. The team decided after comparing the Pros and Cons of each and decided on Ultrasonic Waves as the method that will be used to navigate the vehicle as well as avoid any obstacles that may obstruct the path the vehicle takes. Ultrasonic waves are safe to use, accurate, and offered from a variety of companies as well as a wide range models for different applications. Other methods could be more effective but for the budget and time constraints the Ultrasonic Wave method is the most applicable choice. Locating a fire source is essential for our vehicles goal to be achieved.

The group discussed a few possible methods to locate a fire source accurately. Infrared and Image processing are the two methods that are the most applicable among other methods. The team decided after weighing the pro and cons that infrared would be the best choice to accurately find a fire source. An infrared sensor can accurately filter out all other light waves except those of a flame with a sufficient reading angle. The infrared sensor method is quite cheap compared to the cost of using image processing as well as lighter on software which results in an overall better choice.

3.9.1 Infrared

An infrared sensor is a type of sensor that either emits or receives infrared light. In the case of this project, an infrared sensor receiver will be used. Infrared waves range from 700 nanometers to 1,000,000 nanometers. The IR module that the team will use to effectively achieve that goal of finding the fire will have to be able to filter out all of the light waves except for that of that flame. The range of a flame that the sensor will pick up on is between 700 nanometers and 1100 nanometers. Detecting a flame is necessary for this project or else putting out the flame will be impossible. The method of using an IR module is the method the team chose, because the team found it was a better choice than using image processing. The specific sensor that is used needs to have a tuning application to it so that it can be adjusted properly. The module itself is fast because it is an analog device that only has to filter out all of the waves that are less than 700 nanometers and above 1100 nanometers. The receiving angle of the IR module needs to be small to medium, or about five degrees to thirty degrees. Since it is hard wired, it is almost instantaneous, which can be used in a real time reading so that the vehicle does not miss the flame. This is important because the goal is to detect and extinguish the flame in as little amount of time as possible. This method chosen is very light in coding compared to that of image processing, because the output of this module is an analog signal instead of a digital signal. When coding for a digital input such as a camera, a program such as MATLAB would have to be used to handle the image processing. Whereas any simple microcontroller program, for example Arduino IDE or Texas Instruments platforms can easily by themselves read an analog input, therefore it will be less coding, faster and cheaper since a cheaper microcontroller will be able to handle an analog input compared to a digital input. One the most important reasons to choose an IR module is the cost effectiveness. For the price of one of these sensors, which is normally less than twenty dollars, much can be accomplished. This is a more viable option than purchasing an infrared camera, which starts out at fifty dollars, but can increase much higher for a precise one. The IR module that is used needs to pull less than 40 milliamps. This is because most microcontrollers will only supply 40 milliamps per input output pin. The IR module also needs to be less than five volts for the same reason as only using 40 milliamps. Some cons of the IR module include the accuracy of the range, where it can be used and the beam width. Unfortunately the IR module is not extremely accurate on how far the source is away from the sensor. IR modules also cannot be used in the sunlight because there is a high change that the sunlight will interfere with the sensor. This would cause the vehicle to malfunction. The team is choosing to do testing inside a building, where no sunlight can interfere with the flame. Another significant con is the width of the beam. The IR module tends to have a narrow beam width. This is only a con for part of the testing. When finding the flame, the beam width needs to be slightly bigger, so the vehicle can detect it before locating it precisely. Once the flame is detected, that is when a narrow beam width is needed.

3.9.1.1 ElecFreaks E00397 Flame Sensor

The ElecFreaks E00397 is an infrared flame detection sensor. This model has an effective operating voltage of five volts and a working current pull of five milliamps. These constraints are sufficient for almost every microcontroller because most input output pins have a max output current of forty milliamps and a max output voltage of five volts. This sensor is fast, has a high sensitivity and an extensive lifetime. The operating temperature is between negative twenty five degrees and eighty five degrees. Refer to Fig 3.9.1.8 for more information on the specific sensor.

3.9.1.2 acc-175

The acc-175 is an IR flame sensor module detector for temperature detecting. The model has an effective operation voltage of three to five volts and a working current pull of two milliamps. These constraints are sufficient for almost every microcontroller because most input output pins have a max output current of forty milliamps and a max output voltage of five volts. This IR module can detect a flame between the wavelength of 700 nanometers and 1100 nanometers. The angle of detection is sixty degrees. This particular IR module has a potentiometer adjustment. This is used to adjust the tuning of the wavelengths. It helps with the accuracy of detecting a flame. This IR module has four pins: one for VCC, one for ground and two for input output. This IR module has 3 pins, only one of them is an input output pin. This means that it will use pull less current than those of other models that have two input output pins. This also leaves more available pins in the microcontroller. Refer to Fig 3.9.1.8 for more information on the specific sensor.

3.9.1.3 MLX90614 STM32F030F4P6

The MLX90614 STM32F030F4P6 is an infrared close temperature sensor module. This model has an effective operation voltage of five volts and a working current pull of two milliamps. These constraints are sufficient for almost every microcontroller because most input output pins have a max output current of forty milliamps and a max output voltage of five volts. The range of temperature of the sensors is between -40 degrees to 125 degrees Celsius. Refer to Fig 3.9.1.8 for more information on the specific sensor.

3.9.1.4 Phantom YoYo B00AFSEC2Y

The Phantom YoYo B00AFSEC2Y is a mini flame sensor. This model has an effective operation voltage of 4.5 volts and a working current pull of five milliamps. These constraints are sufficient for almost every microcontroller because most input output pins have a max output current of forty milliamps and a max output voltage of five volts. The wavelength range is between 760 nanometers and 1100 nanometers. Refer to Fig 3.9.1.8 for more information on the specific sensor.

3.9.1.5 SainSmart B00K8PLGMI

The SainSmart B00K8PLGMI is an infrared flame detection sensor module detect fire flame sensor. This model has an effective operation voltage of 3.3-5 volts and a working current pull of three milliamps. These constraints are sufficient for almost every microcontroller because most input output pins have a max output current of forty milliamps and a max output voltage of five volts. Refer to Fig 3.9.1.8 for more information on the specific sensor.

3.9.1.6 Grove SEN05082P

The Grove SEN05082P is an infrared flame sensor. This model has an effective operation voltage of 4.75-5.3 volts and a working current pull of twenty milliamps. These constraints are sufficient for almost every microcontroller because most input output pins have a max output current of forty milliamps and a max output voltage of five volts. The wavelengths range between 760 nanometers and 1100 nanometers. Refer to Fig 3.9.1.8 for more information on the specific sensor.

3.9.1.7 HYCG01

The HYCG01 is an infrared flame sensor. This model has an effective operation voltage of five volts and a working current pull of ten milliamps. These constraints are sufficient for almost every microcontroller because most input output pins have a max output current of forty milliamps and a max output voltage of five volts. The wavelengths range between 760 nanometers and 1100 nanometers. Refer to Fig 3.9.1.8 for more information on the specific sensor.

3.9.1.8 Flame Sensor Comparison Chart

A chart is used to compare all of the flame sensors researched in a way that makes it easy to make the best choice when deciding on the best motor controller for the vehicle. The chart below in figure 3.9.1.8 displays the model name, the voltage, the maximum current output in Amps, the cost, the I/O pins and the angle. The voltage is an important characteristic because power consumption is vital to any electrical system, especially an autonomous system that relies solely on non-human input. If voltage consumption is too high, the battery life will be shortened and therefore results in a shorter operating time. If there is more battery lifetime, this creates more time for the vehicle to achieve the goal of fire suppression. The max current rating is important to know because the flame sensor selection is partially based off of the max current that the sensor pulls. The I/O pins are very important because the fewer number of pins, the better. This will save a lot of room on the final printed circuit board. There will be more pins that can be used for something else. The price column may not be a huge factor for some but for this project the budget is a main factor when making all decisions and will help decide on major components used. The angle is also important because the range has to be great enough to detect a flame, but also not too large. If the angle is too large, more than one sensor will pick it up and could mess up the code. Refer to figure 3.9.1.8 for the complete details of all of the infrared flame sensors compared.

Type	Voltage	Current	Cost	I/O Pins	Angle
ElecFreaks E00397	5V	5mA	$6.81	1	60
acc-175	3-5V	10mA	$6.99	2	60
MLX90614 STM32F030F4P 6	5V	2mA	$17.99	4	60
B00AFSEC2Y	4.5V	5mA	$4.99	2	60
B00K8PLGMI	3.3-5V	3mA	$3.20	2	60
SEN05082P	4.75-5.3V	20mA	$6.90	2	N/A
HYCG01	5V	10mA	$8.70	2	60

Figure 3.9.1.8: Comparison Chart for Flame Sensors

3.9.2 Ultrasonic Sensors

Ultrasonic Sensors use sound propagation with frequencies that range from the peak of human hearing at 20 kilohertz up to several gigahertz. Ultrasonic Sensors prove to be more accurate of distance than infrared sensors. Sound waves will always be able to detect an object regardless of the shape or type of coating the object may have such a metallic or mirror coating that may affect infrared sensors. Sound wave effectiveness is not diminished due to vibrations or other external sources such as light, temperature or infrared radiation. The response time to objects and navigations are mainly contributed to the ultrasonic sensors. SONAR emits what is called an echo sound that propagates through the air from an initial direction. Once the sound wave bounces off an object back towards the trigger sensor that listens for reflected sound waves. Using the echo and trigger sensors the ultrasonic sensor module can determine the distance of an object by using the speed of sound and the time that it took the sound wave to be sent from the SONAR and received by the TRIGGER. This method presents the ability to get an almost instantaneous response to an object. The way the code is written will most likely determine how quickly an object can be detected as long as an ultrasonic sensor with the corrected specifications is chosen. The cons to using an Ultrasonic Sensor as the object detection system are the possibility of what is known as a 'ghost echo'. A ghost echo is a sound wave that is received after reflecting off of multiple surfaces before the TRIGGER sensor receives the initial echo sent by the SONAR. This can be thought of as the same scenario as pointing a laser pointer at an ---array of mirrors that reflect the initial light from the laser pointer off of different mirrors until the final mirror reflects the light to a non-reflective surface. The difference between sound waves and light is that sound waves treat most everything as a reflective surface. In addition, sound absorbing objects such as sound dampening pads can disrupt the original echo from the SONAR and give the TRIGGER an inaccurate reading which can result in the vehicle crashing. These two shortcomings of sound waves will be avoided during testing.

3.9.2.1 Ultrasonic Ranging Module HC - SR04

HC - SR04 is a long range ultrasonic proximity signal. This module uses an analog output pulse width modulation (PWM) along with digital serial signals. The HC-SR04 uses 4 pins; a 5v, ground, trigger and echo pin. This particular module has an effective operating voltage of 5 volts and a working current pull of 15 milliamps which is sufficient for almost any microcontroller since most I/O pins have a max current output of approximately 40 milliamps. The working frequency is 40 kilohertz; once the echo pin is activated the module automatically sends eight 40 kilohertz signals and detects whether there is a pulse signal back. The minimum range is 2 cm and the max range is 400 cm. The measuring angle is 30 degrees and the trigger input pulse width is 10 micro seconds. The dimensions for this module measures 45*20*15 mm. shown below in figure 3.9.2.1 a timing diagram shows the behavior of each pin on the ultrasonic sensor.

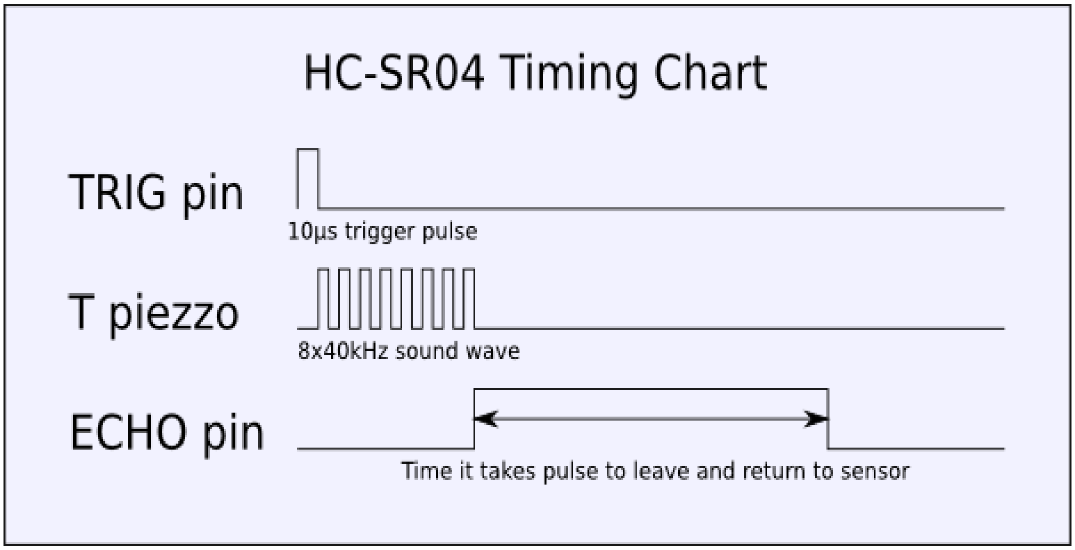


Fig 3.9.2.1 shows the timing chart for the HC-SR04 Ultrasonic Sensor.

3.9.2.2 SeeedStudio Ultrasonic Range Finder

SeeedStudio Ultrasonic Range finder is a long range ultrasonic proximity signal. This module uses an analog output pulse width modulation (PWM) along with digital serial signals. The SeeedStudio uses 4 pins; a 5v, ground, trigger and echo pin. This particular module has an effective operating voltage of 5 volts and a working current pull of 15 milliamps which is sufficient for almost any microcontroller since most I/O pins have a max current output of approximately 40 milliamps. The working frequency is 40 kilohertz. The minimum range is 3 cm and the max range is 400 cm. The measuring angle is 30 degrees and the trigger input pulse width is 10 micro seconds. The module dimensions are 43x20x15 mm.

3.9.2.3 Parallax PING Ultrasonic Sensor

Parallax PING Ultrasonic Sensor is a long range ultrasonic proximity signal. This module uses an analog output pulse width modulation (PWM) along with digital serial signals. The Parallax Ultrasonic sensor is slightly different than most other of its kind since it uses only three pins instead of four. The module uses a pin for 5v in, ground and only one I/O pin for both the trigger and the echo. Having only one I/O pin makes this sensor stand out from the rest as the microcontroller will have more free pins and possibly less current will be pulled. The Parallax module has an effective operating voltage of 5 volts and a working current pull of 30 milliamps which is sufficient for almost any microcontroller since most I/O pins have a max current output of approximately 40 milliamps. The working frequency is 40 kilohertz. The minimum range is 2 cm and the max range is 330 cm. The measuring angle is 45 degrees and the trigger input pulse width is 2 micro seconds at the smallest acceptable and typically recommended at 5 micro seconds. It is listed from the company's website that the percent error of this module is the magnitude of 11 to 12 percent. The module dimensions are 0.84 in x 1.8 in x 0.6 in. It is noted that this device takes up to 200 micro seconds between pulses. Shown in figure 3.9.2.3 below the pin connection and the basic concept of out an ultrasonic sensor operates can be seen.

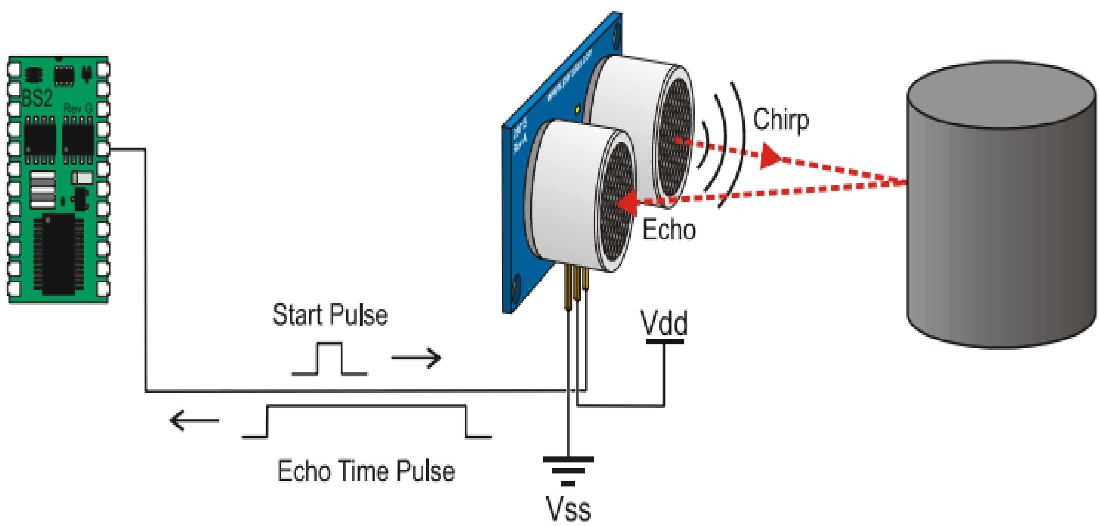


Fig. 3.9.2.3 (note most Ultrasonic sensors use 4 pins while the Parallax uses only 3 and chirp is usually called trigger from this diagram)(approval pending)

3.9.2.4 Devantech SRF05 Ultrasonic Range Finder

Devantech SRF05 Ultrasonic Range finder is a long range ultrasonic proximity signal. This module uses an analog output pulse width modulation (PWM) along with digital serial signals. The Devantech uses 4 pins; a 5v, ground, trigger and echo pin. This particular module has an effective operating voltage of 5 volts and a working current pull of 4 milliamps which is sufficient for almost any microcontroller since most I/O pins have a max current output of approximately 40 milliamps. The working frequency is 40 kilohertz. The minimum range is 3 cm and the max range is 400 cm. The measuring angle is 30 degrees and the trigger input pulse width is 10 micro seconds. The module dimensions are 43x20x17 mm. it is noted that this devive takes 700 micro seconds between pules.

3.9.2.5 Maxbotix LV-EZ1 Mb1010

Maxbotix LV-EZ1 Mb1010 is a long range ultrasonic proximity signal. This module uses an analog output pulse width modulation (PWM) along with digital serial signals. The Maxbotix module has an effective operating voltage of 2.5-5.5 volts and a working current pull of 2 milliamps which is sufficient for almost any microcontroller since most I/O pins have a max current output of approximately 40 milliamps. The working frequency is 42 kilohertz. The minimum range is 0 cm and the max range is 6.45 m but even though objects are detected at 0 cm this module will output a value of 6 inches for any objects that appear in the field of view from 0 to 6 inches. Instead of an angle field of view this device uses a narrow beam instead. The trigger input pulse width is 10 micro seconds. The module dimensions are 2.2 x 2.0 x 1.6 cm. it is noted that this device takes 50 milliseconds between pulses which is quite longer than most ultrasonic sensors this module also uses 7 pins, one Vcc, one Ground, one TX, one RX, one PW, one BW and one AN.

3.9.2.6 DFRobot URM04 v2.0

DFRobot URM04 v2.0 is a long range ultrasonic proximity signal. This module uses an analog output pulse width modulation (PWM) along with digital serial signals. This module has an operating voltage of 5 volts and a working current pull of 20 milliamps which is sufficient for almost any microcontroller since most I/O pins have a max current output of approximately 40 milliamps. The working frequency is 40 kilohertz. The minimum range is 4 cm and the max range is 500 cm. The measuring angle is 30 degrees and the trigger input pulse width is 10 micro seconds. The module dimensions are 34mm × 51 mm 16 mm.

3.9.2.7 GH-311

GH-311 is a long range ultrasonic proximity signal. This module uses an analog output pulse width modulation (PWM) along with digital serial signals. This module has an operating voltage of 6-12 volts and a working current pull of 2 milliamps which is sufficient for almost any microcontroller since most I/O pins have a max current output of approximately 40 milliamps. The working frequency is 40 kilohertz. The minimum range is 0.2 cm and the max range is 800 cm. The measuring angle is 15 degrees and the trigger input pulse width is 10 micro seconds. This module uses only three pins instead of four. The module uses a pin for Vcc, ground and only one I/O pin for both the trigger and the echo. Having only one I/O pin makes this sensor stand out from the rest as the microcontroller will have more free pins and possibly less current will be pulled.

3.9.2.8 Data Chart for Ultrasonic Sensors

A chart is used to compare all ultrasonic sensors researched in a way that makes it easy to make the best choice when deciding on the best ultrasonic sensor for the vehicle. The chart below in figure 3.9.2.5 displays the device’s name, Operating voltage in volts, current consumption in milliamps, the minimum distance the sensors can read, the max distance the sensors can read, the measuring angle in degrees, the working frequency, the number of input/output pins the sensor uses, the delay time the sensor takes between readings and the cost per sensor. Operating voltage is important for any sensor used because most likely they power will be provided by the microcontroller. If the voltage is higher than the voltage that can be outputted by the microcontroller then a different power source will have to be used like a linear or switching regulator. Current consumption directly puts strain on the microcontroller. The current absolutely must be within the output current of the output pins on the microcontroller. If the minimum distance read by the ultrasonic sensor is not short enough then the vehicle will most likely collide with objects. Max distance will most likely not be an issue between the sensors because the tests that will be conducted will be done in a small area and will not need long distances. If the measuring angle is too large then distinguishing between front, left and right will be difficult or impossible. The number of input/output pins used is a strain on resources the microcontroller has to offer. If too many pins are used by the sensor there will not be enough open pins for other needed components, as well as the amount of current that will be used. The time delay is not always listed on data sheets for ultrasonic sensors. If this specification is listed it is very important. If a sensor takes too long to between distance readings the vehicle may collide with an obstacle because there was not enough time for the vehicle to adjust its path. Lastly the price column may not be a huge factor for some but for this project the budget is a main factor when making all decisions and will help decide on major components used. Refer to Chart 3.9.2.5 below for a detailed comparison between each ultrasonic sensor researched.

Device Name	**Operating Voltage (V)**	**Current Consumption (mA)**	**Distance Min (cm)**	**Distance Max (cm)**	**Measuring angle in degrees**	**Working Frequency (KHz)**	**# of I/0 pins used**	**Cost per sensor**	**Delay time if found**
HC - SR04	5	15	2	400	30	40	2	$10	N/A
Seeed Studio	5	15	3	400	30	40	2	$15	N/A
Parallax	5	30	2	330	45	40	1	$25	200 µs
Devantech SRF05	5	4	3	400	30	40	2	$22	700 µs

Maxbotix LV-EZ1 Mb1010	2.5-5.5	2	15.24	645.16	N/A Uses a narrow beam configuration	42	5	$29.95	50 ms
DFRobot URM04 v2.0	5	20	4	500	30	40	2	$19.95	N/A
GH-311	6-12	2	.2	300	15	40	1	$14.98	N/A

Table 3.9.2.5: Comparison of Ultrasonic Sensors

3.10 Algorithm Development

This section will provide a rough overview for the proposed method of autonomous navigation that will be used in the robot's design. Ideally, the robot would be optimized using a mathematical that would relate the robot's position to desired position and translate this error to a voltage level to control the amount of torque of each motor individually. Because the scope of this project does not include visual based servoing techniques or any other non-linear control theory, most of the gains and control algorithms will have to be developed utilizing pre-defined libraries and empirical data. This section then, will not necessarily use system identification to create a feed-forward model of the robot, but rather provide the tools and techniques necessary to properly tune the robot to desired specifications. In this instance, the differential equations governing the internal workings of the motors and motor controllers relating to the position and angle of the robot will be treated as a black box. Instead, focus will be placed on controlling the rate of error correction and reduction of steady state error, much like a PID controller. Of course, a physical PID controller is not going to be used in this project, but rather emulated through software techniques.

This section, will also explore various software techniques for "smoothing" error adjustments as well as strict steady-state error correction. Before all this though, it is necessary to also investigate the communication protocol of each sensor and how these will be addressed by the MCU at the software level. To know what type of protocol to use, it is also necessary to first choose a design environment. Based on the heavy reliance of library needs from this project as well as the use of an Atmel microcontroller, it makes sense to start by prototyping and testing this design using the Arduino IDE. Of course, in the final design an Arduino will not be used, but the design environment is very conducive to high level embedded application programming. This makes the Arduino IDE the best candidate for initial investigation into algorithm development.

3.10.1 Peripheral IO Interfacing

This section will define everything connected to the microcontroller input/output pins as peripheral IO. This includes the motor controller(s), flame sensors, and ultrasonic distance sensors. At this time, it is still unknown exactly which control scheme will be used for the motor controller (i.e. motor shield, electronic speed controllers, etc.) so in this section, it will be assumed that they will receive a PWM value between 0-255 corresponding to no movement, up to its max speed. This can easily be achieved in the design environment with the command analogWrite(X,Y). Where in this case, X is the pin desired to be written to a value of Y. Y in this example is of course not really an analog value, but a value generated through PWM to emulate an analog value (especially when filtered by a capacitor) between 0-5 volts.

It is assumed that the motor control scheme will only take up to outputs as there will most likely only be two motors. Making this assumption it can be shown that to turn the vehicle right, some value would have to be commanded to the left side, while leaving the right side at zero. It may be found during testing, that the right side may have to traverse slightly to decrease the amount of friction from the wheel rotating in place. If this is the case, this will be dealt with during testing. Using this basic approach, it is possible to write functions that include “noTurn” (equal speed to each side), “turnRight” (more speed/all speed on left side), and its contrapositive “turnLeft” (more speed/all speed on right side). These will be the primary function mechanics used during every loop iteration of the main code that will be decided based on the state of the sensors. Each of these navigation functions defined above will be continued for a predetermined amount of time (determined through testing to dampen overshoot and turn at reasonable rate), after which the sensors will determine which navigation function to take next.

Communicating with the two or three ultrasonic sensors at this point may be the most cumbersome as far as amount of IO needed. This is because each ultrasonic sensor chosen uses one digital pin to send a pulse, creating a “chirp” from a speaker and a second pin returns a pulse when a filtered microphone receives that chirp’s reflection. The timing between these events will be used to calculate a distance using a custom open-source library entitled “NewPing”. As described above, this distance will be used to make a decision based off of which sensor senses an obstacle. For example, if there is an obstacle detected ahead, but nothing detected (or something far) to the right, the robot will use the “turnRight” function defined above. It will continue pinging and turning, until it detects nothing on the front sensor and will then continue forward. Later in this section it will be shown why there is no need to have a sensor on the left in this application when the “right-hand search” method is explored. The problem then becomes apparent that each ultrasonic sensor will then need two data lines, equating to at least 4 IO pins (minimal case only utilizing 2 sensors). It may be possible though to “daisy chain” the ping lines together, but keep the echo lines separate. This means that each time the ping function is called, both pins will return a value, but only one of these values would be used. In this case it would be helpful to write a ping function that passes a parameter in to decide which pin contains the valid data. An example would look something like this: “ping(right)” would ping both sensors of course, but would only use the data from the IO pin corresponding to the right sensor’s echo line. The other side of this would be the function “ping(front)” which would again ping both sensors, but only poll data from the IO pin corresponding to the echo line of the sensor on the front of the device. This daisy chain would free up IO real estate on the MCU. An example of the wiring is given in the figure below. Although the figure below is the simplified example using only two sensors, this configuration is scalable to more and will reduce the amount of pins necessary by 2*N-(N+1), where N is the number of sensors used. Refer to the picture below for an explained wiring configuration.

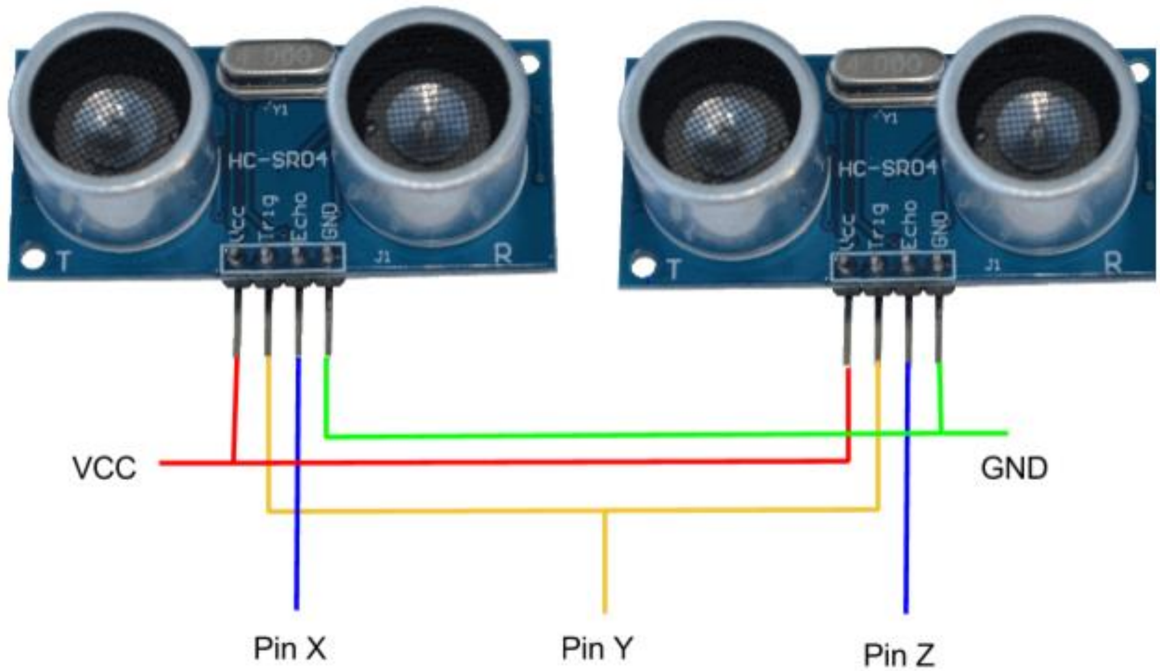


Figure 4.6.1.1: Wiring configuration explained above to optimize code and MCU IO space. This figure is not meant to explain the mechanical configuration of these sensors or even the wiring. The figure is being used to show that the amount of pins necessary can be reduced, which in turn affects the complexity of the algorithm as well.

The next peripheral communication section is the interface with the flame sensors. As noted before (not including power and ground) the flame sensors will each take up 1 IO pin on the MCU. These sensors will be individually read into the microcontroller using the “analogRead” function, which will place their values between 0 and 255. These values correspond to the likelihood (and distance) of a flame present, where 255 corresponds to a small flame that is close or a large flame at a distance. The differentiation between the two will be made by a number of sensors (between 5 and 7) that are place at regular angular offsets from each other. If multiple sensors are reading a very high value, it is more likely that the flame is large as it is seen by a wide field of view. On the other hand, if only one sensor is outputting a high value consistently, it is more likely that this is a small flame that is close. In the scope of this project, testing will be done with a small tea-candle sized flame, so this will be the only case of interest. Each sensor value will be read with each iteration of the main loop of code. In most cases the sensor values will be constant (possibly not zero depending on calibration) and will not affect the direction of the vehicle. In some cases however, when there is a flame within view of the robot, the detection of the flame will interrupt the main maze algorithm and start the flame-seeking subroutine. This subroutine will be explained in detail in a later section, but will be explained now from a high level perspective.

Once a flame has been detected and the robot is no longer operating in the maze-solving algorithm, the code will drive the motor opposite the side that the flame is detected from until the center flame detector reads the highest level. When the center flame detector reads the highest level, this indicates that the flame is directly in front of the robot and it will continue straight until an empirical threshold level is met. This value will be obtained by holding the target flame a set distance away and recording the value shown by the sensor to create a “stop” threshold. At this point the final communication peripheral (fire suppression) will take over and complete the task.

The final piece of peripheral communication from the MCU is the fire suppression unit. This portion of the communication will only be initiated from the “flame detected” subroutine as this is the only time that this system is needed. As described above, the distance at which the robot stops will be derived empirically through the center flame sensor value and the max distance the fire suppression unit can properly extinguish a flame. Once this empirical threshold has been reached during the flame detected subroutine, the motors will stop, and a simple “digitalWrite(HIGH)” command will be used to relay power through the fire suppression unit to stifle the fire. After a set amount of time, the flames sensors will quickly check for a flame, and if one is still found at the center, the robot will continue powering the suppression unit. In the case that no flame is found within the field of view, the robot will jump back into the maze solving algorithm and continue searching.

3.10.2 Right/Left-Hand Search

This technique is a common search strategy used by search professionals like firefighters and paramedics. The underlying concept to this technique is to pick a side, either left or right, and keep a hand on that wall as you walk through the “maze” or building until you find what you are looking for; in this case a flame and then an exit. The figure below shows the equivalence and effectiveness of both a left and right hand search. Refer to the picture below for a demonstrated right hand rule.

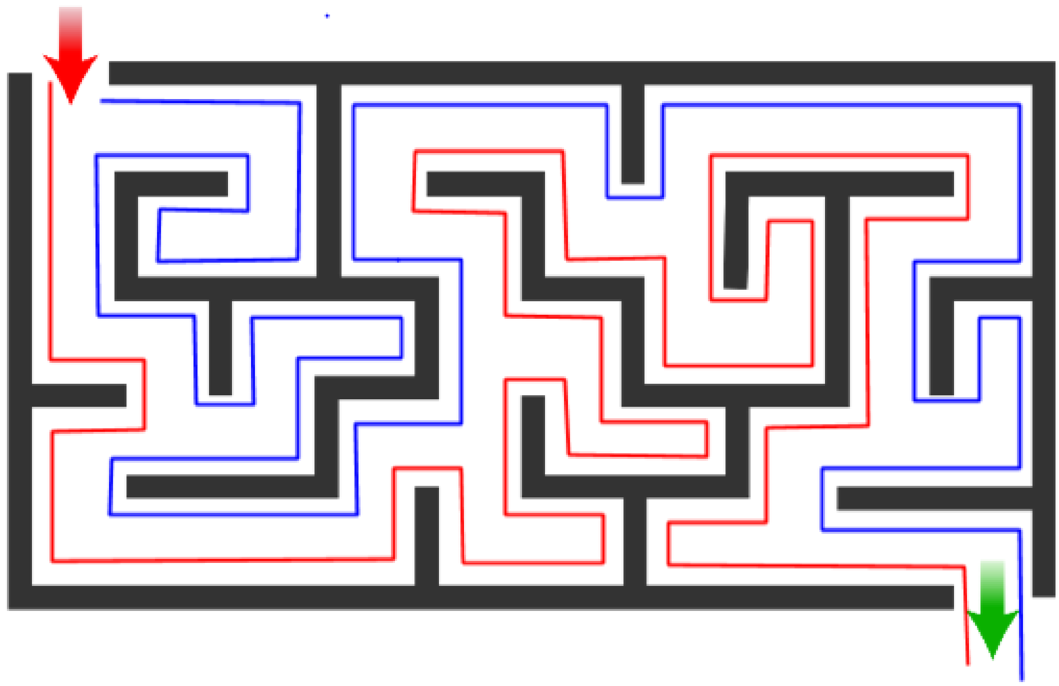


Figure 4.6.2.1: Right hand search demonstrated by red line and left hand search in blue.

The biggest rule to this search technique is that once a side is chosen (either left or right) it cannot be changed, or a risk of back-tracking is introduced. It should also be noted that this technique may need some modification if there is an “island” in the maze. What is meant by this is if the robot is searching a wall that has no other connections to the outside perimeter, it is possible that it could get stuck circling this one area. It should also be noted though, that the specifications for this design do not require a decision making loop for islands, as the test maze will not contain any.

3.10.3 Control Techniques

This section will be used to investigate various techniques used in software development to implement stable and precise feedback control. Although there will be no use of hardware (other than an MCU) to implement this control, the use of delay and smoothing algorithms will give similar effects to a PID controller. These techniques may not be as robust or fast as control obtained when using a dedicated hardware compensator, but they will allow this project to meet the specification requirement for budget. This section will not explore heavy control theory as there is no developed model of the plant, but instead will describe tuning tactics as an alternative to computed gain values.

The first method used will be a tuning for a constant velocity step to turn the robot. A balance will be determined between adjusting to desired position quickly, and adjusting to position without much overshoot. As mentioned before, these overshoot and rise-time values are not clearly specified by any requirements and will be left to engineering judgment during product development. Once the step velocity has been determined, a step duration will also be decided based on the maximum overshoot desired. Once again, this will be derived completely empirically and depends on many factors. The longer the step duration chosen, the smoother each turn could appear, but it also would provide the most overshoot of desired position. This is because the sensors will not be able to accurately read wall distance while the robot is performing a turn and will not notice the overshoot until it has already occurred. By compromising between these two factors, step duration will be obtained.

The next method will be used to improve data fidelity from the sensors. Although there may be hardware filtering in place (shunt capacitors), there can also be additional smoothing obtained through software. There are two main concepts that will be tested to determine which is more effective at correcting jittery data. These techniques will both be a form of averaging, both arithmetically (adding and dividing by the number of samples) and geometrically (multiplying and taking the "# of sample"th root). A certain number of readings will be stored in an array and each form of average will be taken. The averaging that results in the least amount of jittering at the full system level will be used in the code. Besides the type of averaging that will be used a decision will also have to be made about how many samples are to be averaged. This determination again will be decided using engineering judgment in a trade off between delay time and mechanical jitter.

A final method to decrease jittering will be the implementation in hysteresis during decision making. What is meant by this is that the code will essentially try to stay within a range of distances from the wall rather than adjusting every single time the distance changes in the slightest bit. These values will be based on the size of the robot as well as the size of the maze, and also the precision of wall following desired

3.11 Fire Suppression

As indicated previously in the specifications section, for demonstration purposes, our robot must be able to extinguish (or suppress) a tea-candle size flame. This could be accomplished in a number of ways including air displacement, chemical extinguishers, water, and physical smothering. Of course there are more ways to put a fire out, but for the sake of simplicity, these are the topics that will be explored in this section.

3.11.1 Air Displacement

The air displacement category will in this paper be grouped into 2 categories for ease of explanation. Much like direct current and alternating current, air displacement will be split into continuous pressure (like wind), and alternating pressure (acoustic in this case).

3.11.1.1 Continuous Pressure

This method could be accomplished in a number of ways. One proposed idea would be to have a solid flat fan-like structure (possibly a sheet of plastic) attached to the robot by a link on a servo. This fan could be lifted and lowered continuously to blow air onto the fire until it is extinguished. A more practical way of applying continuous pressure in order to extinguish a flame would be through the use of a small fan, similar to one you would find in a computer to cool the motherboard. The fan would be able to apply just enough pressure to the small flame to be able to extinguish it, and it is also not an extremely technical build. This is favorable when considering diagnostics in design as well as a working model. The fan could potentially be connected to a MOSFET to buffer the signal from the microcontroller into enough power to run this fan (see diagram below).

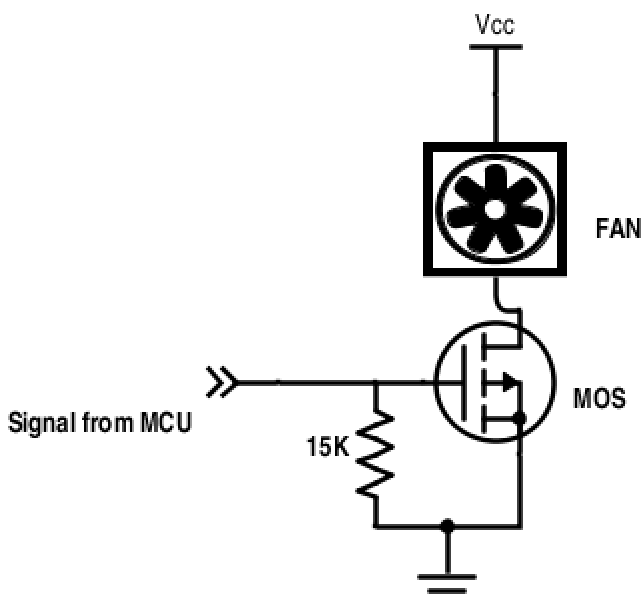


Figure 3.11.1.1.1: Potential wiring diagram for continuous pressure suppression system

In this configuration, a microcontroller with a high power output is not required because its signal is being relayed through the MOSFET. This would give more freedom when determining which microcontroller to use as power output is no longer an issue. The 15K resistor is used to extend the longevity of the MOSFET, but may not be populated in the final design as it is not crucial.

3.11.1.2 Alternating (Acoustic) Pressure

This idea has been used before with success, but never integrated into another design as would be done in this situation. The original idea was researched by DARPA in 2012 with little success, but was accomplished recently by two engineering students at George Mason University. The concept that they used could be applied in a similar fashion, but at a smaller scale with this design. The design consisted of a 30-60 Hz sound generator, an amplifier, and a speaker in an acoustic collimator jacket. The problem with this design is the lack of specifications and documentation by the students and in turn, the great amount of testing that would need to be done in order to find the perfect settings. For example, there may be a single sine wave frequency that works best or there may be a superposition of multiple frequencies. It may also be the case that a sweep through multiple frequencies in this range is best, but at what rate? It would also be necessary to test if this still works for a PWM generated frequency or if it has to be a smooth analog signal.

Because there has not yet been too much research into this area, all of the research would have to be done on our own. It's probable that the amount of tests that would be needed to be conducted would outweigh the usefulness of this subsystem. In the event that this technology may be feasible, a system overview is attached below.

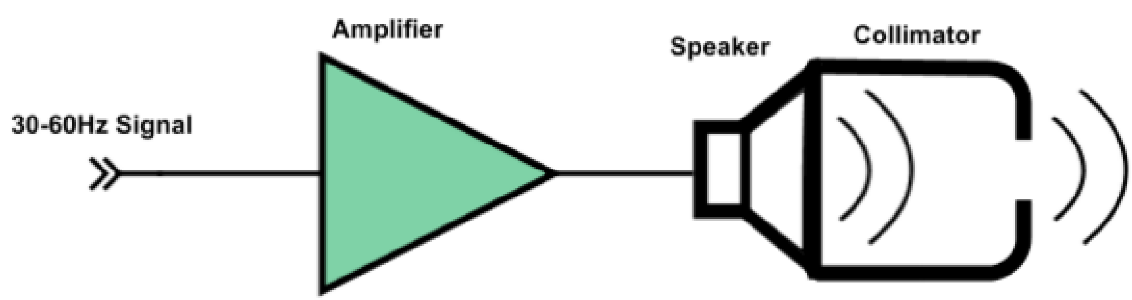


Figure 3.11.1.2.1: System overview for the acoustic suppression system concept

In Figure 3.11.1.2.1, it is undecided whether the signal will be generated by the MCU using PWM, analog means, or if a separate sound card is needed. It's possible that even while using PWM from an MCU, we could filter the signal with a shunt capacitor enough to make it seem very close to analog. At this stage, the feasibility of this design needs to be tested before any more planning is done.

NOTE: As of 11/8/15 preliminary testing has shown that it is possible to extinguish a tea-candle sized flame using sound waves. Using a Quadraflex 969 400W amplifier, a 10-inch 8 Ohm Radio Shack subwoofer and the "Function Generator" app on a Samsung

Galaxy S4- a tea candle was extinguished from a distance of about 8 inches. The frequency used was 40.91 Hz according to the application and the volume of the amplifier was at about ⅓ of its total. There was no good way of measuring the exact amount of power needed using the current set-up, so portability still may not be possible. It should also be noted that at further distances, the candle seemed closer to extinguishing in response to slightly higher frequencies (~50 Hz).

3.11.2 Chemical Extinguishers

Because the specifications of this project require that this extinguisher only needs to be used to extinguish a tea-candle sized fire, only one type of chemical extinguisher really applies. The type A chemical fire extinguisher is to be used for ordinary solid combustibles which would include the flame created by a small candle. It makes more sense to use a dry chemical extinguisher to minimize the mess created, but there are some very portable AFFF (aqueous film forming foam) extinguishers on the market. Below is a small comparison chart of dry chemical extinguisher versus a foam. Regardless of which extinguisher is selected the design will be the same-a bracket will hold the extinguisher in place with the nozzle facing forward at a downward angle. There will be a servo (or possible linear actuator) attached to the trigger of the extinguisher that will pull as commanded by the MCU. As shown in the chart below, the “Fire Gone” option is much lighter and cheaper, but it is also much messier as it is foam.

Type	**Brand**	**Weight**	**Price**
Dry Chem ABC	Kidde FA110 Multi Purpose	2.5 lbs	$29.50
AFFF ABC	Fire Gone 2NBFG2704	1.4 lbs	$8.00

Table 3.11.2.1: Chemical Extinguisher Comparison

3.11.3 Water Extinguishers

There are full fire extinguishing systems that use CO_2 or some other propellant to spray water out of a pressurized canister, but these are very similar to chemical extinguishers that were covered in the previous section and will not be discussed here. The system being explored by this section is that containing a tank, pump, and some sort of spray nozzle. The most practical solution would be to obtain an aquarium with a water filtration system. The water filtration system could be modified (by removing the filter and constricting flow at the end of the pump) to pump a pressurized stream of water capable of extinguishing a tea candle sized flame.

There are of course certain issues with a design involving a tank of water on top of a robot. If there was any leaking at all from the tank, this could cause a short circuit and prove fatal for the project if the circuitry is not protected. If the robot is not equipped with a way to deal with the disturbance induced by the oscillation of the tank of water, it may be guided off course or could even be too top heavy and flip over.

The benefit to this design is the price could be well under 20$ (multiple pumps found for 10$ online), the nozzle could be designed to yield wider coverage, and is a relatively simple build. Much the figure shown previously (the MOSFET relay to computer fan) this design would use a simple power relay circuit to turn on the pump when the fire is detected.

3.11.4 Physical Smothering

The fire could also be extinguished by means of oxygen deprivation due to physical smothering. One option which would be more novel than practical would be to have a candle snuffer at the end of a prismatic joint attached to a revolute joint that rotates in the vertical direction. The robot would drive up to the fire with the prismatic joint fully extended, and the revolute at about a 45 degree angle until it detected that the snuffer was directly over it. Once detected, the robot would slowly retract the prismatic joint while lowering the revolute joint such that the snuffer came straight down over the flame. The kinematics would be identical to a crane lowering straight down over something to pick it up. The problem with this design is finding a light and affordable prismatic joint. The cheapest, most practical track found is a linear slide track PN TRH15A2L1 which is $83.51 after tax/shipping on aliexpress.com.

It would also be possible to use two revolute joints instead of a revolute and prismatic. In practice, this could be done using two metal geared servos attached to lightweight aluminum links. This method complicates the math slightly more, but it would reduce cost by about $60 and also reduce weight.Another option would be to have a fire blanket suspended in front of the robot, held on by one or two servoed links. When the robot detects the fire and approaches, the servos are actuated by the MCU, dropping the blanket to smother the fire.

3.11.5 Conclusion

Listed below is a table of the most reasonable ideas that were discussed in the above sections. These methods have been compared based on their contributions to weight as well as cost. In addition to this table, it may be helpful to consider the difficulty of each design. Looking at the table below, it is clear to see that when considering weight and cost constraints as outlined in the Specifications section of this document, the continuous pressure suppression system is the best choice. It also happens, that this method would be relatively easy to build. The only downfall to this choice, is it is not scalable to larger fires, but that is not what the specification requires.

Suppression Method	Materials	Estimated Added Weight (Not including weight if included in another subsystem)	Added Cost (Not including cost if included in another subsystem)
Continuous Air Displacement	Computer fan MOSFET 15k resistor	1-2 oz ~0 ~0	0$ (obtained) 0$ (obtained) 0$ (obtained)
Acoustic Pressure	30-50Hz oscillator Amplifier Speaker Acoustic collimator	0 (if using MCU) < 1 lb < 1 lb ~0 (foam)	0$ (obtained) TBD <50$ 1-2$
Chemical Extinguisher (AFFF ABC)	Fire Gone 2NBFG2704 Mounting Bracket	1 lb 2 oz	8$ 2$
Water Extinguisher	Water Pump Water Reservoir	8 oz 2 oz	10$ 0$ (obtained)
Physical Smothering	2 Servos Aluminum Bar Bowl (candle snuffer)	4 oz 2 oz 4 oz	20$ 13$ 0$ (obtained)

Table 3.11.5.1: Fire Suppression Comparison

3.12 Camera

A camera on an autonomous firefighting robot is useful because it helps the operator to accurately pilot the vehicle with ease and potentially up to miles away without being there in person. The only alternative way to pilot the vehicle without first person view is GPS, which is not accurate enough to find and suppress a fire system. There is a wide variety of camera types that can be used to successfully pilot the vehicle. The worst case scenario, if there is no light inside the building, a night vision portable camera would be ideal. In situation where light is heavily present, this choice would not be appropriate because night vision cameras are extremely sensitive to light. This would wash out all visible object in view. In this case, for testing purposes, the vehicle will only be subjected to ideal conditions. This includes proper lighting without extreme darkness or extreme light. With these testing parameters, a night vision camera will not be necessary. The next option for camera use is an infrared sensing camera. An infrared sensing camera detects different light waves that display different colors on the video display of the camera. For example, high temperatures display warm colors such as red, yellow and orange; whereas low temperatures display cold colors such as blue, purple and aqua. With these distinctive video characteristics, it is easy to distinguish the difference between hot and cold objects. This makes it hard to navigate around colder objects because colder objects such as a wall or a floor because all of these sources appear the same on the first person view. The pilot cannot distinguish anything because the video feed will appear mostly blue. The pilot could easily find the heat source, but once the fire is suppressed it would be extremely difficult to leave the room because of the entire room being the same temperature. When choosing a normal RGB video camera, the two main characteristics to look for are viewing angle and the resolution of the camera. The wider the view angle that is available through the camera, the better the human can pilot the vehicle. Ideally, 180 degrees would be the best that one can achieve through an FPV camera. Realistically it turns out to be around 140-160 degrees is the target area for the camera selection. The reasoning behind using a wide angle view is because the pilot wants to get as close to human eyesight as possible. The human field of view is approximately 200 degrees. The closer an FPV can get to this degree, the more realistic the video will seem to the pilot. If there is a small view angle of less than 90 degrees, the chances of colliding with an obstacle will be greatly increased because it will be outside of the viewing angle. If the size of the camera is too big, it will not fit chassis. Ideally, the camera needs to be small in size so it can be easily mounted and still have enough room for all of the other components of the project.

3.12.1 Ultimate 700TVL. high resolution Super WDR

The Ultimate 700TVL. high resolution Super WDR is a small, portable, lightweight camera used mostly for first person view (FPV) and also for security purposes. This cameras small size and low profile allows it to be mounted and placed in small areas making it perfect for an autonomous vehicle. This camera pulls a continuous current of 55 milliamps which is extremely low for the requirements of the vehicle and great on battery life. The operating voltage for this camera is 5-17 volts making it a great selection for using 2 to 4 cell LIPO batteries. The size of this camera is 26 x 26 mm making it a great selection for mounting on the vehicle since space is always an important characteristic when building a small electronic system. If the size of the camera is too large then there may not be enough for other vital components of the vehicles system. The resolution measures 700 tvl which is more than sufficient for first person view to drive the vehicle via an external display. The price of this camera is $34.95. The weight of this camera is 47 grams. Refer to Fig 3.12 for more information on this specific camera.

3.12.2 Boscam CM210 Mini HD FPV Camera

The Boscam CM210 Mini HD FPV Camera is a small, portable and lightweight camera used mostly for first person view (FPV) and for security purposes. This camera's small size and low profile allows it to be mounted and placed in small areas making it perfect for an autonomous vehicle. This camera pulls a continuous current of 100 milliamps which is great for the requirements of the vehicle and great on battery life. The operating voltage for this camera is 10-13 volts, making it a great solution for using two to four cell LIPO batteries. The size of this camera is 9.5x6.5x5.5 cm which is a great selection for mounting on the vehicle because space is always an important characteristic when building a small electronic system. If the size of the camera is too large then there may not be enough room for other vital components of the vehicles' system. The price of this camera is $38.87. The weight of this camera is 0.17 kg. The viewing angle for this first person view camera is 90 degrees. This is great because it allows the person looking through the camera to see most of the room that the vehicle is currently in. This helps with the navigation, ensuring that it goes according to plan. Refer to Fig 3.12 for more information on this specific camera.

3.12.3 HeliStar CMOST FPV Camera

The HeliStar CMOST FPV Camera is a small, portable and lightweight camera used mostly for first person view (FPV) and for security purposes. This camera's small size and low profile allows it to be mounted and placed in small areas making it perfect for an autonomous vehicle. This camera pulls a continuous current of 60 milliamps which is great for the requirements of the vehicle and great on battery life. The operating voltage for this camera is 5-10 volts, making it a great solution for using two to four cell LIPO batteries. The size of this camera is 20x20 mm which is a great selection for mounting on the vehicle because space is always an important characteristic when building a small electronic system. If the size of the camera is too large then there may not be enough room for other vital components of the vehicles' system. The resolution measures 480 tvl which is more than sufficient for first person view to drive the vehicle via an external display. The price of this camera is $55. The viewing angle for this first person view camera is 90 degrees. This is great because it allows the person looking through the camera to see most of the room that the vehicle is currently in. This helps with the navigation, ensuring that it goes according to plan. Refer to Fig 3.12 for more information on this specific camera.

3.12.4 Mini Wide Angle FPC

The Mini Wide Angle FPC is a small, portable and lightweight camera used mostly for first person view (FPV) and for security purposes. This camera's small size and low profile allows it to be mounted and placed in small areas making it perfect for an autonomous vehicle. This camera pulls a continuous current of 80 milliamps which is great for the requirements of the vehicle and great on battery life. The operating voltage for this camera is 5-12 volts, making it a great solution for using two to four cell LIPO batteries. The size of this camera is 1.4x1.3x1 cm which is a great selection for mounting on the vehicle because space is always an important characteristic when building a small electronic system. If the size of the camera is too large then there may not be enough room for other vital components of the vehicles' system. The resolution measures 700 tvl which is more than sufficient for first person view to drive the vehicle via an external display. The price of this camera is $12.59. Refer to Fig 3.12 for more information on this specific camera.

3.12.5 Mini CMOS Wide Angle FPV

The Mini CMOS Wide Angle FPV is a small, portable and lightweight camera used mostly for first person view (FPV) and for security purposes. This camera's small size and low profile allows it to be mounted and placed in small areas making it perfect for an autonomous vehicle. This camera pulls a continuous current of 55 milliamps which is great for the requirements of the vehicle and great on battery life. The operating voltage for this camera is 9-12 volts, making it a great solution for using two to four cell LIPO batteries. The size of this camera is 2x1.6x1.5 cm which is a great selection for mounting on the vehicle because space is always an important characteristic when building a small electronic system. If the size of the camera is too large then there may not be enough room for other vital components of the vehicles' system. The resolution measures 600 tvl which is more than sufficient for first person view to drive the vehicle via an external display. The price of this camera is $15.99. The viewing angle for this first person view camera is 170 degrees. This is great because it allows the person looking through the camera to see most of the room that the vehicle is currently in. This helps with the navigation, ensuring that it goes according to plan. The weight of this camera is 30 grams. Refer to Fig 3.12 for more information on this specific camera.

3.12.6 520TVL HD Micro HD Color FPV

The 520TVL HD Micro HD Color FPV is a small, portable and lightweight camera used mostly for first person view (FPV) and for security purposes. This camera's small size and low profile allows it to be mounted and placed in small areas making it perfect for an autonomous vehicle. This camera pulls a continuous current of 80 milliamps which is great for the requirements of the vehicle and great on battery life. The operating voltage for this camera is 3.3-5 volts, making it a great solution for using two to four cell LIPO batteries. The size of this camera is 100x80x20 mm which is a great selection for mounting on the vehicle because space is always an important characteristic when building a small electronic system. If the size of the camera is too large then there may not be enough room for other vital components of the vehicles' system. The resolution measures 520 tvl which is more than sufficient for first person view to drive the vehicle via an external display. The price of this camera is $20.52. The viewing angle for this first person view camera is 120 degrees. This is great because it allows the person looking through the camera to see most of the room that the vehicle is currently in. This helps with the navigation, ensuring that it goes according to plan. The weight of this camera is 40 grams. Refer to Fig 3.12 for more information on this specific camera.

3.12.7 MC900D NTSC

The MC900D NTSC is a small, portable and lightweight camera used mostly for first person view (FPV) and for security purposes. This camera's small size and low profile allows it to be mounted and placed in small areas making it perfect for an autonomous vehicle. This camera pulls a continuous current of 100 milliamps which is great for the requirements of the vehicle and great on battery life. The operating voltage for this camera is 5 volts, making it a great solution for using two to four cell LIPO batteries. The size of this camera is 2x1.1x1.1 cm which is a great selection for mounting on the vehicle because space is always an important characteristic when building a small electronic system. If the size of the camera is too large then there may not be enough room for other vital components of the vehicles' system. The resolution measures 520 tvl which is more than sufficient for first person view to drive the vehicle via an external display. The price of this camera is $41.44. The viewing angle for this first person view camera is 90 degrees. This is great because it allows the person looking through the camera to see most of the room that the vehicle is currently in. This helps with the navigation, ensuring that it goes according to plan. The weight of this camera is 5 grams. Refer to Fig 3.12 for more information on this specific camera.

3.12.8 HD Sony CCD FPV

The HD Sony CCD FPV is a small, portable and lightweight camera used mostly for first person view (FPV) and for security purposes. This camera's small size and low profile allows it to be mounted and placed in small areas making it perfect for an autonomous vehicle. This camera pulls a continuous current of 50 milliamps which is great for the requirements of the vehicle and great on battery life. The operating voltage for this camera is 12 volts, making it a great solution for using two to four cell LIPO batteries. The size of this camera is 3.8x3.8x0.2 cm which is a great selection for mounting on the vehicle because space is always an important characteristic when building a small electronic system. If the size of the camera is too large then there may not be enough room for other vital components of the vehicles' system. The resolution measures 700 tvl which is more than sufficient for first person view to drive the vehicle via an external display. The price of this camera is $14.59. The viewing angle for this first person view camera is 90 degrees. This is great because it allows the person looking through the camera to see most of the room that the vehicle is currently in. This helps with the navigation, ensuring that it goes according to plan. The weight of this camera is 32 grams. Refer to Fig 3.12 for more information on this specific camera.

3.12.9 HD Mini Camera FPV CCTV

The HD Mini Camera FPV CCTV is a small, portable and lightweight camera used mostly for first person view (FPV) and for security purposes. This camera's small size and low profile allows it to be mounted and placed in small areas making it perfect for an autonomous vehicle. This camera pulls a continuous current of 100 milliamps which is great for the requirements of the vehicle and great on battery life. The operating voltage for this camera is 12 volts, making it a great solution for using two to four cell LIPO batteries. The size of this camera is 2x1.1x0.2 cm which is a great selection for mounting on the vehicle because space is always an important characteristic when building a small electronic system. If the size of the camera is too large then there may not be enough room for other vital components of the vehicles' system. The resolution measures 420 tvl which is more than sufficient for first person view to drive the vehicle via an external display. The price of this camera is $26.00. The viewing angle for this first person view camera is 90 degrees. This is great because it allows the person looking through the camera to see most of the room that the vehicle is currently in. This helps with the navigation, ensuring that it goes according to plan. The weight of this camera is 50.9 grams. Refer to Fig 3.12 for more information on this specific camera.

3.12.10 Mini Sony CCD EFFIO-P

The Mini Sony CCD EFFIO-P is a small, portable and lightweight camera used mostly for first person view (FPV) and for security purposes. This camera's small size and low profile allows it to be mounted and placed in small areas making it perfect for an autonomous vehicle. This camera pulls a continuous current of 100 milliamps which is great for the requirements of the vehicle and great on battery life. The operating voltage for this camera is 12 volts, making it a great solution for using two to four cell LIPO batteries. The size of this camera is 41x41 mm which is a great selection for mounting on the vehicle because space is always an important characteristic when building a small electronic system. If the size of the camera is too large then there may not be enough room for other vital components of the vehicles' system. The resolution measures 700 tvl which is more than sufficient for first person view to drive the vehicle via an external display. The price of this camera is $58.99. The viewing angle for this first person view camera is 90 degrees. This is great because it allows the person looking through the camera to see most of the room that the vehicle is currently in. This helps with the navigation, ensuring that it goes according to plan. The weight of this camera is 130 grams. Refer to Fig 3.12 for more information on this specific camera.

3.12.11 Camera Comparison Chart

A chart is used to compare all motors researched in a way that makes it easy to make the best choice when deciding on the best camera for the vehicle. The chart below in figure

3.12 displays the model name, the maximum output current, the voltage, the viewing angle, the size, the resolution and the price. The voltage is an important characteristic because power consumption is vital to any electrical system, especially an autonomous system that relies solely on non-human input. If voltage consumption is too high, the battery life will be shortened and therefore results in a shorter operating time. If there is more battery lifetime, this creates more time for the vehicle to achieve the goal of fire suppression. The max current rating is important to know because the motor controller selection is solely based off of max current that the motor pulls. The viewing angle is an important characteristic because it helps the person viewing the real time video. If the viewing angle is too small, the operator will not be able to see everything and therefore miss the fire and never find it. Also, if the angle is too large it could distort the video, causing it to seems skewed and stretched. This would be a negative trait because it could cause the operator to go to the wrong point. It will seem as if the flame is in a position that it is not. The size is important solely because of how much space is left on the chassis. It cannot be a large camera such as a DSLR because there would not be enough room for the rest of the pieces to comfortably fit. The resolution of the camera is one of the most important characteristics. The resolution has to be great enough so the operator can distinguish things in the live feed. If the resolution is not great enough, it is possible that the operator maybe not be able to see that there is a fire in the field of view. The price column may not be a huge factor for some but for this project the budget is a main factor when making all decisions and will help decide on major components used. Refer to figure 3.12 for the complete details of all of the cameras compared.

Model	Current (mA)	Voltage (Volts)	Viewing angle(degrees)	Size	Resolution	Price
Ultimate 700TVL. high Super WDR resolution	55	5-17	N/A	26x26 mm	700tvl	$34.95
Boscam CM210 Mini HD FPV Camera	100	10-13	90	9.5x6.5x5.5 cm	N/A	$38.87
HeliStar CMOST FPV Camera	60	5-10	90	20x20 mm	480tvl	$55

Mini Wide Angle FPC	80	5-12	N/A	1.4x1.3x1cm	700tvl	$12.59
Mini CMOS Wide Angle FPV	55	9-12	170	2x1.6x1.5cm	600tvl	$15.99
520TVL HD Micro HD Color FPV	80	3.3-5	120	100x80x20mm	520tvl	$20.52
MC900D NTSC	100	5	90	2x1.1x1.1cm	520tvl	$41.44
HD Sony CCD FPV	50	12	90	3.8x3.8x0.2cm	700tvl	$14.59
HD Mini Camera FPV CCTV	100	12	90	2x1.1x0.2cm	420tvl	$26.00
Mini Sony CCD EFFIO-P	100	12	90	41x41mm	700tvl	$58.99

Figure 3.12: Comparison Chart for Cameras

3.13 Video Transmitter and Receiver

There are a couple of different ways to transmit and receive data from the camera to get a live view. One approach would be to run wires from the camera to the screen that the pilot chooses to use. Each camera comes with a connector that has a ground, positive and video wires which can be run to a power source and the video wires can be run to RCA wires that can be plugged directly into a television. This is not a very effective method because there is a high chance that the wire will have to be longer than two hundred feet. It is also not the best method for being inside a building. Running wires straight from the camera to the chosen screen would have to go through walls and hallways. Unless holes are drilled into the walls, it would be too difficult to ensure the wires would never get damaged. The other common method is to find a compatible wireless and transmitter and receiver pair that has the right kind of cable. The transmitter plugs directly into the camera while the receiver is plugged into any compatible screen most commonly using RCAs. This is the better option because the pilot then does not have to worry about any wires on the ground. Another characteristic of a transmitter and receiver pair is the frequency of it. There are many different radio frequency band values available. The two most common frequency bands are 2.4 gigahertz and five gigahertz. The frequency band 2.4 gigahertz is the most common frequency band used. A pro of using this frequency is that it is very common and easy to find. A lot of transmitter and receiver pairs will come as 2.4 gigahertz. Cons of this frequency band include the frequency getting crowded easily, because most components use the same frequency and that it is also easily interfered. The five gigahertz frequency is not as commonly used and that is usually because the range is not a great as the 2.4 gigahertz frequency band. This could be a problem because if the vehicle goes out of range of the camera, the pilot will not be able to see anything therefore not being able to suppress the fire appropriately. A pro of the five gigahertz frequency band is that is never crowded. Things such as home phones, wire networks and garage door openers are not being using on this frequency band to crowd it. This makes it very easy for transmitting live feed.

3.13.1 Sourchingbay TS832+32CH

The Sourchingbay TS832+32CH is a wireless transmitter and a receiver pair. The transmitter has an operating voltage of 7.4-16 volts. The receiver has an operating voltage of twelve volts. The working current of the transmitter is two hundred twenty milliamps. The working current of the receiver is two hundred milliamps. The range of this transmitter receiver pair is five kilometers. The frequency of this transmitter receiver pair is eight megahertz. The cost of this component is $49.99. Refer to figure 3.13.11 for more information on this specific video transmitter and receiver.

3.13.2 2.4G 600M Wireless AV Transmitter Receiver Set

The 2.4G 600M Wireless AV Transmitter Receiver Set is a wireless and a receiver pair. The transmitter has an operating voltage of 3.3-5.5 volts. The receiver has an operating voltage of 3.3 volts. The working current of the transmitter is 250 milliamps. The working current of the receiver is 150 milliamps. The range of this transmitter receiver pair is five kilometers. The frequency of this transmitter receiver pair is 2.4 gigahertz. The cost of this component is $19.99. Refer to figure 3.13.11 for more information on this specific video transmitter and receiver.

3.13.3 5.8G FPV AV TXRX 2000M

The 5.8G FPV AV TXRX 2000M is a wireless and a receiver pair. The transmitter has an operating voltage of 12 volts. The receiver has an operating voltage of 7-15 volts. The working current of the transmitter is 150 milliamps. The working current of the receiver is 150 milliamps. The range of this transmitter receiver pair is five kilometers. The frequency of this transmitter receiver pair is 5.8 gigahertz. The cost of this component is $31.90. Refer to figure 3.13.11 for more information on this specific video transmitter and receiver.

3.13.4 AV Audio Video Transmitter + Receiver

The AV Audio Video Transmitter + Receiver is a wireless and a receiver pair. The transmitter has an operating voltage of 7-15 volts. The receiver has an operating voltage of 12 volts. The working current of the transmitter is 150 milliamps. The working current of the receiver is 150 milliamps. The range of this transmitter receiver pair is five kilometers. The frequency of this transmitter receiver pair is 5.8 gigahertz. The cost of this component is $51.30. Refer to figure 3.13.11 for more information on this specific video transmitter and receiver.

3.13.5 800MW 8CH Wireless FPV Transmitter and Receiver

The 800MW 8CH Wireless FPV Transmitter and Receiver is a wireless and a receiver pair. The transmitter has an operating voltage of 7-12 volts. The receiver has an operating voltage of 10 volts. The working current of the transmitter is 260 milliamps. The working current of the receiver is 200 milliamps. The range of this transmitter receiver pair is 1500 meters. The frequency of this transmitter receiver pair is 1.3 gigahertz. The cost of this component is $88.95. Refer to figure 3.13.11 for more information on this specific video transmitter and receiver.

3.13.6 Hot Boscam FPV TS351 + RC805

The Hot Boscam FPV TS351 + RC805 is a wireless and a receiver pair. The transmitter has an operating voltage of 7-15 volts. The receiver has an operating voltage of 6.5-12 volts. The working current of the transmitter is 150 milliamps. The working current of the receiver is 150 milliamps. The range of this transmitter receiver pair is 500 meters. The frequency of this transmitter receiver pair is 5.8 gigahertz. The cost of this component is $27.96. Refer to figure 3.13.11 for more information on this specific video transmitter and receiver.

3.13.7 8CH Boscam Wireless Transmitter Receiver

The 8CH Boscam Wireless Transmitter Receiver is a wireless and a receiver pair. The transmitter has an operating voltage of 7-15 volts. The receiver has an operating voltage of 12 volts. The working current of the transmitter is 150 milliamps. The working current of the receiver is 150 milliamps. The range of this transmitter receiver pair is 500 meters. The frequency of this transmitter receiver pair is 5.8 gigahertz. The cost of this component is $33.99. Refer to figure 3.13.11 for more information on this specific video transmitter and receiver.

3.13.8 FPV 8CH Transmitter + Receiver RC305

The FPV 8CH Transmitter + Receiver RC305 is a wireless and a receiver pair. The transmitter has an operating voltage of 7-15 volts. The receiver has an operating voltage of 5 volts. The working current of the transmitter is 500 milliamps. The working current of the receiver is 400 milliamps. The range of this transmitter receiver pair is one kilometers. The frequency of this transmitter receiver pair is 5.8 gigahertz. The cost of this component is $59.80. Refer to figure 3.13.11 for more information on this specific video transmitter and receiver.

3.13.9 5.8G FPW Video US NI50

The 5.8G FPW Video US NI50 RC305 is a wireless and a receiver pair. The transmitter has an operating voltage of 7-15 volts. The receiver has an operating voltage of 6.5-12 volts. The working current of the transmitter is 150 milliamps. The working current of the receiver is 150 milliamps. The range of this transmitter receiver pair is one kilometer. The frequency of this transmitter receiver pair is 5.8 gigahertz. The cost of this component is $22.44. Refer to figure 3.13.11 for more information on this specific video transmitter and receiver.

3.13.10 5.8G Wireless AV FPV Transmitter + Receiver Set

The 5.8G Wireless AV FPV Transmitter + Receiver Set is a wireless and a receiver pair. The transmitter has an operating voltage of 5 volts. The receiver has an operating voltage of 5 volts. The working current of the transmitter is 250 milliamps. The working current of the receiver is 1800 milliamps. The range of this transmitter receiver pair is 500 meters. The frequency of this transmitter receiver pair is 5.8 gigahertz. The cost of this component is $35.99. Refer to figure 3.13.11 for more information on this specific video transmitter and receiver.

3.13.11 Video Transmitter and Receiver Comparison Chart

A chart is used to compare all video transmitter and receivers researched in a way that makes it easy to make the best choice when deciding on the best video transmitter and receiver for the vehicle. The chart below in figure 3.13.11 displays the model name, the frequency, the range, the transmitter voltage, the receiver voltage and the cost. The voltage is an important characteristic because power consumption is vital to any electrical system, especially an autonomous system that relies solely on non-human input. If the voltage consumption is too high, the battery life will be shortened and therefore results I a shorter operating time. If there is more battery lifetime, this creates more time for the vehicle to achieve the goal of fire suppression. when comparing video transmitter and receiver pairs the frequency at which the two components communicate is an important characteristic. The frequency depicts how long of a range the video transmitter and receiver pair can communicate with one another. If the range is too short, the human operator will lose control of the vehicle and that could potentially lead to crashing the vehicle or damaging it. The price column is a bigger factor for this component, because video transmitter and receiver pairs tend to be more expensive. Refer to figure 3.13.11 for the complete details of all of the video transmitter and receiver pairs compared.

Model	Frequency	Range	Transmitter Voltage(V)	Receiver Voltage(V)	Cost
Sourchingbay TS832+32CH	8MHz	5km	7.4-16	12	$49.99
2.4G 600M Wireless AV Transmitter Receiver Set	2.4GHz	600m	3.3-5.5	3.3	$19.99
5.8G FPV AV TXRX 2000M	5.8GHz	2km	12	7-15	$31.90
AV Audio Video Transmitter + Receiver	5.8GHz	5km	7-15	12	$51.30
800MW 8CH Wireless FPV Transmitter and Receiver	1.3GHz	1500m	7-12	10	$88.95
Hot Boscam FPV TS351 + RC805	5.8GHz	500m	7-15	6.5-12	$27.96
8CH Boscam Wireless Transmitter Receiver	5.8GHz	2000m	7-15	12	$33.99
FPV 8CH Transmitter + Receiver RC305	5.8GHz	1km	7-15	5	$59.80

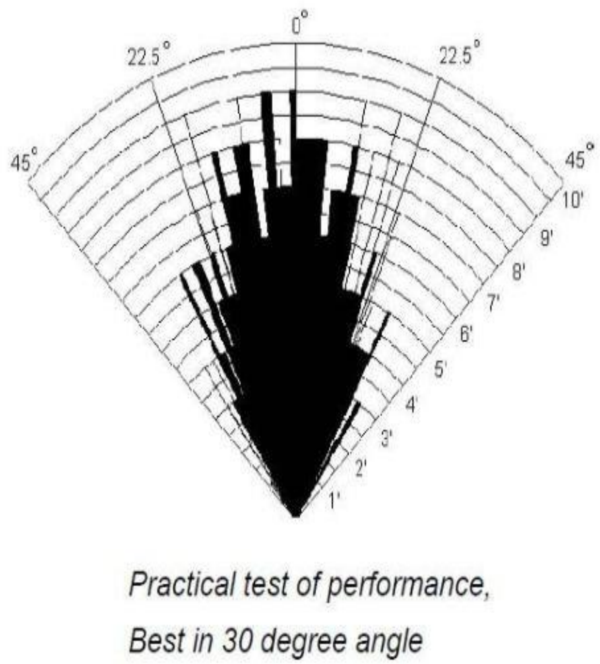
5.8G FPW Video US NI50	5.8GHz	2km	7-15	6.5-12	$22.44
5.8G Wireless AV FPV Transmitter + Receiver Set	5.8GHz	500m	5	5	$35.99

Figure 3.13.11: Comparison Chart for Video Transmitter and Receiver

4.0 Hardware and Software Selections

4.1 Proximity sensor selection

The selection of the proximity sensor plays a large role for the overall functionality of the vehicle. If the minimum range of the TRIGGER sensor is not short enough then the probability of a collision with an object increases and the vehicle may lose its ability to complete the over all goal. Another characteristic the sensor must attain is a low current consumption. Most microcontrollers cannot output a high current. The typical output current for I/O pins of a microcontroller range from around 20 milliamps to around 40 milliamps. The sensing angle of the ultrasonic sensor must around 45 degrees to accurately differentiate between the left, front and right side of the vehicle. Any smaller and the vehicle may need too many sensors and a sensing angle to large may make it impossible to differentiate between which side of the vehicle is facing an object. The lower amount of I/O pins used the more pins will be available to be used on the microcontroller for other components. Fewer pins also ensures less current will be pulled since each I/O input pulls current. When researching different ultrasonic sensors the delay time was not always able to be located but delay time is an important factor when selecting the best sensor. If the delay time is to low the vehicle may not be able to react in time to on coming objects and will therefore collide with the object instead of maneuver around it. Size was not an issue when researching ultrasonic sensors since all were relatively the same size and will mount easily on the vehicle. Lastly, cost is the final factor to consider when selecting the ultrasonic sensor. If funding was given to the team the cost would most likely not be an issue for any of the supersonic sensors that can be purchased online but for our teams budget cost is a constraint that must be considered. With much consideration the team assessed all supersonic sensors that were researched and decided to use the **HC - SR04.** The selection was made to use the HC - SR04 because it uses a 5 volt input, consumes 15 milliamps, has a 30 degree sensing angle, a minimum distance of 2 cm, and only costs $10. Refer to figure 4.1 below left for a test performance of the HC-SR04 and figure 4.1.1 shown below for the actual component that will be used.



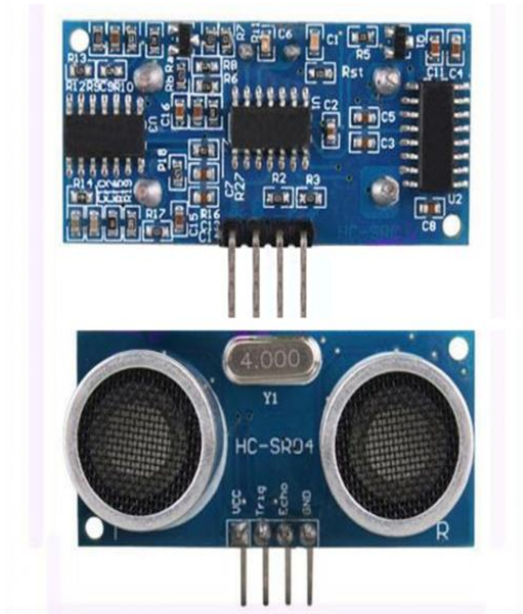


Fig 4.1 (top) shows an acccurate representating of the sensing angle for the HC - SR04.

Fig 4.1.1(bottom) is the actual product image for the HC-SR04.(approval pending)

4.1.1 Pin Connection

The HC-SR04 uses a four pin configuration. One pin is designated for the 5 volt input to the module and one pin is used for the ground. The other two pints are input/output pins, one labeled as the Trigger (RX) and one labeled as the ECHO (TX). The pins are male header pins that are bread board ready, used for easy testing and mounting with no need to solder any connections. For final wiring these pins may be soldered but for testing purposes will not be. Refer to figure 4.1.1 shown below for the pin connections of the ultrasonic connection and how each connection reacts.

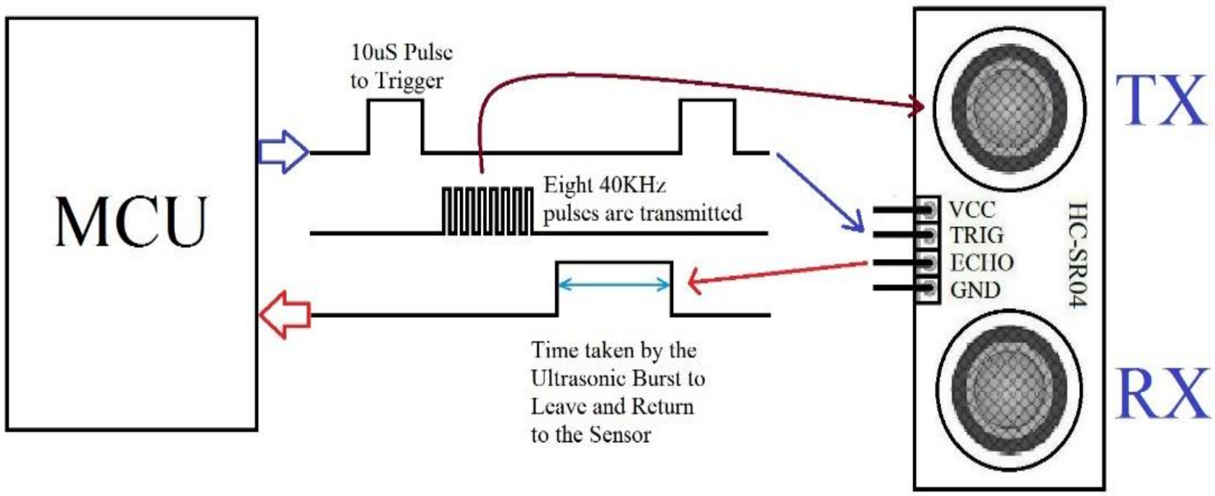


Fig. 4.1.1 shows a simple diagram of the 4 pin layout of the HC-SR04 module and the connection to the microcontroller.

4.1.2 Circuit Design

Refer to figure 4.1.2 below for the circuit design of an ultrasonic transmitter and an ultrasonic receiver.

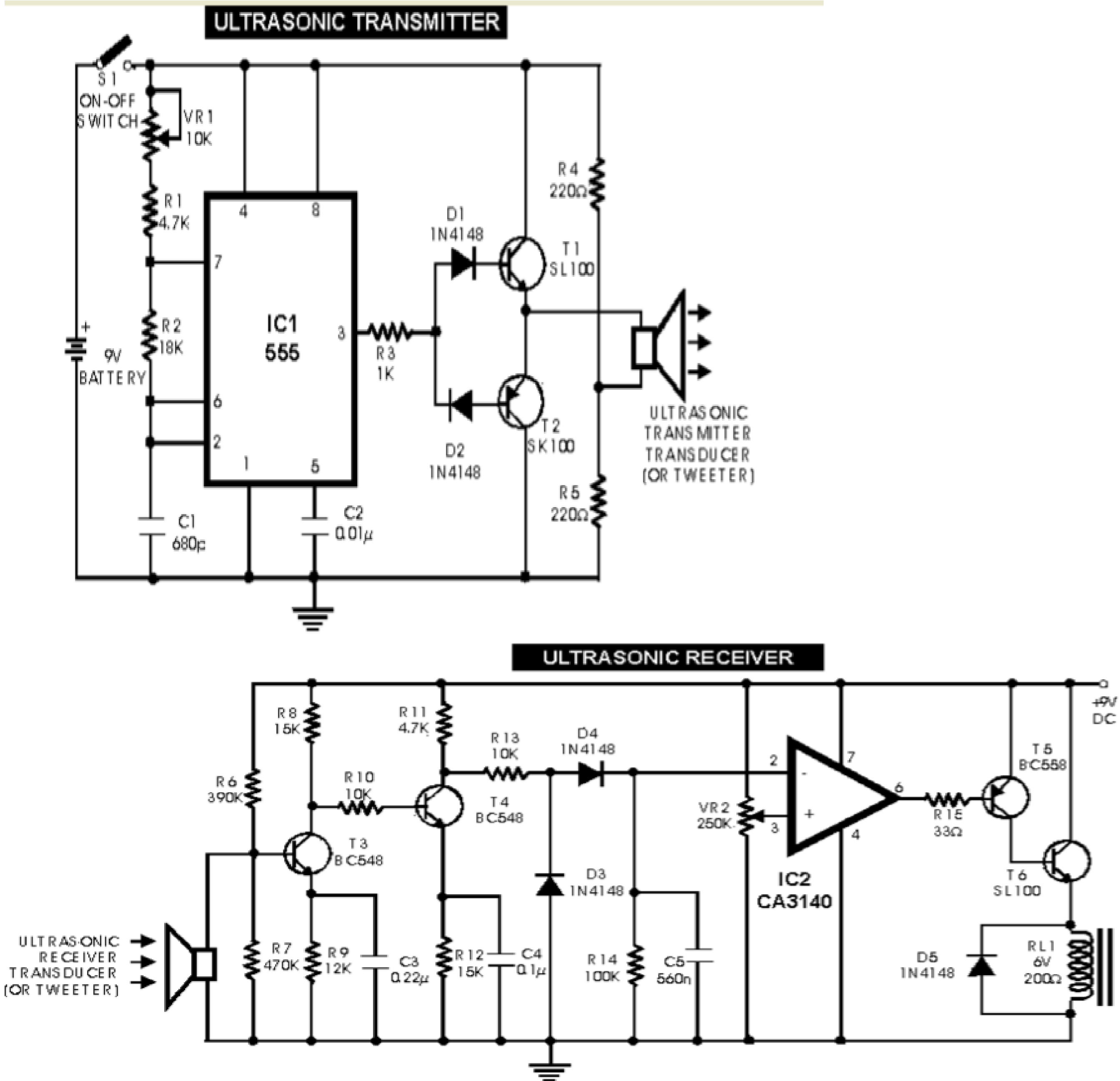


Fig.4.1.2 shows the circuit schematic for how the ECHO(TX) and the TRIGER(RX) are designed.

4.1.3 Mounting

A 3D printer will most likely be used to manufacture a bracket for these sensors to be mounted to using ABS plastic. The bracket will have female header pins for the ultrasonic sensors to be plugged into that will be connected to the microcontroller. Three ultrasonic sensors will be used, so the Bracket will be located towards the front of the vehicle close to the ground so that no other components of the vehicle will interfere with the sound waves produced by the ECHO of the sensors. The bracket will have screw holes drilled out prior to the sensors being mounted so that the HC-SR04 will screw directly to the bracket correctly and securely. Having a screw connection between the ultrasonic sensor and the bracket will ensure that no wire come undone during testing. Double sided thick 3M tape will also be applied between the ultrasonic sensor board and the bracket to help eliminate vibrations that may occur. Vibrations are not a main source of error with these type of sound sensors but eliminating all possible sources or error will only result in accurate performance. The picture below is what our design will be modeled after. In the picture below shows a commercial housing that can be purchased for the HC-SR04. Refer to figure 4.1.3 shown below for the ultrasonic sensor mounting bracket.

Fig. 4.1.3 is a mounting bracket that is commercially sold for the HC-SR04.(approval pending)

4.2 Flame Sensor Selection

The flame sensor is a vital role for the entire vehicle. If the flame cannot be detected, the vehicle cannot do its job. If the angle of the sensor is not wide enough, the sensor won’t be able to pick up on a flame that is in the general vicinity. If the sensor’s angle is too wide, the vehicle won’t be able to pin point the flame to the correct degree of accuracy. If the angle is too small, too many sensors would need to be placed onto to vehicle, and that would cause malfunctioning. A good degree of reference should be around sixty degrees. Another characteristic that the flame sensor should include is low current consumption. This is needed because the typical output current for an input output pin on a microcontroller is anywhere between twenty milliamps and forty milliamps. The sensor that the team is choosing for the project is the ElecFreaks E00397. This flame sensor seemed to be the most economical choice. It only pulls five milliamps, which is the limit for a normal input output pin for microcontrollers. There's also only one input output pin. This is very convenient because it therefore leaves more pins open to be used. The E00397 also only uses five volts. This is necessary because the max output voltage of a microcontroller is normally five volts. Another characteristic that ensured that the team chose this specific sensor is the cost. At $6.81, it is a very economical choice, because many sensors can be purchased and mounted onto the chassis. Figure 4.2 below shows the flame sensor that was chosen by the group to use for the project.

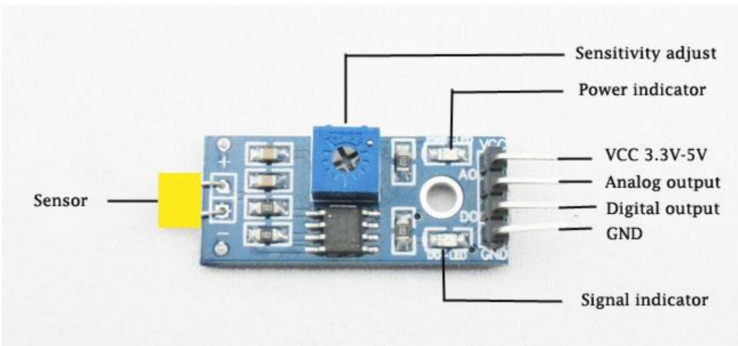


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Figure 4.2: Picture of the Flame Sensor Chosen

4.2.1 Flame Sensor Pin Connection

The E00397 uses a three pin configuration. One pin is designated for the five volt input to the module and one pin is used for the ground. The third pin is an input output pin. The pins are male header pins that are ready for a breadboard. This is great because it can be easily tested and mounted without the need for soldering connections.

4.2.2 Flame Sensor Circuit Design

Figure 4.2.2 below shows the schematic of the flame sensor E00397 that the group chose to use for this project.

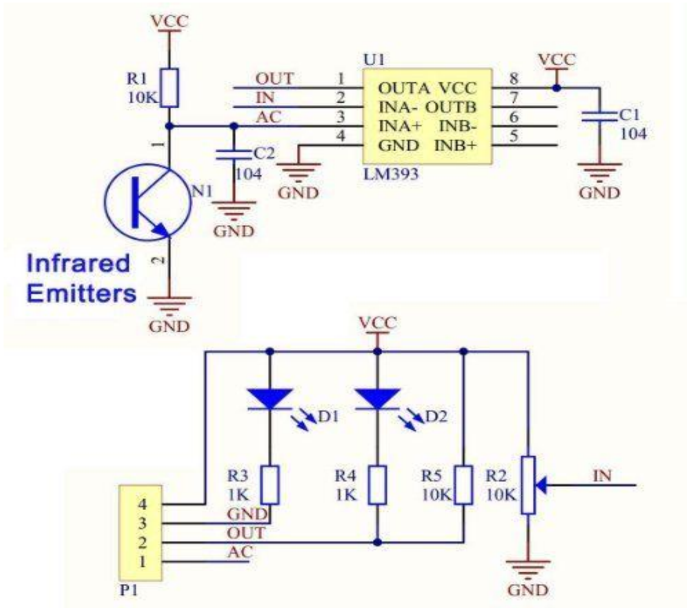


Figure 4.2.2 shows the circuit schematic on how the E00397 is designed.

4.2.3 Flame Sensor Mounting

A 3D protective casing will be printed using ABS plastic. The will also be female header pins for the IR sensors to be plugged into that will be connected to the microcontroller. Five IR sensors will be used. They will be mounted towards the top of the vehicle, so they can accurately scan the current room for the flame. Double sided thick 3M tape will be used to apply between the IR sensors and the board and the housing of the sensors to ensure that they will stay in place and also to minimize vibration.

4.3 Power Systems

Every electronic project has to have a dedicated power system to give the parts some life. Each project will have different demands and stipulations but they all need power. Some projects can use a simple 9v battery and be completely fine, but some may need a 220v hook up. The fire-fighting robot will be an autonomous roaming robot that will not be able to have wires plugged into a power source. So therefore, a battery and regulators are needed. Each application robot has certain amp requirements that are mandatory to the robots function. Large robots may need a four cell LiPo with a voltage of 16.4 volts and others may be little gadget robots that only need a single cell 3.7 volts to maintain its function. The fire-fighting robot is intermittent in terms of needs. The robot will require a 12v source that will need certain regulations of voltage for specific electronics. The main source will come from a Turnigy 3s 5000mah LiPo battery. This battery was chosen for its high amp output (100amps) and amp capacity. 100amps will give the robot plenty of current overhead. The 5000 milli-amp hours will give the robot a long runtime to do its job repeatedly. The long time will be beneficial in terms of cost and functionality. Each battery costs forty dollars, and would be difficult to change out constantly in the term of its tests. In the following sections, the specifics of each part of the power system will be discussed in depth.

4.3.1 Voltage Regulator

With any type of electronic project, the need of different voltages is crucial. In our robot we have at least three separate voltages that will be needed. Our main MCU will need a voltage 9 volts for it run optimally, our multiple sensors will need a voltage of 5 volts, and our motor controllers/ motors will need 12 volts. Since we will be using a 12 volt LiPo battery, the motors will be ran directly off the battery so that they can draw their individual high currents directly from the source to help with voltage drop and losses. However for the MCU and sensors we will not be able to run them off the battery. Voltage regulation will help us be able to run separate voltages without harming the chips and other important pieces of our system

In our project we will be using 2 separate regulators to power our multiple devices and accessories. We do not want a high power loss so we will be implementing switching regulators to give us less power loss in these components. We will be implementing two Texas Instruments LM2576T-ADJ components to achieve our desired voltages. The LM2576T-ADJ also carries a 3A limit, which will give plenty of overhead for our sensors and monitors. Refer to the pictures below for regulators. Figure 4.5.1a shows the hardware that will be used to regulate the voltage to the MCU as well as the different sensors to make the robot function. When used in the circuit in Figure 4.5.1b, 5V are possible with a 3A limit.

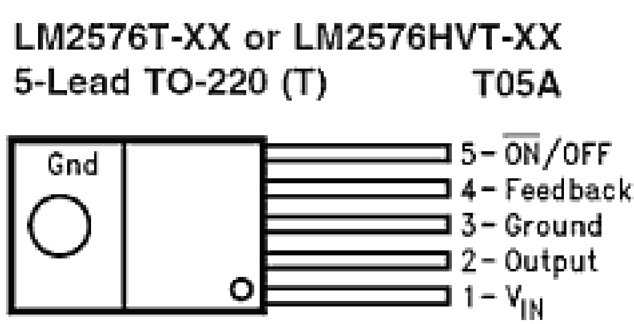


Figure 4.5.1a: Voltage Regulator

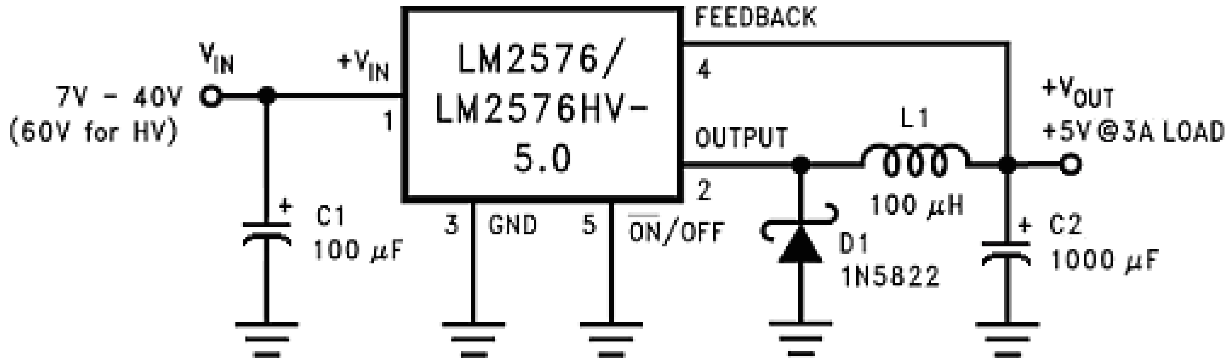


Figure 4.5.1b: Switching Regulator

Parts list:

- IC1: LM2576T-5V or LM2576HVT-5V (National Semiconductor)
- L1: 100µH (415-0930, 67127000, PE-92108, RL2444)
- D1: 1N5822 (Schottky Barrier Rectifier diode)
- C1: 100µF/75V (Aluminum electrolytic capacitor)
- C2: 100µF/75V (Aluminum electrolytic capacitor)

For the MCU, 9V is needed for proper functionality. To achieve this the LM2576T-ADJ can also be used with the same circuit as Figure4.5.1b, but a voltage divider will be need to adjust the regulator. Figure 4.5.1c, from the datasheet from TI, shows the equations needed to calculate the resistor values for the voltage divider where R1=1kohms and R2=6.3kohms. Figure 4.5.1d shows the need addition.

PROCEDURE (Adjustable Output Voltage Versions)	EXAMPLE (Adjustable Output Voltage Versions)
Given: V_{OUT} = Regulated Output Voltage $V_{IN}(Max)$ = Maximum Input Voltage $I_{LOAD}(Max)$ = Maximum Load Current F = Switching Frequency *(Fixed at 52 kHz)*	**Given:** $V_{OUT} = 10V$ $V_{IN}(Max) = 25V$ $I_{LOAD}(Max) = 3A$ F = 52 kHz
1. Programming Output Voltage Use the following formula to select the appropriate resistor values. $V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right)$ where $V_{REF} = 1.23V$ R_1 can be between 1k and 5k. *(For best temperature coefficient and stability with time, use 1% metal film resistors)* $R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$	**1. Programming Output Voltage** *(Selecting R1 and R2)* $V_{OUT} = 1.23\left(1 + \frac{R_2}{R_1}\right)$ Select R1 = 1k $R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right) = 1k\left(\frac{10V}{1.23V} - 1\right)$ R_2 = 1k (8.13 − 1) = 7.13k, closest 1% value is 7.15k

Figure 4.5.1c: Procedure and Example for Output Voltage

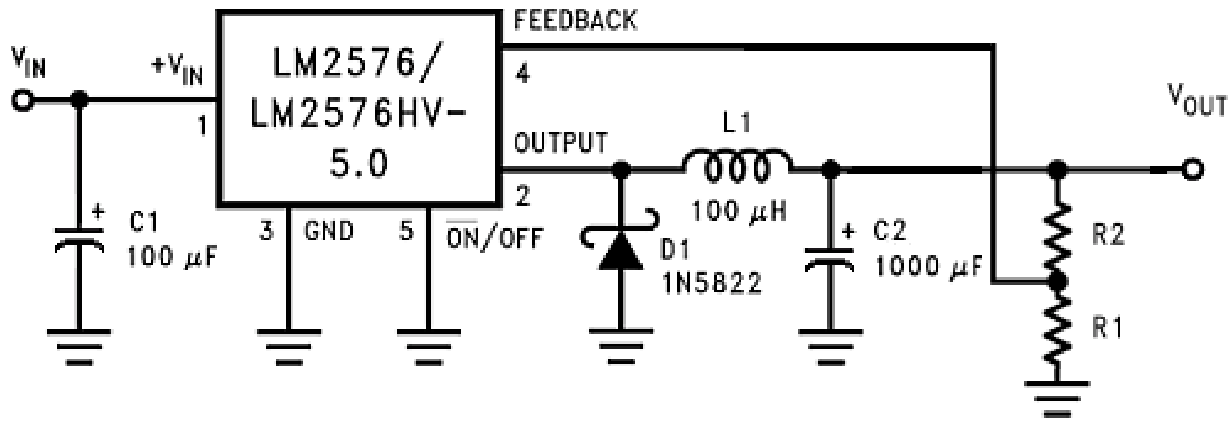


Figure 4.5.1d: Switching Regulator

Parts list:

- IC1: LM2576T-5V or LM2576HVT-5V (National Semiconductor)
- L1: 100µH (415-0930, 67127000, PE-92108, RL2444)
- D1: 1N5822 (Schottky Barrier Rectifier diode)
- C1: 100µF/75V (Aluminum electrolytic capacitor)
- C2: 100µF/75V (Aluminum electrolytic capacitor)
- R1: 1kohm
- R2: 6.3kohm

4.3.2 Voltage Path Diagram

Just like all electronic projects, voltage paths are important. All electronics have different specs and regulations it must follow. One of the most important spec to follow is the voltage of the part. In this fire-fighting robot, three different voltages need to be attended to. Like most sensors, the fire and ultra-sonic sensors for navigation require a 5-volt input. Along with the sensors, the transmitters for sending video and directional data require 5-volts. The microcontroller that will be used will have a 9-v regulator splitting the voltage to it. For the motors and speed controllers, normal battery voltage will work. Since the motors pull high amperage, they will be wired directly from a distribution block that is connected to the battery, to the electronic speed controllers to illuminate any voltage drop through wire or connections. Below is a picture of the voltage path diagram.

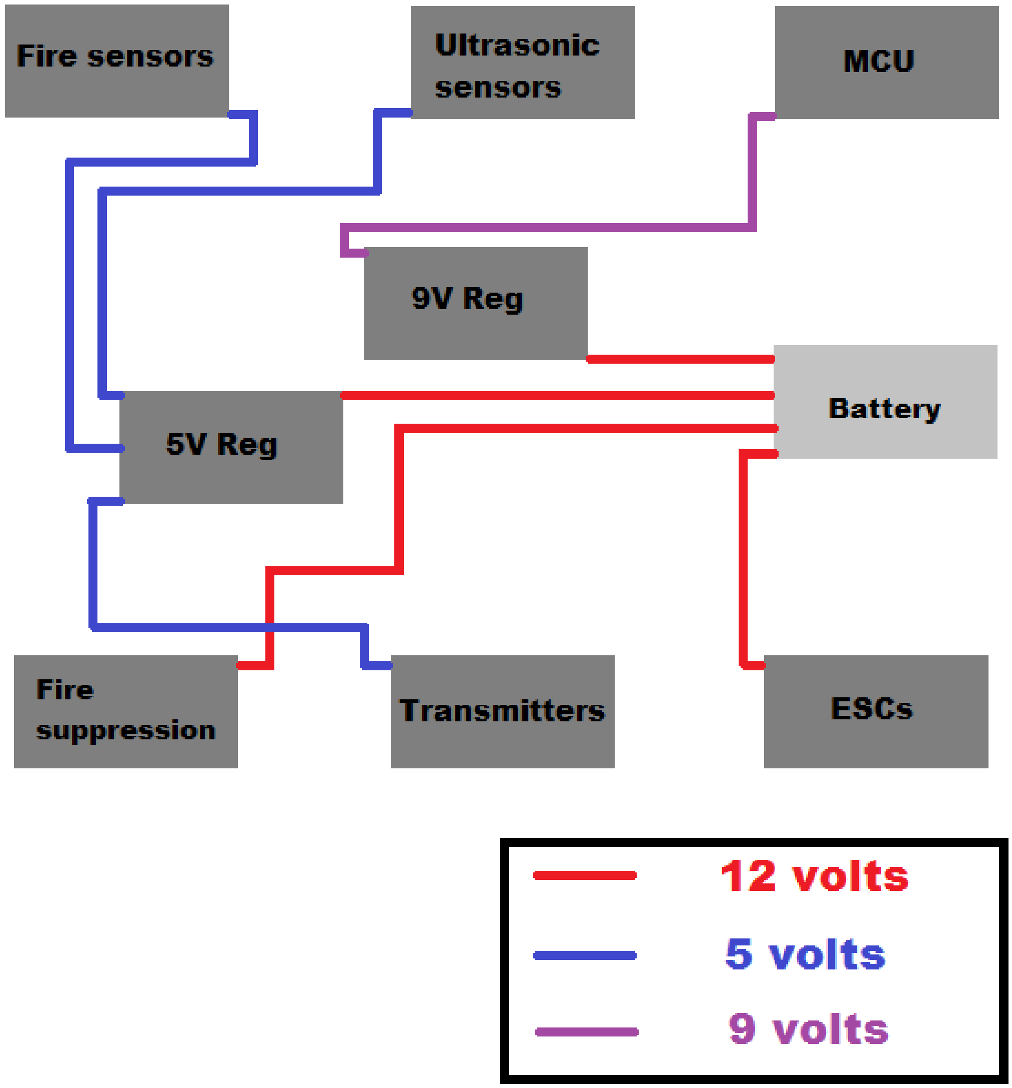


Figure 4.5.2: Diagram of How Everything is Connected

Figure 4.5.2 shows the voltage division that will be utilized in the fire-fighting robot. It is important to keep all the separate voltages separated and from over powering electronics that cannot handle a higher voltage. From the batteries 12.6v, the voltage is then sent to two separate switching regulators to step the voltages down to 5v and 9v for the different electronics that will be used. The motor controllers will have normal battery voltage to obtain the highest efficiency of the motors that can be had.

4.3.3 Battery Selection

From the research of necessary parts including motors (speed controllers), sensors, and microcontrollers, we gather that we will need certain power demands. Voltage, current, capacity, weight, size, and safety all become factors in finding the right power sources and distribution. When considering the load that the robot will be consuming, we have to take in consideration what each piece of the project will be drawing current and how much. Refer to the table below for the chart of power consumption of electronics.

Power Consumption of Electronics			
Part	# of pieces	Voltage(V)	Current Cons(mA)
Motors(ESC)	2	12	10000
Sensors	10	5	30
Microcontroller	1	9	1000
Fire Sup. System	1	12	1000
Total mA			**22300**

Table 4.5.3a: Chart of Power Consumption of Electronics

With the data from the different parts, we see that we will need a power source that can handle at least 23 amps. The following shows the types of batteries that were considered in the planning of our robot, each would include a description of the battery along with the pros and cons that were considered in the choosing of what would be used. Refer to the chart below for a list of potential batteries.

Possible 11.1v (12.6v nom) Batteries					
Brand	Capacity (mAh)	Weight (grams)	Dimensions (mm^3)	Price ($)	Discharge (C)
Venom	4000	314.7	147,960	38.69	20 (80a)
Venom	5000	448.0	168,084	61.97	20(100a)
Mulitstar	4000	244.0	114,240	34.34	10(40a)

Duratrax	4000	340.2	472,635	46.95	25(100a)
Duratrax	5000	430.9	490,724	59.34	25(125a)
Turnigy	4000	347.0	158,400	34.61	30(120a)
Turnigy	5000	412	184,730	39.99	20(100a)
ZIPPY	4000	286.0	127,280	65.95	25(100a)

Table 4.5.3b: Chart of Potential Batteries

Most of the batteries in Table 4.5b can be used and will work for this fire0fighting robot, however reviews and price come into play for the final decision. From the teams personal experience Turnigy batteries are seen to be more reliable and constant in the ratings that are given. In Figure 4.5.3 is the battery that the project will be using. The battery comes from Turnigy with promising reviews of use from many consumers. These batteries are proven to last and give the rated power it boasts. Table 4.5.3c shows the specs from the manufacture of the Turnigy LIPO that will be used. As seen in the table the battery has a C-rating of 20C, which means that continuous amp limit of the battery is 100amps. This rating for surpasses the needs of the robot, but the overhead is a positive for the case where upgrades may be made to the drivetrain. Higher amperage motors can be added for extra pulling and power. Also more accessories can be added to further help with the needs of the fire-fighting robot.

Figure 4.5.3, Turnigy 5000mAh 3S 20C Lipo Pack, approval pending

Capacity(mAh)	5000
Config (s)	3
Discharge (c)	20
Weight (g)	412
Max Charge Rate (C)	2
Length-A(mm)	145
Height-B(mm)	49
Width-C(mm)	26

Table 4.5.3c: Table of the Battery Specs

4.4 Circuit Wiring and Mounting

Knowing ahead of time how all the components of a project are to be placed is crucial. Figures 4.8a&b show how the two switching regulators will be wired. For Figure 4.8a, the input will be from the battery distribution block and have a voltage of 12.6 volts on a full charge. The ground will also connect to the ground of the batteries distribution block. The output will be 5 volts and will be sent to central board for all of the sensors to be connected to. For Figure 4.8b, the input will be from the battery distribution block and have a voltage of 12.6 volts on a full charge. The ground will also connect to the ground of the batteries distribution block. The output will be 9 volts and will be sent to the MCU to compute and send data for the main functions of the fire-fighting robot. Figures 4.8a shows the 5v switching regulators wiring diagram that will be utilized in the robot. This regulator will give power to all the sensors, transmitter, and receiver to achieve the functionality of the fire-fighting robot. Figures 4.8a shows the 5v switching regulators wiring diagram that will be utilized in the robot. This regulator will give power to all the sensors, transmitter, and receiver to achieve the functionality of the fire-fighting robot. Figures 4.8b shows the 9v switching regulators wiring diagram that will be utilized in the robot. This regulator will give power to the robot's main MCU where all the functions of the robot will be handled and sent to all the driving parts.

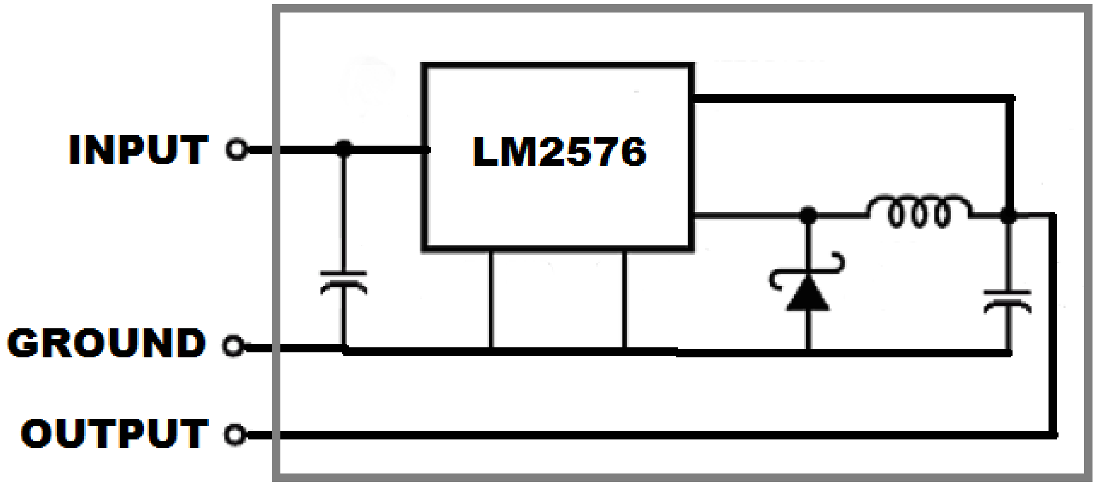


Figure 4.8a: Battery Distribution Block

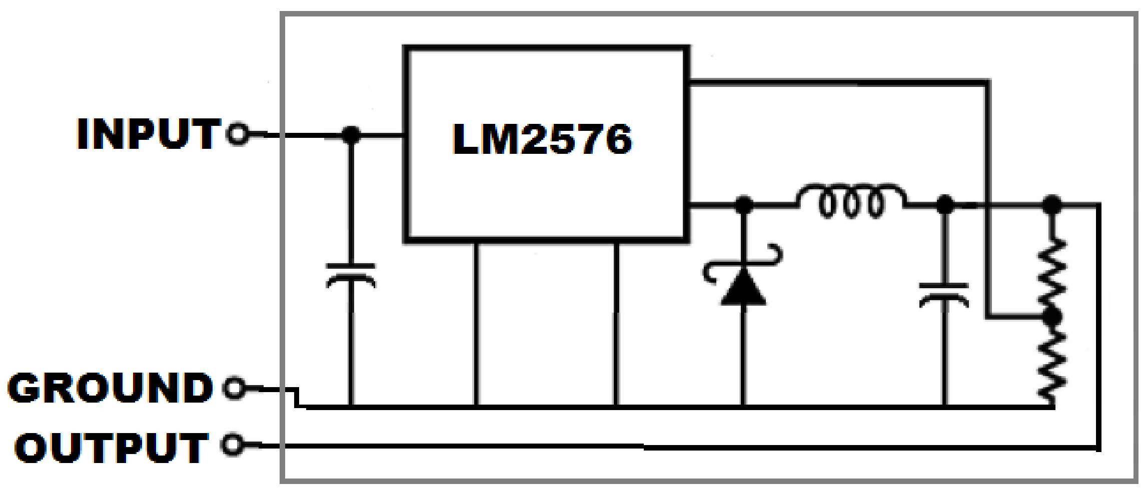


Figure 4.8b: 9 Volt Switching Regulator

4.5 Software Flow Diagram

The software flow diagram in figure is set up as multi-branch state machine diagram that starts with the top function of "Ping Ultra-Sonic Sensors". This shows the high level view of the algorithms that were chosen in earlier sections such as the wall tracking and flame detection. These functions were explained much more thoroughly in previous sections such as the Algorithm Development section under the Research header.

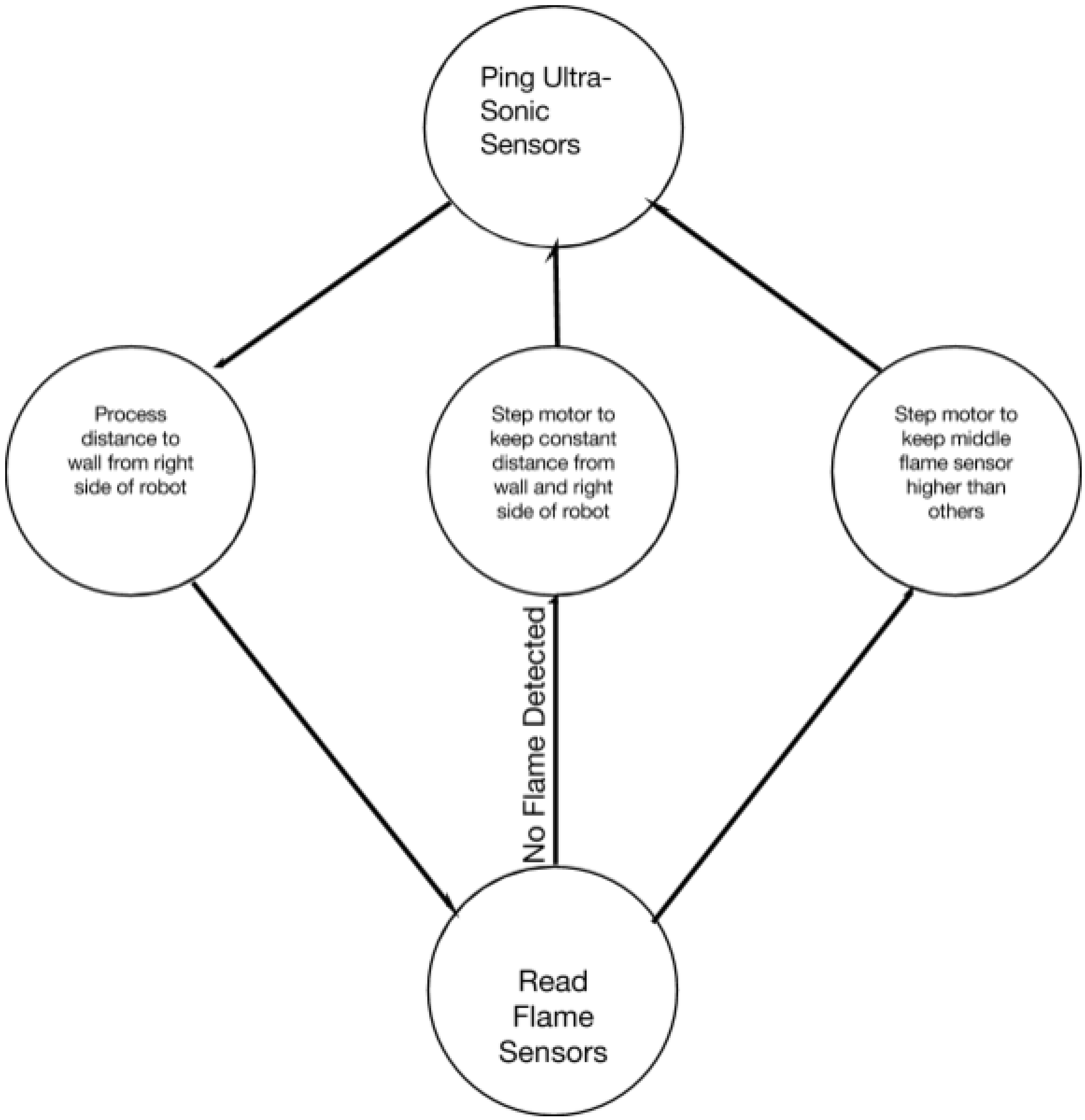


Figure 4.9.1: Software flow diagram depicting main algorithm from a high level perspective.

4.6 Microcontroller and Peripheral Selection

After weighing all options, the most practical choice for microcontroller of this project is an Atmel MCU. In particular, the Atmega640. The reason for this chip selection is due to the generous amount of IO, the package selection including non-SMD footprints, extensive library availability, and reliability. As discussed in earlier sections, it is more desireable to use a microcontroller with a through-hole footprint rather than a surface mount configuration due to complications arising with re-flow soldering as well as the inability to use a development board with SMD parts. With a through-hole footprint, the MCU can easily be placed in a development board for loading the bootloader, adjusting fuses, writing code, and debugging as well. After code has been written, the controller could easily be placed onto a socket on the PCB. With this chip selection the peripherals to the MCU are simply a crystal oscillator and 2 22pF ceramic capacitors, header pins for easy access to the SPI pins of the MCU, and header pins/ integrated on board connector for IO. All of these parts can be obtained from *Digikey.com* and Sky Craft for under 20$. Below is a comparison table for the MCU's.

Part Name	QTY	Description	Price ea. (USD)
Atmega644	1	MCU	10.87
TBD	1	16 MHz Crystal Oscillator	.30
TBD	2	22 pF Capacitor	.10
TBD	20	Sensor and Motor IO Pins	5.00
N/A	6	Standard pitch Header Pins	2.00
Total			18.27

Table 3.6.2.1: Comparison between various MCU's

4.7 Communication Selection

The reciever chosen for receiving the data from the transmitter is the Orange Rx R615X DSM2/DSMX 6CH 2.4 GHz Receiver. This receiver was chosen for its overall better characteristics when compared to all other receivers researched. This receiver offered 6 channels which was not the most channels out of all other receivers researched but will more than suffice for the vehicles' needs. Two channels will control the motors, one for the left motor and one for the right motor. The transmitter will also be used to switch from autonomous mode to manual mode with a flip of a switch allowing the human operator to easily take control of the vehicle. The Orange receiver also offers compatibility with both the DSM2 and the DSMX modulation types. This characteristic gives this receiver the ability to bind to almost any 2.4 GHz transmitter. The Orange receiver also features a failsafe which allows the receiver to send a pulse width to the microcontroller upon losing connection to the transmitter. The pulse width will be mapped to do a specific action in the coding. This action will most likely be to stop the motors of the vehicle and remain in that state until connection is returned to the receiver and the human operator can take back control of the vehicle. The range of the Orange receiver is more than adequate, and unlike the receivers in the MHz range the Orange receiver will be able to transmit without any problem through obstacles within the distance that the vehicle will be tested from. The price on this receiver being only $15.00 makes the Orange receiver one of the best choices. With this choice being $15 dollars most all other transmitters cost around $50.00.

The transmitter that the group will most likely use is a Spektrum DSM2 transmitter which does cost $50.00. Refer to the picture below for the orange six channel receiver.

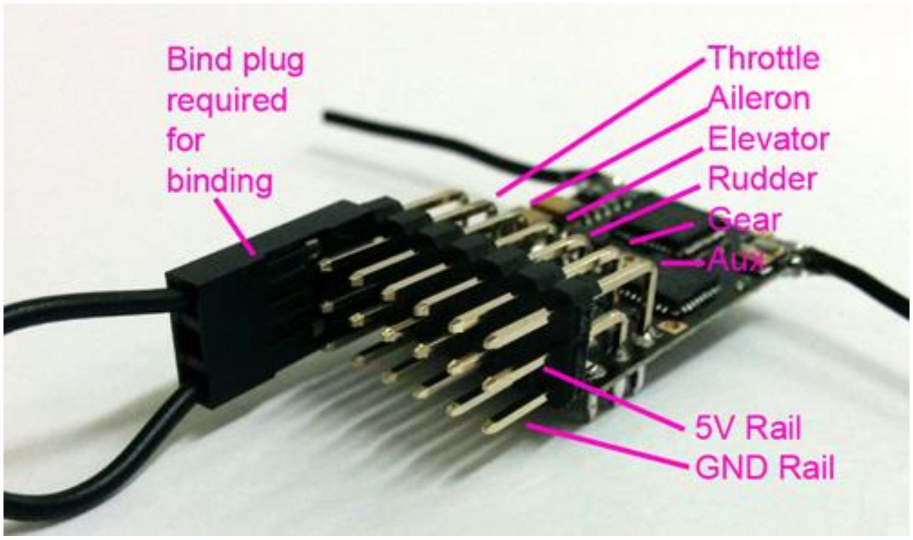


Fig.4.4: Orange Six Channel Receiver

4.7.1 Communication Pin Connection

As seen in figure 4.4.1 the wiring diagram of a simple remote control reciever can be seen. The receiver will have 2.4 GHz antenna that will wirelessly connect it to the transmitter that is given commands directly by a remote control. The remote control will send a command over the 2.4 GHz radio frequency to the remote control reciever which will in return be connected to a micocontroller. The reciever will have three wire connections. Two of the wire connection will be the postive and the ground. The positive wire connection will need a 5 v input which will be readily availble by the mirocontroller that the vehicle uses. The third wire will be the signal wire. The signal wire will send a pulse width moduation that will be connected to an input/output pin located on the microcontroller. If only two motor are be used by the vehicle the receiver will only need to have two signal wires connected to the microcontroller to control the motoros. If more components need to be controlled by the human operator such as the the fire suppression mechanism then more another control signal wire will have to be attached to the microcontroller. There will also need to be one more signal wire connected between the receiver and the microcontroller for the ability to switch between autonomous and manual mode that controls the vehicle. Each signal wire that is connected will deliver a pulse width modulation given by the transmitter that will then be mapped on the micrcontroller to control the motors forward, reverse and stop positions. A two position switch on the controller will deliver either a 1 for autonomous mode or a 0 for manual mode to the micrcontroller that will easily swtich between the different modes that the vehicle offers. Once the motor controller has received the input from the reciever the motor controller will the control the motor and the battery will be supplying all of the power to this entire system.

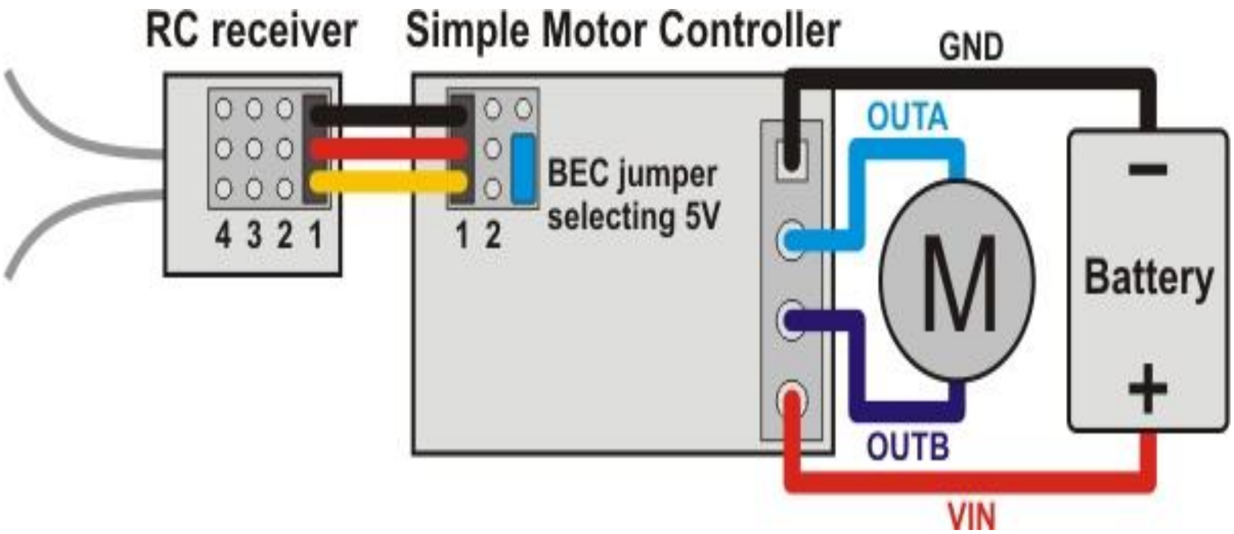


Figure 4.4.1: Receiver Connection

4.7.2 Communication Mounting

For the mounting of the receiver there are a few possible options to choose from. The wireless receiver will most likely be housed in a square shaped protective shell. The square shape will make it easy to adhere to the vehicle. A double sided 3M tape can be used by covering the entire bottom of the receiver and then attaching the receiver to the vehicle. This 3M tape that comes usually in a 10 or 15 pound hold strength will be more than enough adhesive strength to ensure the receiver does not move. Another option is to use velcro. Velcro unlike 3M tape makes it much easier to remove the receiver if there is an issue that requires the receiver be removed. Once the 3M tape is used to attach the receiver, the receiver is permanently attached to the vehicle unless the tape is cut away and then replaced. Using velcro is meant to be repeatidly removed and reatached. Another option is to use a glue to to attach the receiver to the vehicle. Using glue is an appopriate method if there is no possibility that the receiver will have to ever be removed. The issue is that if the receiver has to be removed for some reason there is a high chance that when removing the receiver either the vehicle or the receiver will be damaged in the process. The only ways to remove the receiver once attached by glue is using heat, pure force or a glue solvent, all of which could harm the vehicle or the receiver. Using hardware such as screwes could be an option if the plastic housing of the receivr has screw holes already implemented in the design. If screws holes are available for use then this would most likely be the best way to mount the receiver to the vehicle. If screw holes are not available then using a velcro will most likely be the next best method to mounting the receiver. Once the receiver is mounted, the location of the receiver is the next matter to be decided. If the vehicle frame is made from any metal once so ever then mounting the receiver inside of the vehicle is not a great choice. Metal or thick objects such as concrete can easily disrupt or even block a radio signal. Mounting the receiver on the outside of the vehicle on the top gives the receiver and the transmitter the best possibility of succesffuly communicating with one another.

4.8 Mechanics

4.8.1 Chassis and Motor

When choosing a chassis for a fire-fighting robot many options arise and many different applications need to be sorted. Smaller robots may only need two wheels and a bearing to achieve its goal where a large robot may need tracks for weight and speed. For the application of our fire-fighting robot a mixture of small size and large carrying capability is needed. There will be no turning wheels or joints in the drivetrain so a tank style approach will be taken. Research narrows down the choice between four different robot chassis that will work best for a fire-fighting robot. All four robot chassis considered are from servocity.com.

From research, the best suitable chassis will be the Scout from the Autobotics line made by ServoCity. It has a solid platform made from ¼" ABS plastic which has a melting temperature of 221°F. this temperature will work for the robot since it is a scaled version, and the fire source that will be used will not be out of control nor extremely hot. ABS allows for a strong rigid frame but is also very malleable and easy to cut and mold to the needed dimensions that is needed. The scout has plenty of ground clearance thanks to its 4.3" inch off road styled RC tires and rims. These will come in handy for traction and clearance. The size of the chassis is 7.5" by 10.5", which will give the team plenty of space to mount all parts, accessories and also plenty of space to run all necessary wires to make the robot able to complete its task. The robot has the ability to be low-profile if need be, on account of the space inside having a height of 1.32", with the ability to add on to the top plate for all the sensors and extras need. With this robot also come the motors. The motors are metal geared, so the risk of failure from stripping is reduced. All the specs of the motor that comes with this robot are in Table 4.11.1.

Operating Voltage	3-12v
Rated load	0.6 kgf-cm
Operating Temp	-10 to +60 C
No Load Speed	624RPM
Max Stall Current	4.9A at 12VDC
Output Power Efficiency	3.2W

Gear Ratio	19:1
Bearing Style	Dual Ball Bearing
Shaft Size	4mm
Net Weight	82g / each

Table 4.11.1 Motor Specs

Figure 4.11.1(From ServoCity, approval pending)

Figure 4.11.1 shows the Scout chassis that will be used. Its appearance and functionality will suit the fire-fighting project perfectly. Functionality is the main concern when picking the chassis to use, but appearance is also a main concern as well. From a consumer aspect, if a robot needs to be durable, it also needs to look durable. Specs and words can only go so far when looking at products, but when a product is and looks good, durable, and indestructible, a consumer will have a much easier time purchasing.

4.8.2 Motor Controller Selection

After considering the possible options for the motor controller the group has come to a decision based off of all specifications of each motor and what specifications outweighted the others for the objective of the vehicle. The Hobby Wing Wp-1625-BRUSHED is the motor controller the group has chosen to use to drive the motors. Hobby wing was the brand of motors researched primarily as possible options for a motor controller because this brand is a very well-known affordable and reliable brand of remote control devices and motor controllers. The Hobby Wing Wp-1625-BRUSHED motor controller was chosen for a few reasons. The price of this particular motor controller was the cheapest of the motor controllers researched. The price is less than $20 which makes this a very affordable option when considering that some motor controllers can cost $50 or more. The forward and reverse continuous current is 25 amps and the peak current is 100 amps. These current ratings should be sufficient for the motor that is chosen to drive the vehicle. Having a motor that has a higher current rating is never a bad decision but will prove to be unnecessary for the group goals unless a different motor is chosen that will require more current this motor controller will be chosen. The power requirement of this motor controller will work with the power system of the vehicle and be able to powered by a three or 4 cell LIPO battery efficiently. This motor controller is also water proof. This characteristic could be a very good trait if a water source is used to distinguish the fire source. The motor controller also has a decent sized heat sink that helps to distribute the heat created by the motor controller and since this vehicle is meant to work around a fire every type of cooling the components possess will only help the vehicle function correctly. Refer to figure 4.11.2 below for a labeled diagram of the chosen brushed electronic speed controller.

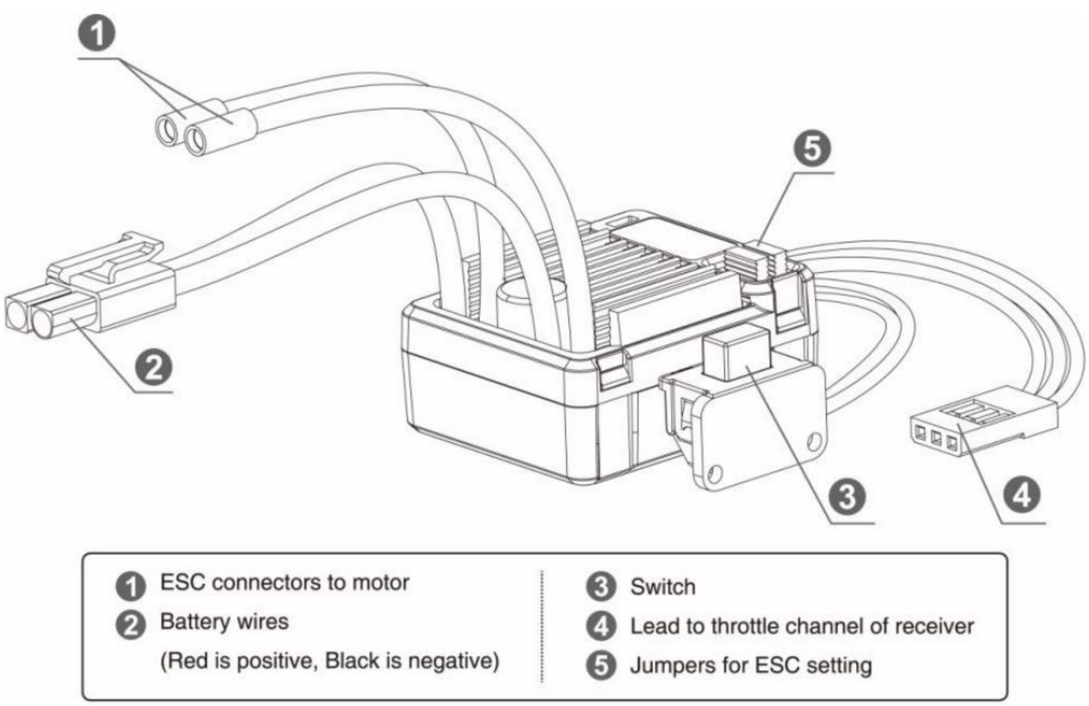


Fig. 4.11.2: Electronic Speed Controller (approval pending)

4.8.2.1 Motor Controller Pin Connection

The pin connections for this Brushed motor controller is very straight forwards. To start with there are two wires, one positive and one negative red and black respectively, that are connected to a power source. In this case the power source will be a three cell lipo. There are certain types of battery connectors that can be used to connect the motorcontroller to the battery by soldering the connecter male side to the motor controller and the female side of the connector to the battery. The female side goes to the batter side so that a short does not occur on the battery side. Connectors such as dean connectors, bullet connectors or even T-connectors. These are just a few connectors out of many and each has its reasons for being used such as preference and the amount of current that each can safely handle. The next two wires that are seen in the figure below will be connected to the actual motor itself. These two wires which are usually but not limited to the color of blue and yellow are the two wires that drive the motor. Generally switching these two wires will just change the rotation direction of the motor since neither one is considered to be negative or positive and there for makes it much safer for wiring and easy to change the direction of the motor. The last set of wires are a set of three that are connected to a servo connector. Two of these wires are ground and positive and one is signal, black, red and white respectively. This set of wires is usually called a BEC which stands for battery eliminator circuit. The battery eliminator circuit is an electronic circuit that is designed to power other electronic components without having to use another battery. Tpyically the BEC has an output of 5 volts and 1 amp of current. This particular motor controller does have a BEC that operates at 5 volts and 1 amp. This can be used if needed to power other devices such as a servo or other sensors. The third wire is on the BEC is a signal wire that is connected either the reciever or the microcontroller. This signal wire allows the ability to give instructions to the motor controller to increases its speed or decrease it as well as brake and in some motor controllers allow it to reverse its direction. Refer to figure 4.11.2.1 below for a wiring diagram of how the brushed electronic speed controller is connected to the brushed motor, reciever and power supply.

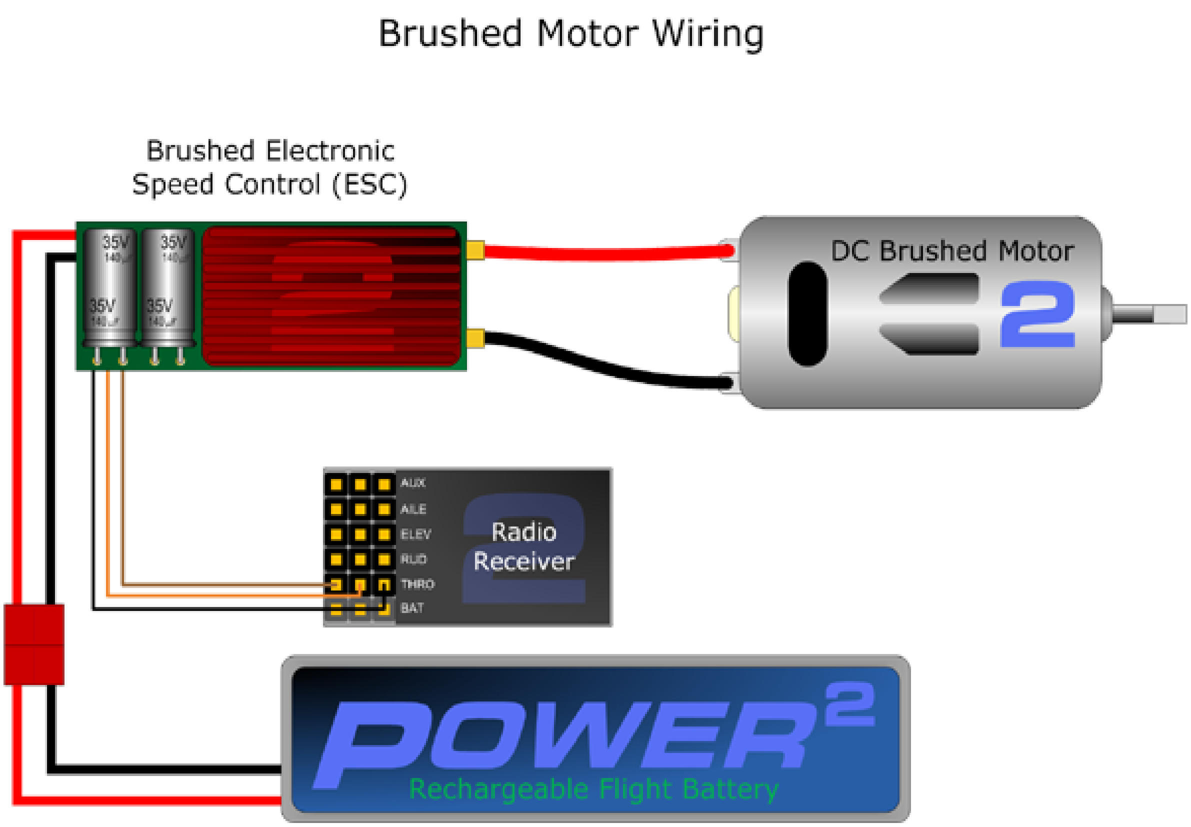


Fig. 4.11.2.1

4.8.2.2 Motor Controller Circuit Design

The circuit schematic below is a simple example of a brushed electronic speed controller used for a remote control car. This schematic has the ability to drive motors forward, reverse and brake. Circuit designs for motor controllers can vary in simplicity depending on the quality and specifications needed.this scematic shows a battery input in the top left hand corner and also the outputs labled vdd, vss, GP5,GP4, GP0, GP1, GP3 and GP2. The BEC can clearly be seen with on the left of the circuit where servo -, serv0 + and signal leads are labeled. The Servo + lead will have a voltage of 5 volts and a be able to output a current of 1 amp. Mosfets are clearly used on the positive and negative terminals of the motors to safely apply the current to the motors and also allow the ability to reverse the direction of the motors. In the top left hand corner of the circuit there is a low drop linear regulator labled L4941BDT that is used to regulate the input voltage of the battery to 5 volts with a current of one amp. This particular linear regulator can handle a voltage up to 16 volts and a voltage regulation accuracy within 4%. The typical voltage dropout is .45 volts at 1 amp. This type of regulator is used in almost all motor controllers that support a BEC and are fairly cheap pricing around $0.62 from an online retailer. The MOSFET used are 30 volt N-channel(SI4435) and a 60 volt, 300 mA N channel trench MOSFET(2N7002). Both are surface mounted and ideal over p-channel MOSFETS due to their electon mobility be much higher the the hole mobility of a p-channel MOSFET. The other components used are capacitors and resistors as needed for the proper design of this curcuit. Refer to figure 4.11.2.2 below for the wiring diagram of a brushed electronic speed controller.

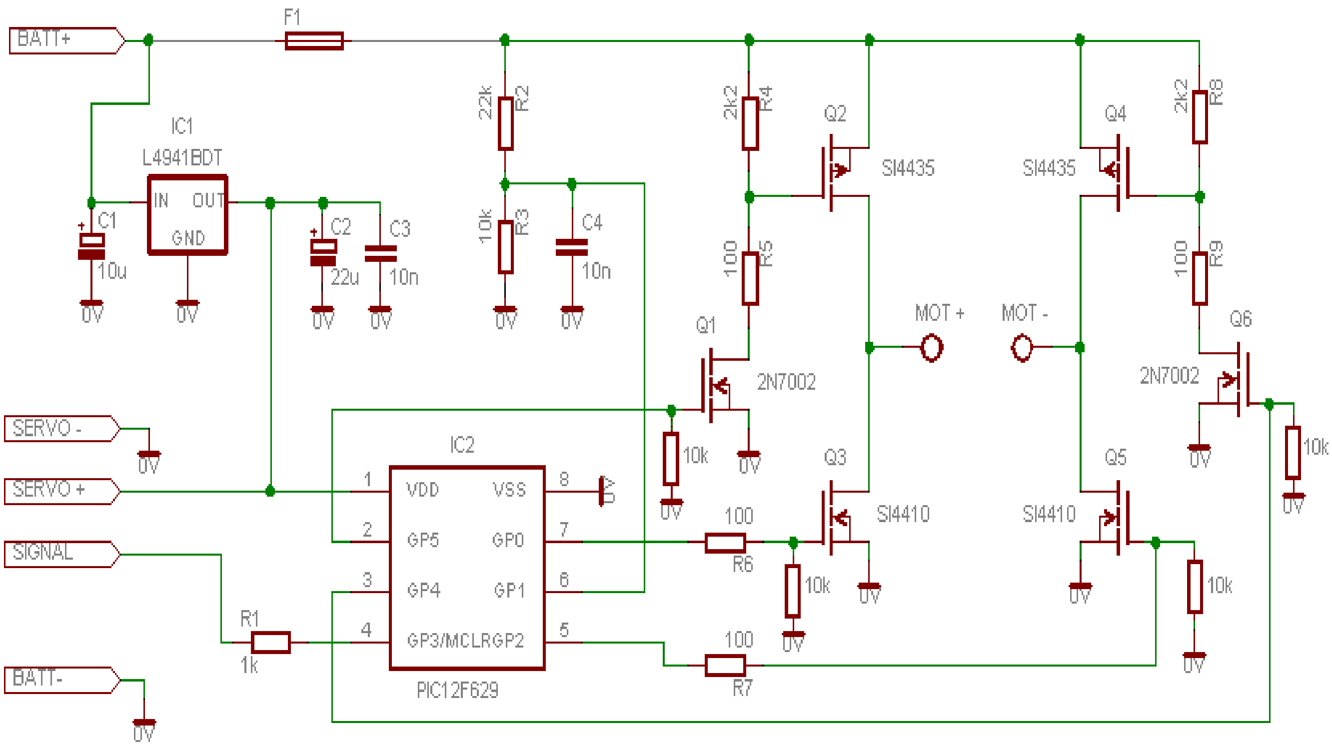


Fig. 4.11.2.2 shows a simply circuit schematic of a burshed electronic speed controller

4.8.2.3 Motor Controller Mounting

The motor controller needs to be mounted inside of the vehicles chassis and somewhat isolated from other components. The motor controller needs to be located inside of the chassis body and not outside so that it is not exposed to the heat of the fire or in potential harm of being snagged by any obstacles that may be encountered. The chassis should hold other components such as the microconntroller and all wiring which means all components must be placed so that there are no connections being made that should not be there. The motor controller will be mounted using 3M doublsided thick tape that can support 10 lbs. This tape will be used for adhesion as well as to elimanted vibrations. Screws will also be used to further secure the motor controller using the screw holes that are already available on the brushed electronic speed controller. A heat sink should not be needed since the electronic speed controller already has one mounted to the component.

4.9 3D printed Parts

For over usefulness and aesthetics, custom-made parts are necessary. To achieve the most functional and clean looking part that is possible, a 3D printer will be used to build the parts needed. A key aspect in building a fire-fighting robot is to keep all the internals of the robot safe and separated from the source of the fire. To have any important electronics visible or exposed could be catastrophic to the overall functionality of the robot itself. With safety being the main reason for keeping all electronics enclosed in the robot itself, aesthetics is important to keep the project looking as nice as possible. To achieve the goal of safety and aesthetics, a 3D printer able to print a strong and durable design is crucial. To achieve this, PLA will be the material used to print all the parts. PLA or Polylactic acid is a thermoplastic used in multiple situations on account of its high melting point of 320 °F, and its durability when used in important parts. Figure4.12e shows a concept 3D model of the fire-fighting robot. To achieve a streamline look multiple prints will need to be made and pieced together. The design calls for three main prints. The first print, Figure4.12a, will be the base. The base will include the bulk of the electronics including the MCU and also house the ultrasonic sensors to navigating. The second print, Figure4.12b, will be the middle bridge. The middle bridge will house the fire sensors and separate them from each other to keep from cross sensing each other's view. The third print, Figure4.12c, is the topper of the robot. The topper will house the fire suppression mechanism. A 120mm powerful computer-cooling fan will be mounted inside. The fan will extinguish the flame that will be used in the final presentation. The angle of the topper is to help aid the fan in the extinguishing of the fire. The last print, Figure4.12d, will actually be three different pieces, but identical. These will be plates to go around the ultrasonic sensors to keep the look around the sensors clean and to help seal off the inside of the base.

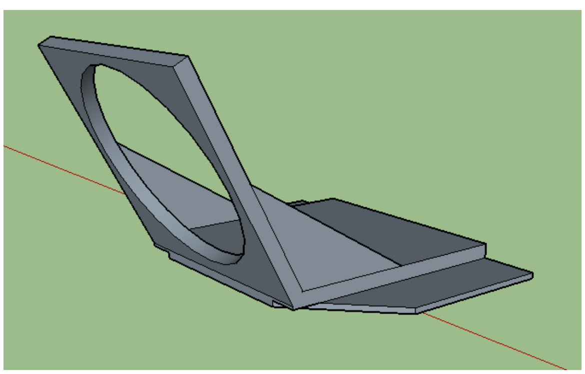


Figure 4.12a: 3D Sketch Up of Fan

The topper will house the fire suppression mechanism. This will be the attachment for the fan that will aid in the fire-suppression stage of the robot. This piece will be printed in multiple stages. Once printed, the pieces will be glued/epoxied to keep the base of the fan solid.

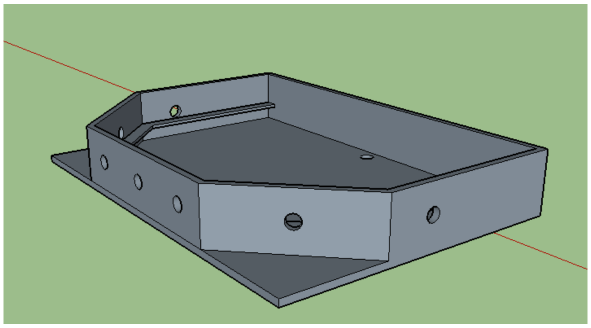


Figure 4.12b: 3D Sketch Up of Flame Housing

The middle bridge will house the fire sensors and separate them from each other to keep from cross sensing each other's view. Each of the seven holes are 1/8" in diameter and will house an single fire sensor. Each sensor will be housed separate so no cross viewing can happen. If they were not separated, the sensors can read false values and not be able to react in a correct manor.

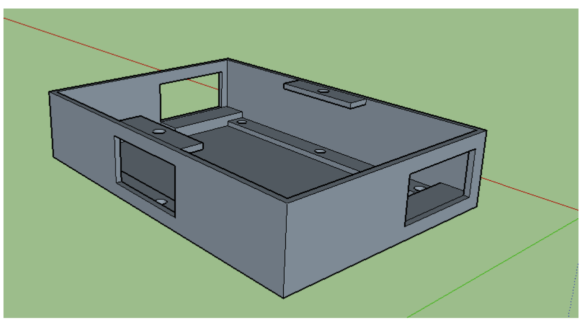


Figure 4.12c: 3D Sketch Up of Ultrasonic Sensor Housing

The base will include the bulk of the electronics including the MCU and also house the ultrasonic sensors to navigating. To keep the different main voltages separate, the battery will be housed in the lower part of the robot in the main chassis. The motors take 12volts ever the electronics in the top will be a lower five and nine volts to keep them separated and not have a risk or shorting or being wired incorrectly.

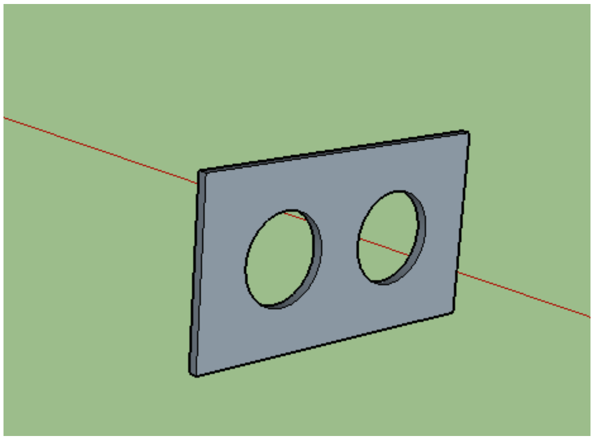


Figure 4.12d: Another Sketch Up of Ultrasonic Sensor Bracket

These will be plates to go around the ultrasonic sensors to keep the look around the sensors clean and to help seal off the inside of the base. Once the ultra-sonic sensors are placed, these covers will be mounted around the body of the sensor to seal off the inside of the base from the outside. This will help keep the electronics safe from external hazards and also keep the look of the robot clean.

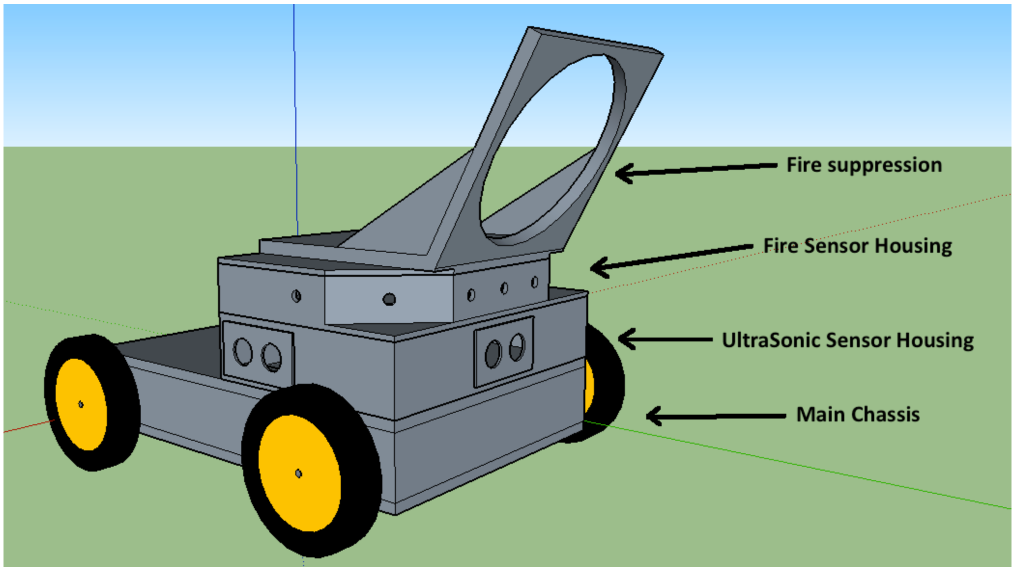


Figure 4.12e: 3D Sketch Up of Entire Robot

Figure 4.12e shows all the 3D printed parts assembled to give the final concept life. In the figure, you can see that the 3 main pieces are stacked on top of each other to give all the sensors the height they need and have the fan angled to the fire for suppression. All the pieces will be assembled by using nuts and bolts to attach each part to the part under it. 1/8” bolts will slide in mounting brackets and be able to fastened to the main chassis of the robot.

4.10 Motor Selection

After considering the possible options for the motor controller the group has come to a decision based off of all specifications of each motor and what specifications outweighted the others for the objective of the vehicle. The RC4WD 540 Crawler Brushed Motor (35T) is the motor the group has chosen to use. The voltage requirements for this motor lie within the ideal battery source that the electrical system will use which is between two to three cell LIPO. The current consumption of this motor at its max is quite low. With the current being only 4.62 amps, the power consumtion will be sufficiently low. Also, with the current being this low almost all of the motor controllers will effectively drive this motor. The torque will adequately drive the motor with the correct strength and speed needed to move the pay load with a satisfactorily speed without stalling. In the budget, motors were alotted $10 per motor. This motor was only $9.99, which meets the budget stipulations. Refer to figure 4.13 to see the motor that the group chose for this project.

Figure 4.13: Picture of Motor Chosen(reprinted with permission from Mike at rc4wd.com)

4.10.1 Motor Pin connection

There will be two brushed motors in order to drive the vehicle left, right, forwards and reverse. Each brushed motor will have two wires connected to an electronic speed controller. One wire will be the positive and one wire will be the negative. In most cases switching the positive with the negative wire will reverse the direction of the motor form clockwise to counter clockwise or vise-versa. This simple wire connection makes it easy to manually change the direction the motor is spinning without any complex coding algorithms. From the electronic speed controller each motor will be driven by a pulse width modulation that will control the speed of the motor as well as have the ability to brake each motor. From the electronic speed controller the positive and ground wires are fed directly to the battery which provides the power to drive the motor. From the electronic speed controller there are also three wires that are connected to the positive, ground and signal of a receiver. The signal wire from the radio receiver gives the digital commands with a pulse width that tells the motor to go forward, reverse or brake. In figure 4.13.1 below, a visual representation shows how the group will wire the brushed motor.

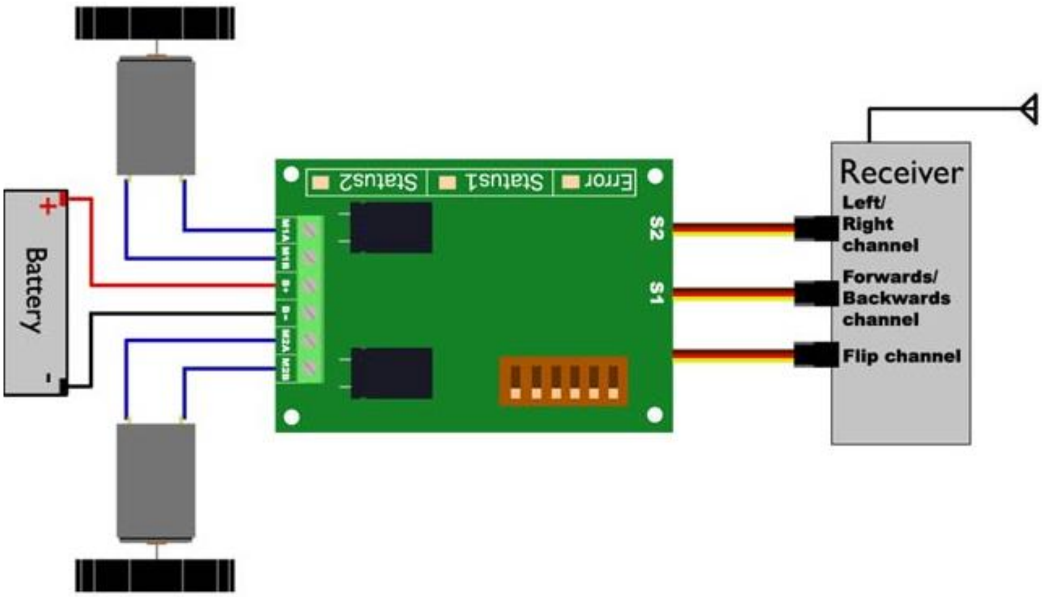


Figure 4.13.1: Wiring Diagram of Two Brushed Motors Connected to ESCs

4.10.2 Motor Design

Figure 4.13.2 below shows the design of the cross sectional area of a brushed motor.

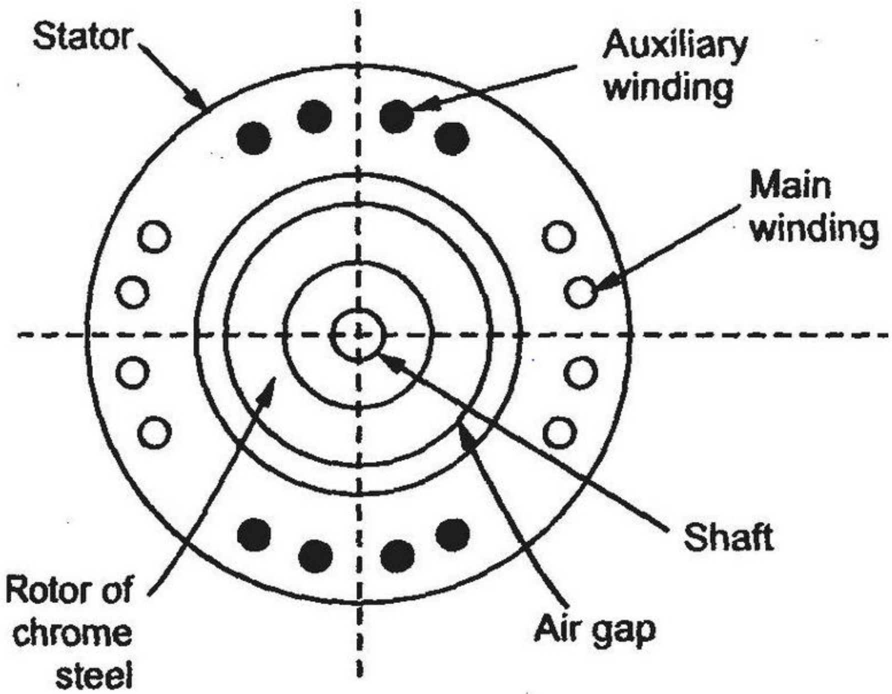


Figure 4.13.2: Cross Section of a Brushed Motor

4.10.3 Motor Mounting

The motor will be mounted using the appropriate screws and motor brackets that usually come with the motors. This will be the best choice for mounting because it is what the manufacturer recommends. Alternative methods of mounting the motors would be to directly insert them into the frame and adhere them to an adhesive or solder/weld. The screws will be secured using thread locker which is a light glue used to secure screws and prevent them from coming loose during vibrations and use.

4.11 Camera Selection

After considering the possible options for the motor controller the group has come to a decision based off of all specifications of each motor and what specifications outweighted the others for the objective of the vehicle. The Mini CMOS Wide Angle FPV is the camera the group has chosen to be used for first person viewing for the vehicle. This camera was chosen because it has a 170 degree viewing angle. This surpasses the other cameras researched and is an extremely important characteristic because without a big enough viewing angle, there will be blind spots which can lead to obstacle collisions. If an obstacle collision occurs, there could be damage to the vehicle and its components. This may hinder the vehicle from completing the task of suppressing the fire. The voltage is 9-12 volts which will require a three cell LIPO battery. A three cell LIPO battery can be used for the power system and be regulated if necessary to step down voltage to other components, while still supplying the necessary voltage to power the camera. The current rating of this camera is 55 milliamps. This is an extremely low amperage rating for an electrical component for the electrical system. With the current pull of this camera being so low, it will hardly place any strain on the power source, leaving ample battery life for other components connected to the electrical system. The resolution of this camera is more than sufficient. If the resolution is too low, the image quality will be poor and that will lead to the user having difficulty navigating the vehicle in the right direction. The price is less than $20, which makes this a very affordable option when considering that most cameras cost more than $45. Figure 4.14 below shows the camera that the group chose for this project.

Figure 4.14: Picture of Camera Chosen(reprinted with permission from Carlos Tong)

4.11.1 Camera Pin Connection

The Mini CMOS Wide Angle uses a four pin configuration. One pin is designated for the five to seventeen volt input to the module and one pin is used for the ground. The third pin is an input output pin that is used for video signal. The fourth pin is also an input output pin that is used for video signal. The pins are male header pins that are ready for a breadboard. This is great because it can be easily tested and mounted without the need for soldering connections.

4.11.2 Camera Mounting

Proper camera mounting is one of the most vital parts of this project. If the camera is mounted too low, the pilot of the vehicle will only be able to see the ground, and nothing else around the vehicle. If the camera is not mounted on the front of the chassis it will not be an accurate video feed. The pilot will not be able to accurately pin point the flame with respect to the fire suppressant. The camera will be mounted using the appropriate screws and motor brackets that can be purchased for a cheap price. This will be the best choice for mounting because it is what the manufacturer recommends. An alternative method of mounting the camera would be to find a case for it, and attach it directly to the chassis. This would be done using thread locker which is light glue used to secure screws and brackets to prevent them from coming loose during vibrations and use. Another way to adhere the camera would be to use double sided 3M tape directly onto the chassis. The last option for mounting the camera would be to use Velcro directly onto the chassis. The camera would be in its appropriate case with brackets and placed at the top of the chassis to ensure the pilot of the vehicle can properly see the video feed.

4.12 Video Transmitter and Receiver Selection

After considering all of the possible option for the video transmitter and receiver pairs, the group has come to a decision based off of each specifications of each video transmitter and receiver pair and what specifications outweighed the others for the objective of the vehicle. The 8CH Boscam Wireless Transmitter Receiver is the video transmitter and receiver pair the group has chosen to be used for the vehicle. This particular video transmitter and receiver pair was chosen because it has a 2000 meter range. This range is more efficient enough for this particular vehicle. Since the group will have a scaled down version of an autonomous firefighting robot, not as much range is needed. The voltage for the transmitter is 7-15 volts which will require a two to four cell LIPO battery. The voltage for the receiver is 12 volts which will require a two to three cell LIPO battery. The frequency of this particular video transmitter and receiver pair is 5.8 gigahertz. This is a good frequency because this particular one is never crowded by other things such as wireless networks, garage doors and cordless phones. All of these things run off of the 2.4 gigahertz frequency band. The price is $33.99, making it a moderate price. Only one video transmitter and receiver pair will need to be purchased so this price will be sufficient and affordable for the group. Figure 4.15 below shows the video transmitter and receiver pair that the group chose for this project.

Figure 4.15: Picture of Video Transmitter and Receiver Pair Chosen(approval pending)

4.12.1 Video Transmitter and Receiver Pin Connection

For the transmitter, there is a power and ground pin and there is a power and ground that goes to the camera. There is also a video signal wire that connects directly to the camera. The power and the ground pin are connected to the battery and the other power and ground pin goes directly into the camera. The antenna wirelessly transmits the video to the receiver. The receiver has a power and a ground pin, and also has RCA cables attached to a headphone jack wire that splits off into RCAs. The power and ground pin are connected to a battery, but a separate battery than the one that is used for the transmitter. The RCA cables are plugged into a display. Figure 4.15.1 accurately shows the pin connection of the video transmitter.

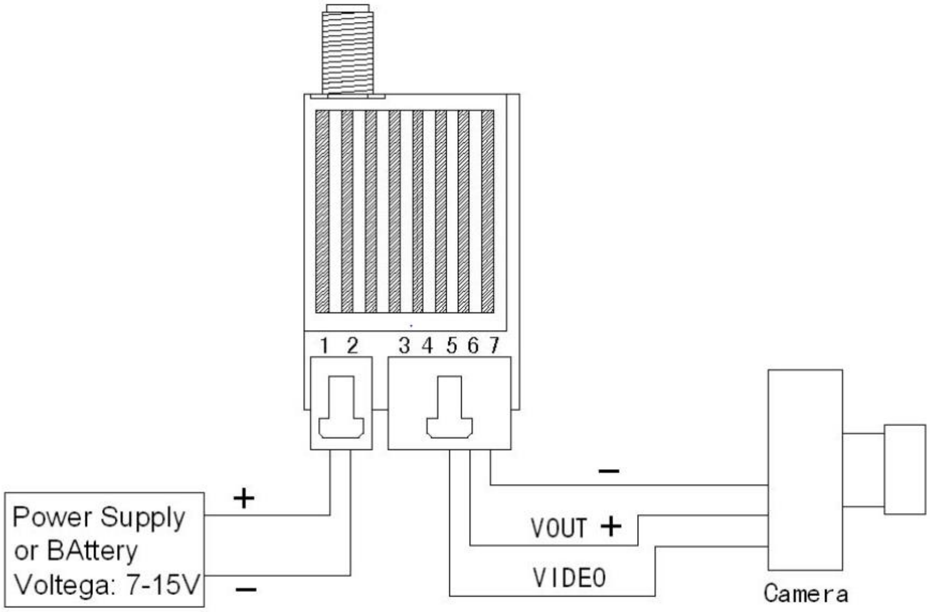


Figure 4.15.1: Pin Connection of a Video Transmitter

4.12.2 Video Transmitter and Receiver Mounting

The transmitter will be connected to the camera. Ideally, the transmitter would be directly next to the camera to reduce the amount of wired. But with all of the other components on the vehicle, there will most likely not be enough room. Wires will be run to accommodate for the space issues. The transmitter will be located behind the camera and be mounted with 3M tape. Another way to mount the transmitter is to use Velcro. Both of these options are sufficient to keep the transmitter attached to the vehicle despite vibration and other movements. The receiver will be connected to the display and it can be mounted several different ways. One way of mounting the receiver is to Velcro it to a tripod, which is what is making the display eye level to the pilot of the vehicle. The receiver can also be mounted using 3M tape. Another way of mounting the receiver is to mount it directly to the display. The receiver will be mounted using either Velcro of 3M tape on the back of the display. This has the least amount of wire. The last way of mounting a receiver is to make a briefcase display. This is used for portability. The mounting that the group will use is the method of taping the receiver directly onto the display. This is the easiest and safest method to use.

5.0 Engineering Standards

What are standards? Standards are documents that define certain characteristics of a product, procedure or service, such as size constraints, safety protocols, and performance requirements.

Following certain standards for the fire-fighting robot can be tough but is also very important. Each part of the robot assembly and design needs to follow the IEEE standards to be a successful project. All the Standards that were found and followed are listed with the type of standard and the standard number.

Standard Subject	Standard Number
Rechargeable Batteries	1625-2008
Ultrasonic Sensors	139-1988
DC Motors	113-1985
MCU	15205-2000
Fire Protection	979-1984

Table 5.0: Engineering Standards Chart

These standards in Table 5.0 will be followed so that all persons involved with the fire-fighting robot will be safe and free from detriment.

6.0 Test Procedure

This test has been constructed to verify the feasibility of the flame sensors purchased that have been mentioned in previous sections. These tests will include testing limited functionality as well as accuracy, but will NOT be in final tuning or design. The limited functionality test will be used to filter out any units that do not operate due to manufacturing defects. This test simply verifies that the unit under test is able to be powered on and can output some value related to an introduced flame, or no flame at all. The accuracy test will verify that over a distance from 4-24 inches, the flame sensor can detect the flame, and has output variation as a function of distance. This relationship between output level and flame distance (with flame size remaining fairly constant) will be used to tune the sensors on a hardware level, as well as a software level. The test system overview section provides information as to how signal will flow from the reading of the sensor to the test operator as well as how every piece of test equipment will be powered. The specification section below is not necessarily based on the overall specifications outlined at the beginning of this document, but apply to the specifications required for the test equipment used. These specifications may or may not have been derived from previously defined global specifications. The wiring section below shows how each device is individually connected into one test system at the lowest wiring level needed by the test operator. The pass fail criteria section at the end of this test procedure will be used to define failure for each test, as well as a tool to provide adequate suggestions for the next decision. It should be mentioned that the pass fail criteria section is merely a suggestion for the next step, and therefore does not always provide the best solution. Engineering judgement should be used as a first resort when dealing with product failure, and the pass fail criteria should be used as an aid. Note that every flame sensor unit that is to be used in the final design must go through both the limited functionality test as well as the accuracy test listed below as to gather useful data that will be used to customize tuning at the software level. It should also be noted that in every test listed below, standard electrostatic discharge safety and power safety precautions should be followed.

6.1 Test System Overview

From a top level, the power flow will be as follows: a PC connected to a stable power source with earth ground will provide 5v DC regulated power through a standard USB type “A” outlet to the Atmel development board USB type “B” power input. This input is located on the same side of the development board as the 5v DC jack power input. There is no need to pass this power through any other devices such as a current/voltage buffer. This power will then be regulated and filtered again through the development board’s on-board power section. The flame sensor will then be powered from a 5v output header pin from the development board, completing the power flow chain. A basic power flow diagram is listed below:

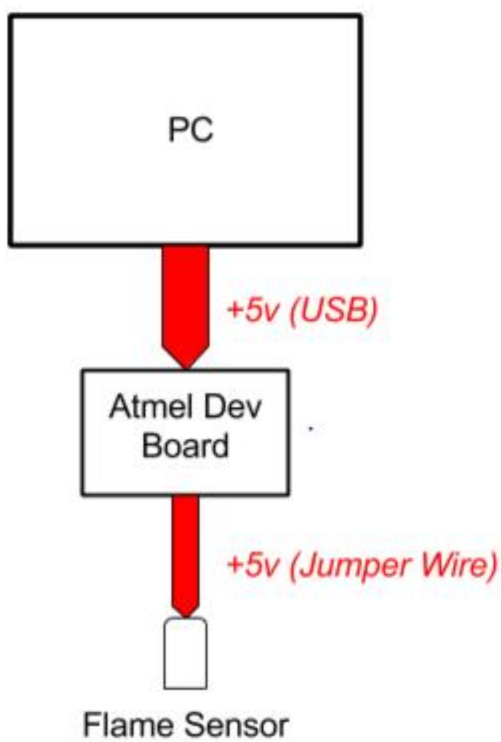


Figure 5.2.1a: Top level system power flow overview test set-up for flame sensors

From a top level signal flow perspective, a laptop will be connected via serial link (USB) to a development board for the Atmel chip, which is connected to the flame sensor. The flame sensor will send analog data back to the development board's analog to digital converter (ADC) which will then be sent to a serial monitor display on the connected PC. A basic signal flow diagram is listed below:

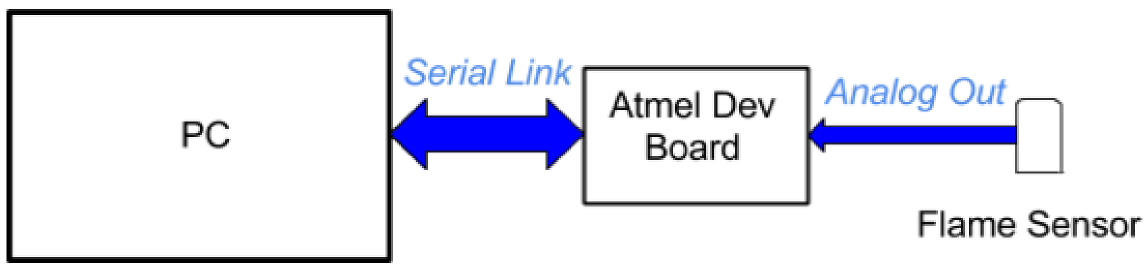


Figure 5.2.1b: Top level system signal flow overview test set-up for flame sensors

6.2. Test Set-Up

This section will be used to outline the testing equipment specifications and low level wiring diagrams of each test configuration.

6.2.1 Specifications

The test set-up for the limited functionality test will be identical to the set-up for the accuracy test. For the sake of simplicity, an Arduino development board will be used during testing and prototyping stages only. Although it would be ideal to use an Arduino board with the same Atmel chip that will be used in the final design, this is not necessary. For example, if the final design will use the ATmega 256, it is OK to test limited functionality and accuracy with an Arduino Uno (ATmega 16). The PC used is also not extremely specific as the code and software development platform being used are very portable, although a computer running Windows 7 or later is preferred with the latest release of the Arduino IDE software. The serial monitor within the Arduino IDE will be used to read the analog output of the flame sensor. The code to be used for this test will be provided in the appendix of this document. The serial link between the PC and Arduino board shall be a USB type "A" male to USB type "B" male. The power, ground, and analog wires between the Arduino and flame sensor shall be standard 28-36 AWG solid core copper/silver/gold wire or male to male jumper wire. Unit under test (UUT) shall be defined in previous research section of flame sensors.

6.2.2 Wiring

Although all voltages used in this configuration are moderately low, proper voltage safety precautions should still be followed. For this reason, it is ideal to wire the Arduino to the sensor before connecting to external power (PC to Arduino). Using a jumper wire and breadboard (or other wire approved in above specification section) connect the output pin of the flame sensor to the first analog input of the Arduino (pin A0). Similarly, connect the VCC pin of flame sensor to Arduino 5v output and GND to Arduino ground. Verify wiring matches that shown in image below. Next, connect the male USB “B” end to the Arduino power/programming port and connect the male USB “A” end to a PC. It is not necessary, but if possible, connect this PC to a 120V AC “wall” power outlet using a standard 3 prong cable to properly ground the system. (Can attach 10uF capacitor between A0 and GND for stability) See wiring diagram given below.

6.3 Limited Functionality Test Procedure

Verify that system components meet requirements as specified in all previous sections of this document, especially those pertaining directly to this test given above. Verify that wiring is connected correctly and that the PC can identify the specific development board being used in this test. Load test code (given in appendix) onto development platform using the latest release of the Arduino IDE software. Open the serial monitor within Arduino IDE and verify baud rate is set to 9600. Verify that the sensor is outputting some value to the serial monitor, which would be evident by numbers scrolling up the screen. Take note of what number is displayed under the control case (no flame). Using a grill lighter while watching the serial monitor, create a flame about 12 inches from the direct center of the flame sensor and verify that the numbers on the serial monitor change to some other value. (See figure below) Now, twist the potentiometer on the flame sensor a quarter turn clockwise and repeat this test. Verify that the numbers have changed between these two cases. Power down test set-up after recording results. Below is a picture of the testing of the flame sensor.

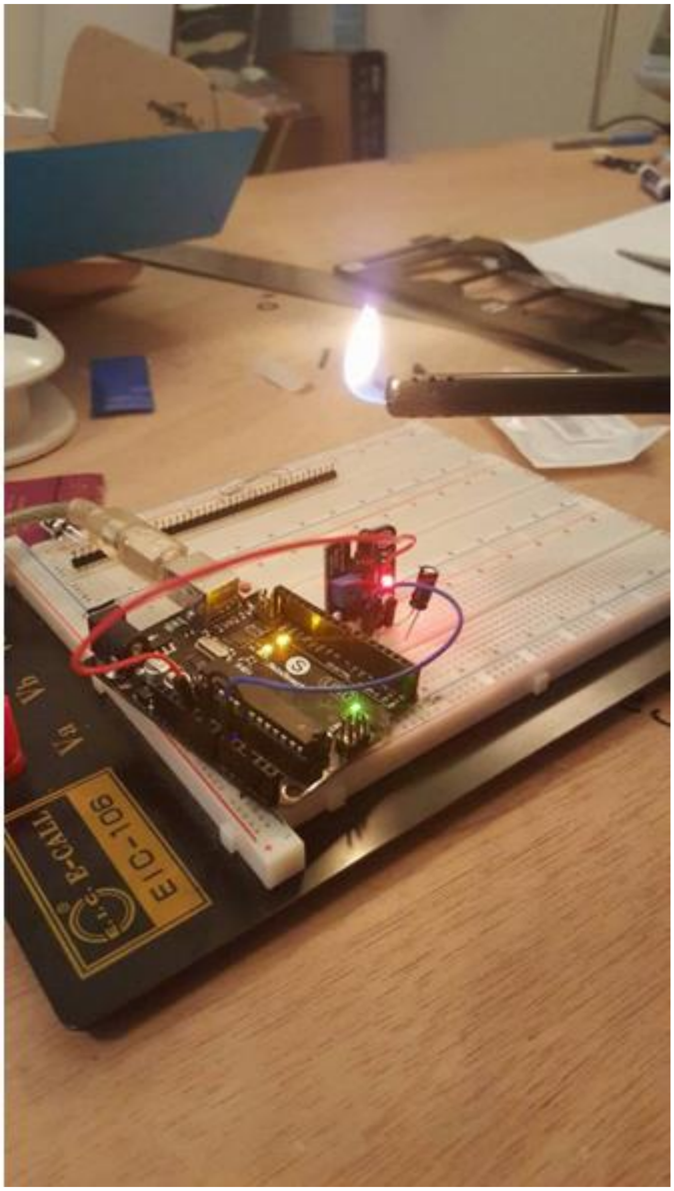


Figure 5.2.3.1: Test set-up for both LFT and accuracy testing

For this test setup below, the equipment used is as follows: breadboard, Arduino UNO microcontroller, USB data cable, laptop, infrared sensor and a candle. This test was to see what values are read through the serial monitor based off of distance between the flame and the sensor. The data that was gathered through testing is vital to ensure that the groups programmers has accurate information to correctly program the flame finding algorithm. The procedure used is: initiate serial connection between laptop and MCU, place candle two inches from sensor, light the candle, take serial monitor reading value, increment the candle distance by two inches and retake reading. These steps are continued until the distance is three feet in length. This testing is pictured below.

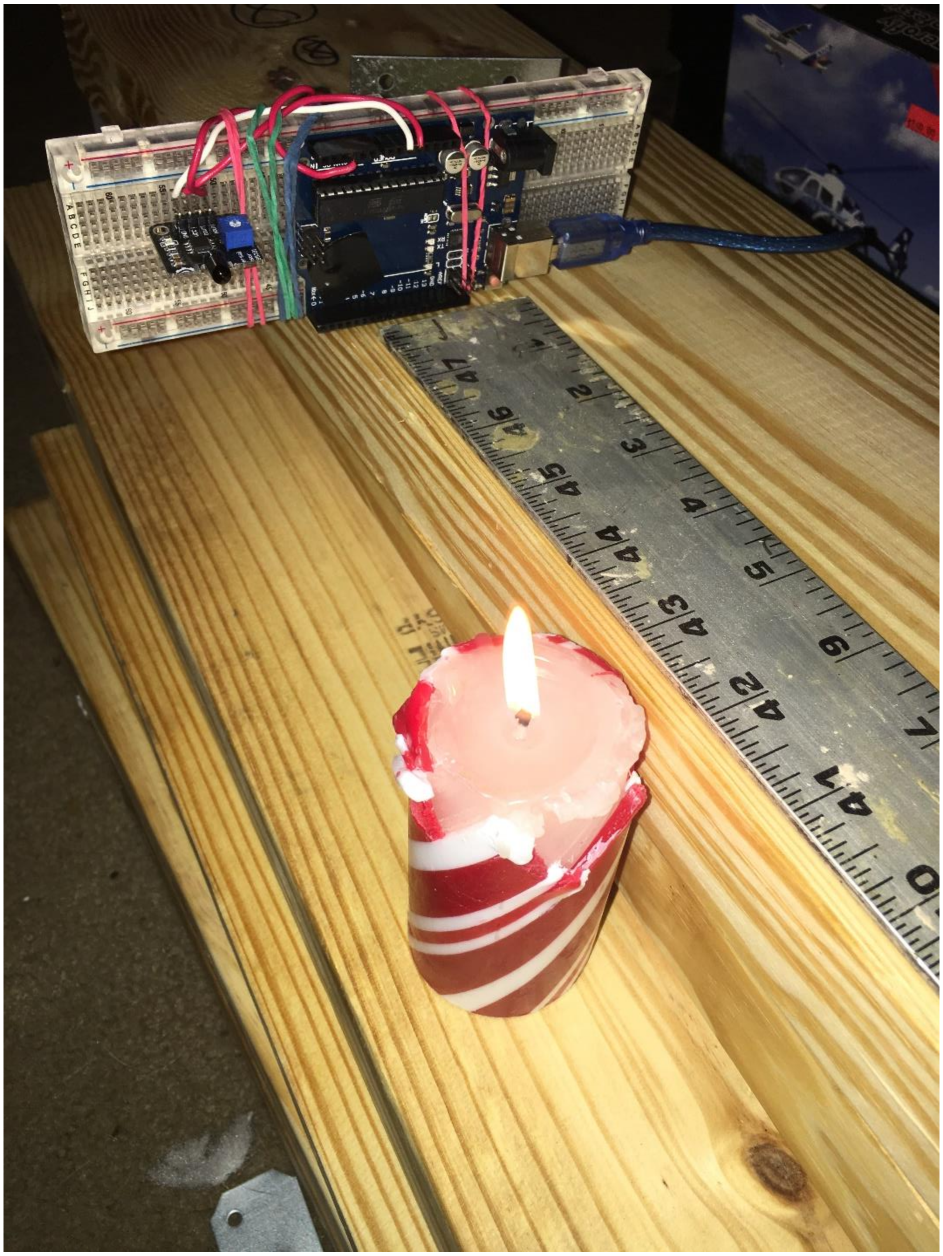


Figure 5.2.3.2: Testing of the IR Sensor

For the testing procedure below, the equipment used is as follows: Arduino UNO microcontroller, USB for serial connection, laptop, breadboard, ultrasonic sensor, and a poster board for a flat surface. This testing procedure was used to test the accuracy of the ultrasonic sensors. The testing procedure is: initiate serial connection between laptop and MCU, increment distance between ultrasonic sensor and flat surface by two inches, intake the serial reading and the distance on the ruler. Repeat these steps until three feet is reached. The testing is pictured below.

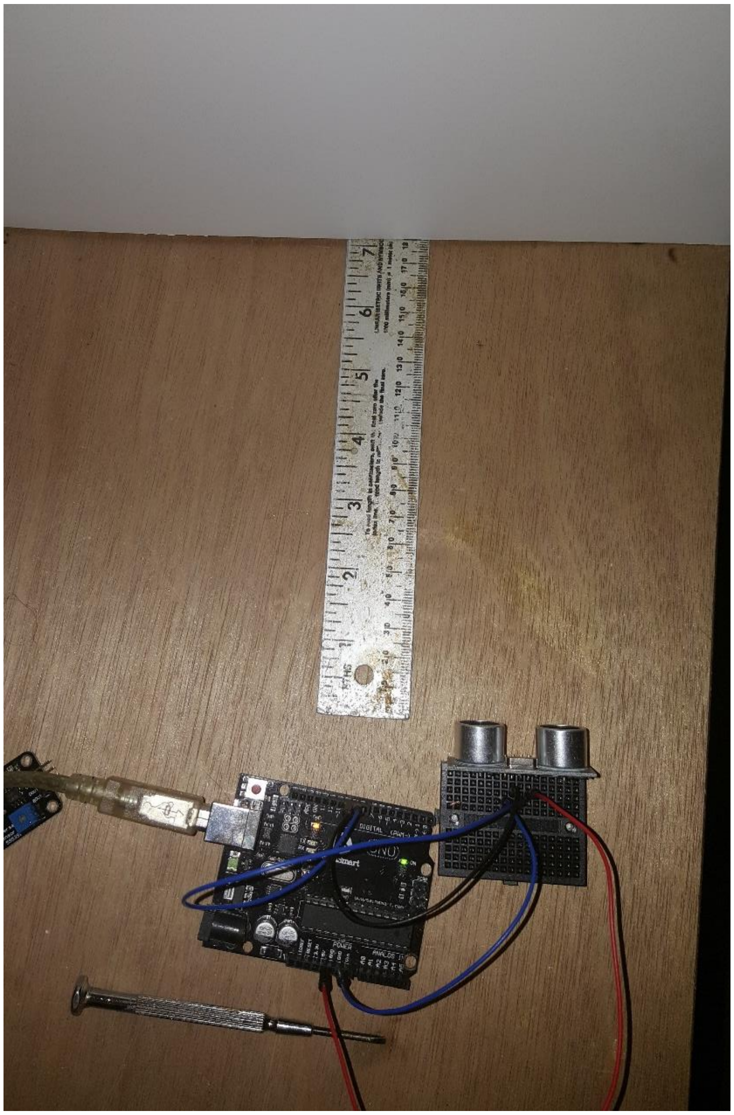


Figure 5.2.3.3: Testing of Ultrasonic Sensor

In the figure below are the results for the flame distance testing. The X-Axis shows the distance in inches between the lit candle and the infrared sensor. The Y-Axis shows the intensity that the infrared sensor was reading during each incrimination in distance. There are no units for the intensity. The intensity value decreased as distance was closer to the infrared sensor. These values were used to map out the algorithm for the flame seeking portion of the code. The graph is pictured below.

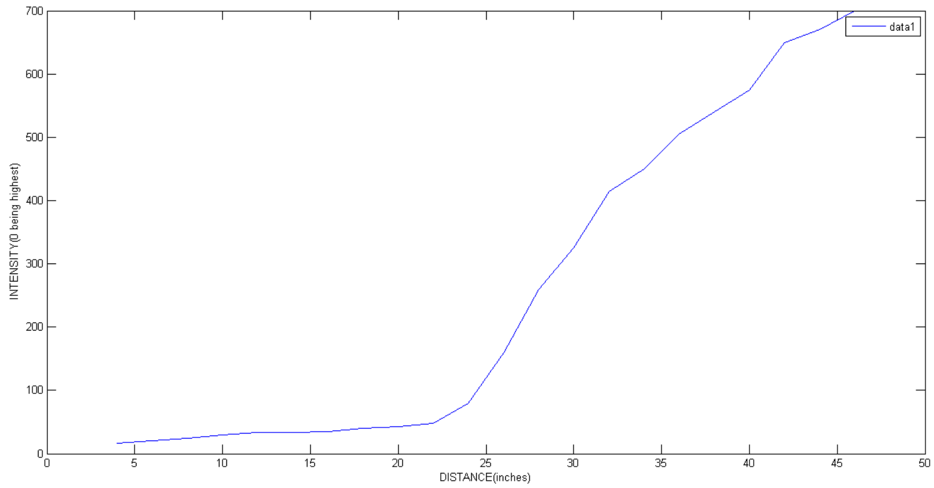


Figure 5.2.3.4: Graph of Flame Sensor Test Results

This picture below was the final test for the groups' project. This test integrates all components of the project, which includes: wireless communication, flame sensing, distance sensing, motor control, fire suppression, successful programming and maze following algorithm. This test was completed multiple times and would be the same exact demonstration for the board of judges. This autonomous robot went into a mock room made out of wood and was constantly looking for a flame. Once the flame was seen by the infrared sensor(s), the robot would move towards the flame. Once the robot became close enough to the flame, it would stop and start its' fan and blow out the fire. After the flame has been suppressed, the robot went back to the wall, and used the right hand rule algorithm to get out of the mock room. A small candle was used because the group could not use anything larger in the engineering atrium. The group could also not use any flammable gases or liquids, so that meant no tiki torch. The group used a computer fan because no chemicals could be used inside of the engineering building, and using water seemed like a risk for the exposed electronics. These fire suppression ideas would also make the robot a lot heavier. The testing is pictured below.

Figure 5.2.3.5: Final Testing

6.4 Accuracy Test Procedure

Using the same set-up as mentioned in the limited functionality test procedure connect the PC serial monitor to the Arduino. Turn the potentiometer on the flame sensor as far counter-clockwise as it can go. Now record the base case value (no flame) and then record the values obtained from a flame produced in incremental distances of 4 inches, starting from 4 inches and ending at 24 inches. Turn the potentiometer or the flame sensor by a quarter turn clockwise and repeat the procedure. Continue measuring these values and turning the potentiometer a quarter turn after each test, until the potentiometer has reached its limit. This data will be used to find the optimum tuning needed for the code. Power down test set-up after recording results. The figure below shows a simple code for accuracy testing.

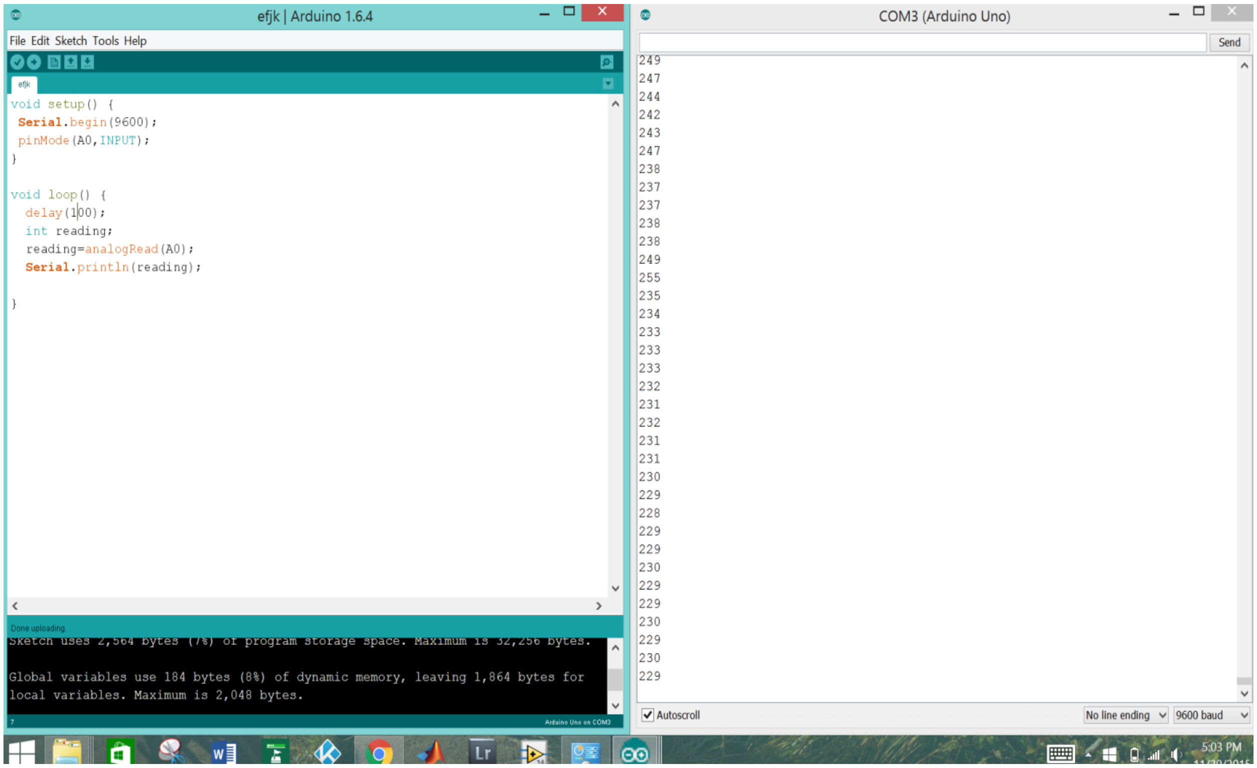


Figure 5.2.4.1: Left- code used for accuracy testing. Right- serial monitor output example.

6.5 Pass/Fail Criteria and Corrective Actions

If a unit has failed the limited functionality test, i.e. does not display any values to the serial monitor, does not change values when flame is within 24 inches, or exhibits some other erratic behavior; this unit will be considered a factory defect. Erratic behavior will be defined here as intermittent functionality or output swings of more than 25% without any changes to the test environment. Factory defect units will not be used in the final design and will likely be replaced by the manufacturer or distributor as soon as they are detected. If a unit has failed the accuracy test, i.e. very little variation in sensor readings as a function of flame distance for all potentiometer positions; this unit will be considered a "weak" unit and will need to be filtered (most likely using software) before it's value is used in any decision making branches of the main algorithm. If the output of a weak unit is not able to be corrected using software, a capacitor will be added between the output and ground pins to help filter high frequency deviation. If this capacitor causes the sensor to behave too sluggishly, the unit will be replaced by a unit that reacted with more variation during accuracy testing.

7.0 Administrative Content

7.1 Milestones

Figure 7.1 below shows the milestones of the group for senior design one.

Name of Milestone	Date of Process	% successfully completed
Senior Design Project Idea	08/28/15	100%
Project Decision	09/1/15	100%
Group Identification Form	09/3/15	100%
Initial Document	09/15/15	100%
Begin Research	09/20/15	100%
Table of contents submission	10/15/15	90%
Finish Research	10/16/15	100%
Start Rough Draft	10/17/15	100%
Complete 10 Pages per group member for rough draft review	11/12/15	85%
Create date to review rough draft paper	11/18/15	100%
Meeting 1: research paper	11/20/15	33%
Meeting 2: research paper	11/27/15	70%
Meeting 3: research paper	12/3/15	95%
Meeting 4: final research paper edits	12/5/15	100%
Print and bind final paper	12/7/15	100%

Table 7.1: Milestones

7.2 Division of Labor

The group tried as best as possible to split the topics up fairly and evenly. The topics that Bryanna Saavedra covered includes: heat detection, realistic design constraints, all motors researched such as brushless and brushed motors, the infrared sensors, camera, video transmitter and receiver pairs, the pin mounting, pin connection, mounting and selection of each component that was researched by Bryanna and lastly division of labor. The topics that Philip Fritz covered includes: the executive summary, collision avoidance, the motor controller, the wireless transceivers, the ultrasonic sensors, the pin mounting, pin connection, mounting and selection of each component that was researched by Philip and lastly the mechanics of the motor controller. The topics that Dylan Moro covered includes: the microcontroller, the printed circuit board, the algorithms, the fire suppression, the software block diagrams, the microcontroller and peripherals, the mechanics of the fire suppression and lastly the prototype and testing. The topics that Dustin James covered includes: the project description, the motivation, the power/size constraints, the reference projects, the chassis, batteries and power, power systems, the mechanics of the chassis and motor, related engineering standards, the bill of materials and lastly the project summary and conclusion.

7.3 Bill of materials

The team will not have sponsors and have chosen to fund the project from inside sources. The total will be split amongst four individuals to cover all costs and possibly overflow constancies. All parts listed are parts that must be bought; all else already has been obtained from personal supplies. These supplies include but limited to transmitter for driving the robot manually, wires, glue/epoxy, all fasteners, paint if need be, and accessories. All items will be ordered from an independent source set up by the treasurer of the group, whom will keep the budget in mind and make sure everything is bought in an advance and orderly manner. Refer to table 7.3 for a full budget of materials.

Item	Company	Product	Quantity	Price
Chassis				
Robot	ServoCity	Scout	1	169.99
Claw	ServoCity	ServoCity	1	9.99
Motor-controller	Hobbywing	WP-1625brushed	2	18.49
Sensors				
Ultra-sensor	SainSmart	hc-sr04	4	9.99
Fire-sensor	SainSmart	Elecfreaks e00397	5	6.81

MCU				
Microcontroller	Atmel	ATmega2560	1	9.99
PCB made	3PCB		5	38
Communication				
Receiver	Orange	rs15x 6ch 2.4ghz	1	14.99
Transmitter	Spectrum	dsm2 16ch	1	49.99
Power				
LIPO Battery	Turnigy	5000mAh 3S 20C Lipo	2	35
5v Regulator	TI	LM2576T-ADJ	2	5
Fire Suppression				
Blower	Cooler Master	12v fan	1	8.79
Feedback				
Camera	RioRand	1/3 inch CMOS 600TVL	1	19.99
Vtx/Vrx	Boshcam	5.8G Wireless 8CH	1	33.99
Extra Expenses				
	Parts	Parts	TBD	200
Total				**898.71**

Table 7.3: Budget of Materials

The team still chose to not to have funding for the project. The total will be split amongst four individuals to cover all costs and possibly overflow constancies. All parts listed are parts that must be bought; all else already has been obtained from personal supplies. These supplies include but limited to transmitter for driving the robot manually, wires, glue/epoxy, all fasteners, paint if need be, and accessories. All items will be ordered from an independent source set up by the treasurer of the group, whom will keep the budget in mind and make sure everything is bought in an advance and orderly manner. Refer to the picture below for a full budget of materials.

Item	Campany	Product	Quantity	Price	Our Cost
Chassis					
robot	ServoCity	scout	1	$ 169.99	$ 169.99
claw	ServoCity	servocity	1	$ 9.99	$ 9.99
motorcontroller	Hobbywing	WP-1060	2	$ 22.30	$ 44.60
Sensors					
ultrasensor	SainSmart	hc-sr04	3	$ 7.95	$ 23.85
firesensor	SainSmart	elecfreaks e(	5	$ 4.40	$ 22.00
MCU					
Microcontroller	Atmel	ATmega256(	1	$ 9.99	$ 9.99
PCB made/parts	3PCB		1	$ 60.00	$ 60.00
Communication					
reciever	Orange	rs15x 6ch 2.4	1	$ 14.99	$ -
transmitter	Futaba 9c/Spectrum	dsm2 16ch	1	$ 200.00	$ -
Power					
LIPO Battery	Turnigy	4000mAh 3S	1	$ 35.00	$ -
5v Regulator	TI	LM2576T-AD	1	$ 8.28	$ 8.28
Fire Supression					
Blower	Cooler Master	12v fan	1	$ 8.79	$ 8.79
Feedback					
camera	RioRand	1/3 inch CM(	1	$ 15.99	$ 15.99
vtx/vrx	Boshcom	5.8G Wireles	1	$ 33.99	$ 33.99
Monitor	tbd	7" FPV	1	$ 49.99	$ -
Extra Expenses					
		parts	tbd	$ 200.00	$ 50.00
Total				$ 857.46	$ 457.47

Figure 7.3.1: Updated Bill of Material

8.0 Summary

With all the research and testing that the team has done, we are confident that our fire-fighting robot will be exactly what it needs to be. To display the robot the group will make a course that tests its functionality and usefulness. It must navigate the course without intervention of a human and find and extinguish a fire source without out a glitch. The robot must be fully autonomous and also have the option to be manually guided by a human. Figure 6.0a shows the concept of the final product of our fire-fighting robot. Figure 6.0b shows the design of the course that will be used in testing the robot. It is designed to simulate the robot going through a house and searching for a fire source. The source of the fire will be a tea candle so that fire regulations inside can be kept and not over stepped.

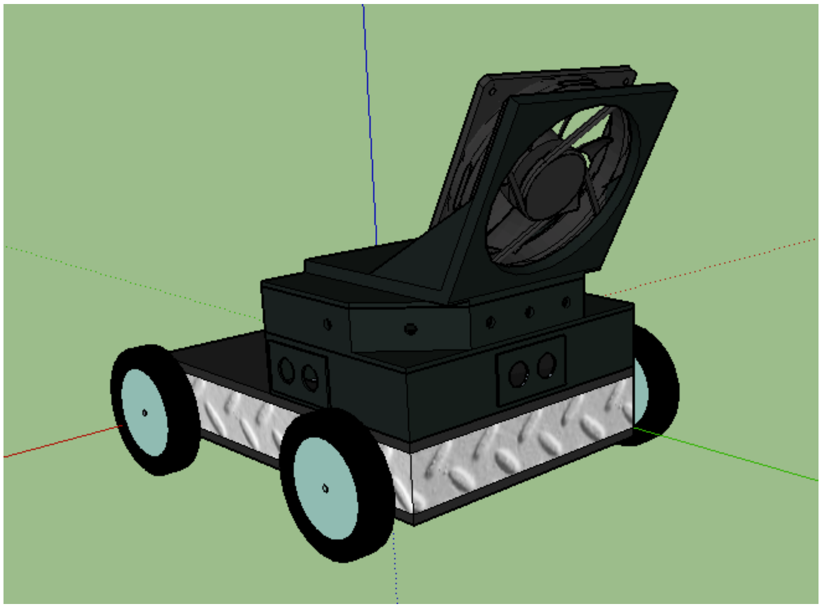
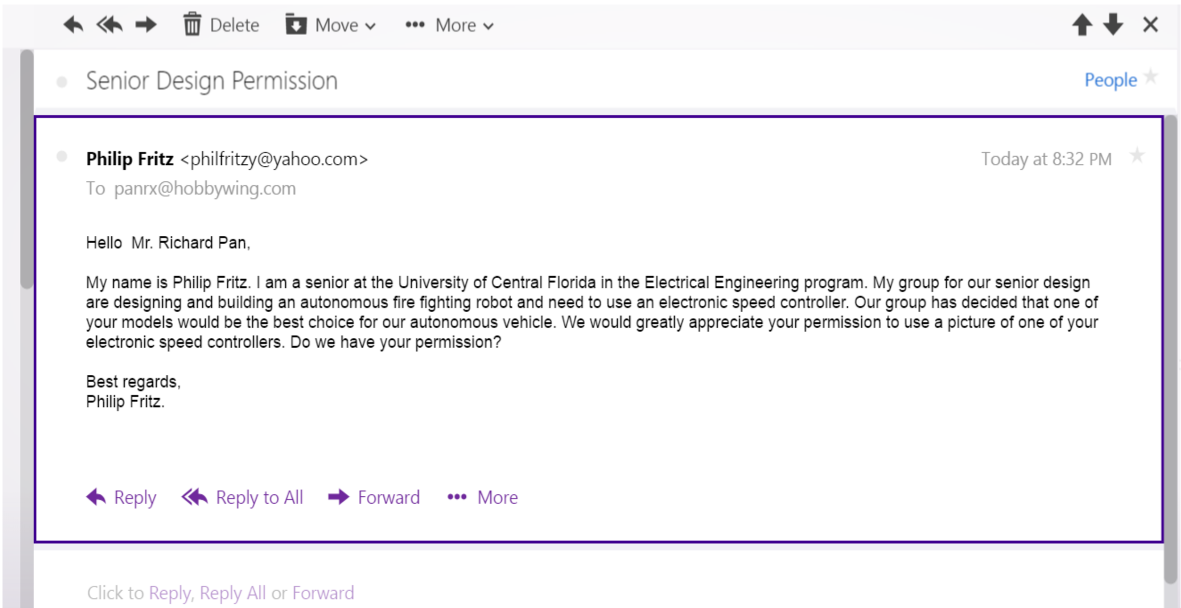


Figure 6.0a: 3D Sketch up of Vehicle

9.0 Appendices

9.1 Copyright Permissions

Figure 4.11.2 (pending)



Delete Move More

Senior Design Permission

People

Philip Fritz <philfritzy@yahoo.com> Today at 8:32 PM

To panrx@hobbywing.com

Hello Mr. Richard Pan,

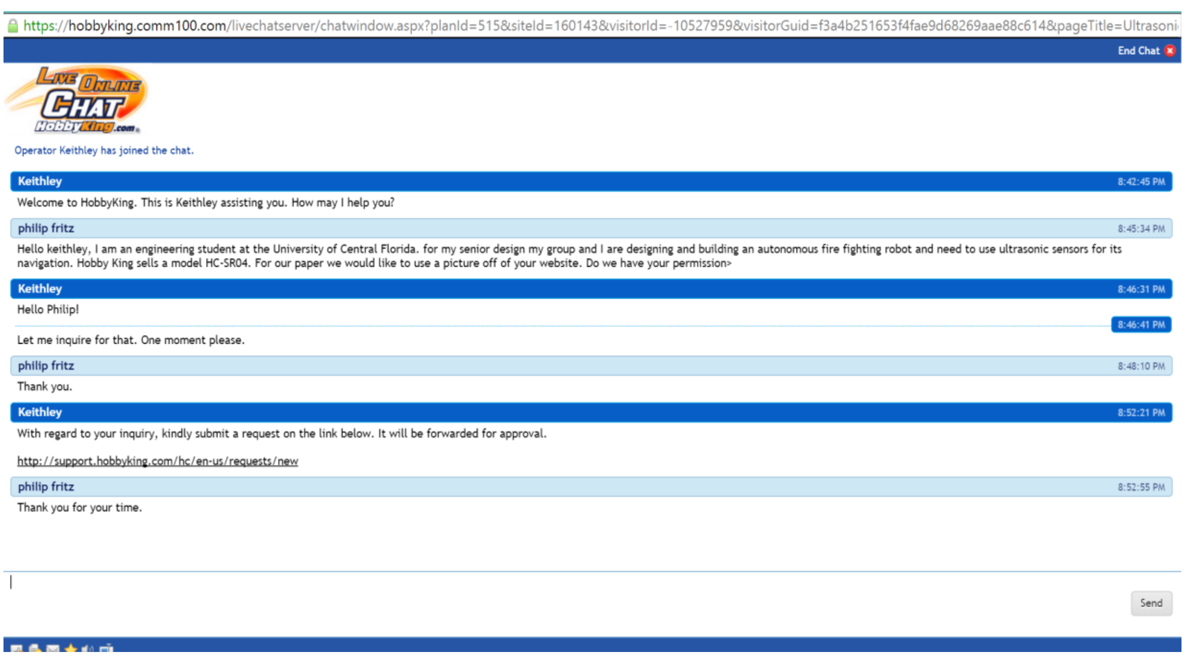
My name is Philip Fritz. I am a senior at the University of Central Florida in the Electrical Engineering program. My group for our senior design are designing and building an autonomous fire fighting robot and need to use an electronic speed controller. Our group has decided that one of your models would be the best choice for our autonomous vehicle. We would greatly appreciate your permission to use a picture of one of your electronic speed controllers. Do we have your permission?

Best regards,
Philip Fritz.

Reply Reply to All Forward More

Click to Reply, Reply All or Forward

Figure 3.9.2.3 (pending)



https://hobbyking.comm100.com/livechatserver/chatwindow.aspx?planId=515&siteId=160143&visitorId=-10527959&visitorGuid=f3a4b251653f4fae9d68269aae88c614&pageTitle=Ultrasoni

End Chat

Operator Keithley has joined the chat.

Keithley 8:42:45 PM

Welcome to HobbyKing. This is Keithley assisting you. How may I help you?

philip fritz 8:45:34 PM

Hello keithley, I am an engineering student at the University of Central Florida. for my senior design my group and I are designing and building an autonomous fire fighting robot and need to use ultrasonic sensors for its navigation. Hobby King sells a model HC-SR04. For our paper we would like to use a picture off of your website. Do we have your permission?

Keithley 8:46:31 PM

Hello Philip!

8:46:41 PM

Let me inquire for that. One moment please.

philip fritz 8:48:10 PM

Thank you.

Keithley 8:52:21 PM

With regard to your inquiry, kindly submit a request on the link below. It will be forwarded for approval.

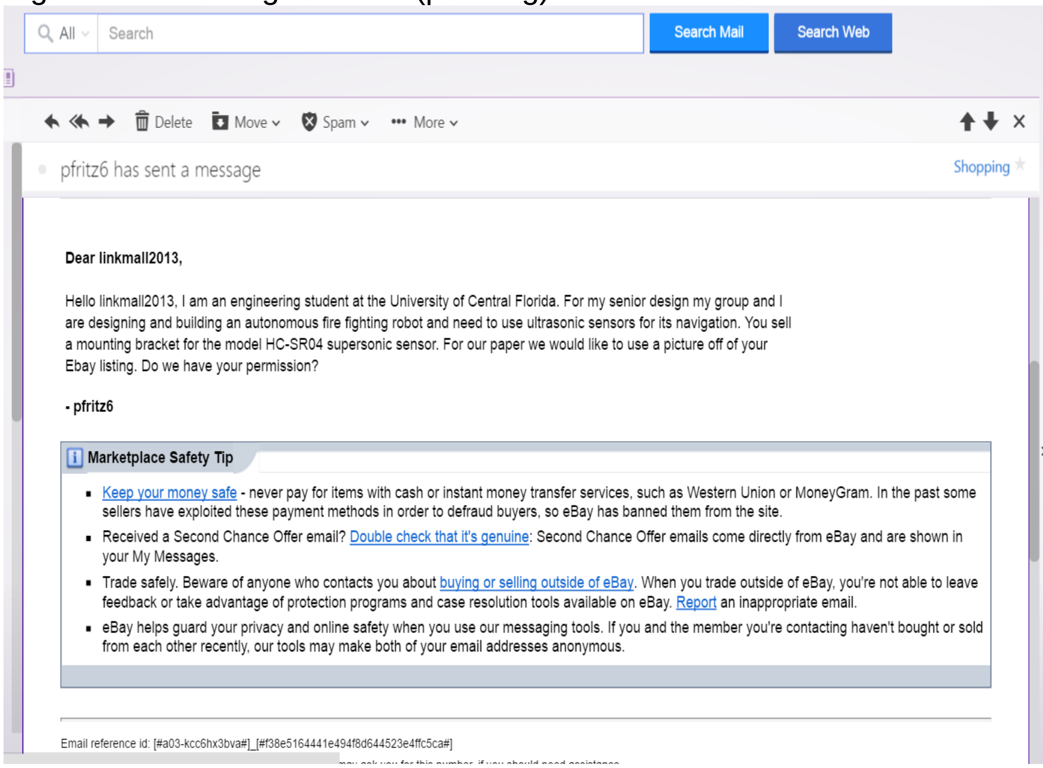
http://support.hobbyking.com/hc/en-us/requests/new

philip fritz 8:52:55 PM

Thank you for your time.

Send

Figure 4.1.1 and figure 4.1.3 (pending)


pfritz6 has sent a message

Dear linkmall2013,

Hello linkmall2013, I am an engineering student at the University of Central Florida. For my senior design my group and I are designing and building an autonomous fire fighting robot and need to use ultrasonic sensors for its navigation. You sell a mounting bracket for the model HC-SR04 supersonic sensor. For our paper we would like to use a picture off of your Ebay listing. Do we have your permission?

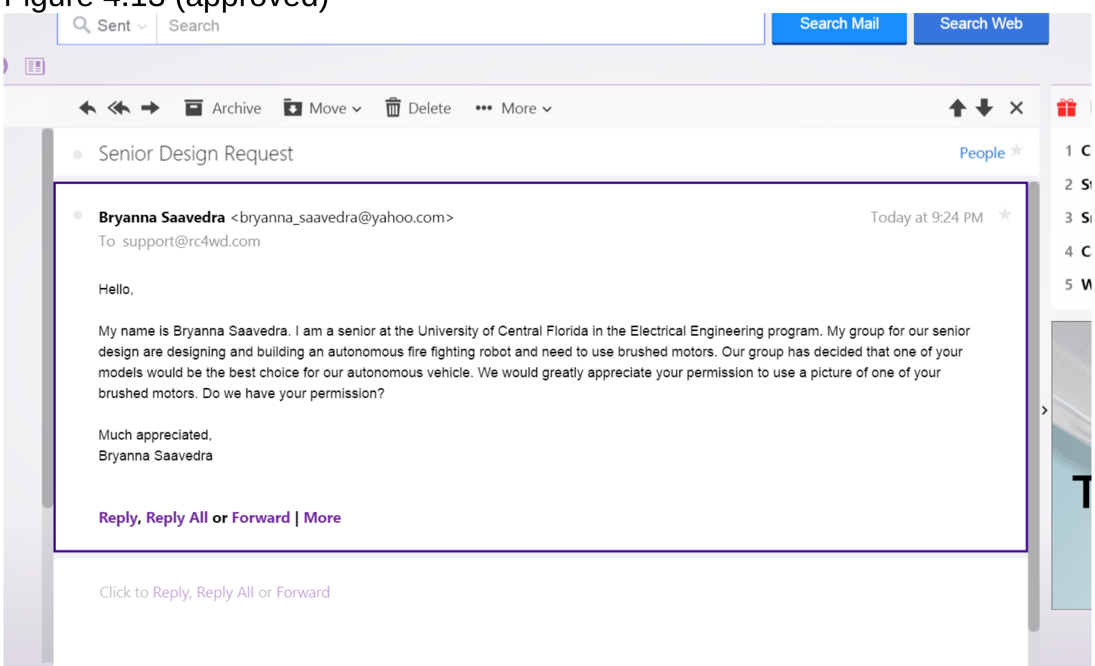
- pfritz6

Marketplace Safety Tip

- Keep your money safe - never pay for items with cash or instant money transfer services, such as Western Union or MoneyGram. In the past some sellers have exploited these payment methods in order to defraud buyers, so eBay has banned them from the site.
- Received a Second Chance Offer email? Double check that it's genuine: Second Chance Offer emails come directly from eBay and are shown in your My Messages.
- Trade safely. Beware of anyone who contacts you about buying or selling outside of eBay. When you trade outside of eBay, you're not able to leave feedback or take advantage of protection programs and case resolution tools available on eBay. Report an inappropriate email.
- eBay helps guard your privacy and online safety when you use our messaging tools. If you and the member you're contacting haven't bought or sold from each other recently, our tools may make both of your email addresses anonymous.

Email reference id: [#a03-kcc6hx3bva#]_[#f38e5164441e494f8d644523e4ffc5ca#]

Figure 4.13 (approved)


Senior Design Request

Bryanna Saavedra <bryanna_saavedra@yahoo.com> Today at 9:24 PM
To support@rc4wd.com

Hello,

My name is Bryanna Saavedra. I am a senior at the University of Central Florida in the Electrical Engineering program. My group for our senior design are designing and building an autonomous fire fighting robot and need to use brushed motors. Our group has decided that one of your models would be the best choice for our autonomous vehicle. We would greatly appreciate your permission to use a picture of one of your brushed motors. Do we have your permission?

Much appreciated,
Bryanna Saavedra

RC4WD <rock@rc4wd.com>
To bryanna_saavedra@yahoo.com

Hi Bryanna

Sure you can use it.

If you send me from your school email and pictures of your project.

We might be able to donate some parts too.

-Mike

Figure 4.14 (approved)

Send Message to Supplier

To: Carlos Tong

*** Message:** Hello Mr. Carlos Tong,

My name is Bryanna Saavedra. I am a senior at the University of Central Florida in the Electrical Engineering program. My group for our senior design are designing and building an autonomous fire fighting robot and need to use an FPV camera. Our group has decided that one of your models would be the best choice for our autonomous vehicle. We would greatly appreciate your permission to use a picture of one of your FPV cameras. Do we have your permission?

About this Product:
HD 600TVL 1/4" 5MP 170 Wide Angel 1.8mm Len Super Mini color video CCTV FPV camera with audio Mini Camera for DVR Free Shipping

Insert smileys

1 of 7 Page

Upload a photo: Upload a photo
Only one picture (max size 5MB) is supported in one message. The format should be jpg, png, gif or bmp.

Send

Safe Buying Tips

- Every payment made on AliExpress is protected by our Buyer Protection System. The payment is only released to the seller after you receive & confirm satisfactory delivery of your purchases. Any payment made that bypasses AliExpress is not protected by us.
- If any seller requests you make payment bypassing AliExpress, report them to us.

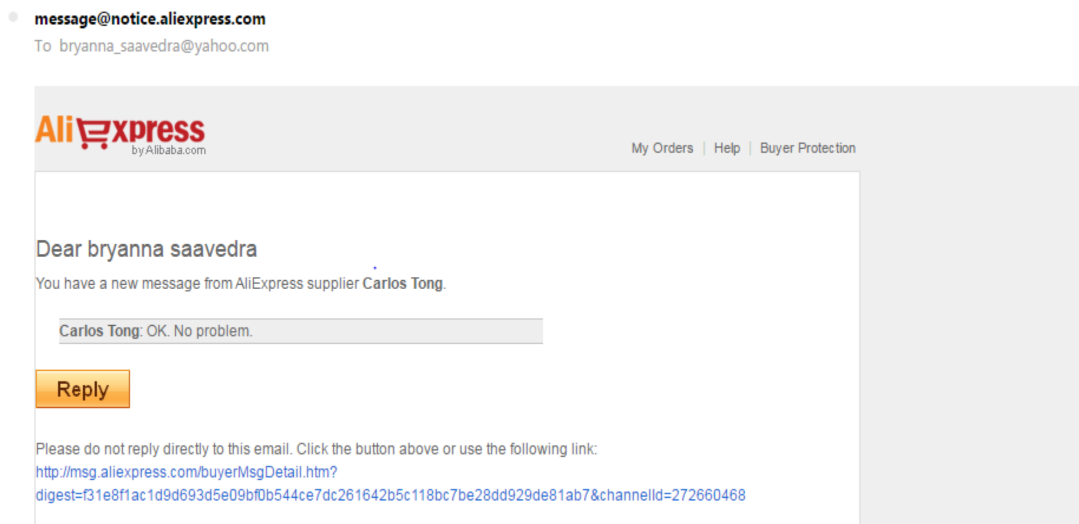


Figure 3.7.1.1(pending)

Figure 3.2.1.a(pending)

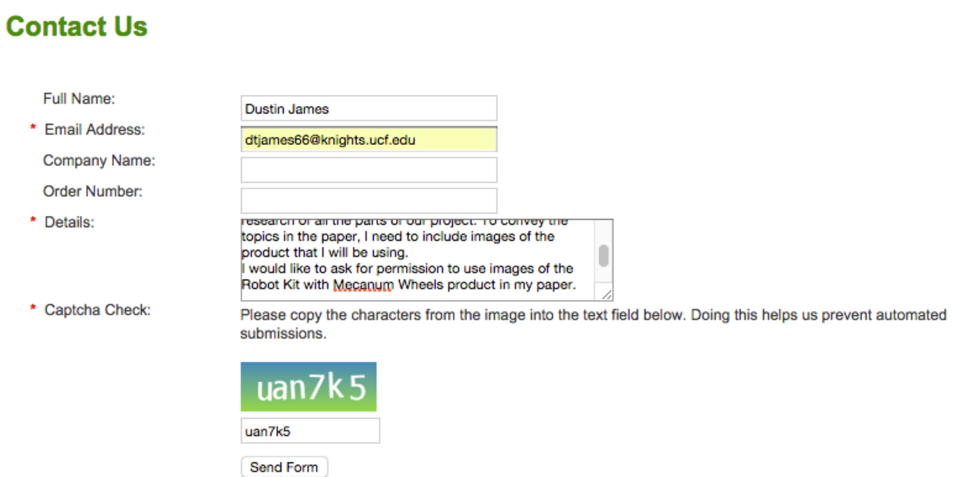


Figure 3.2.1.b(pending)

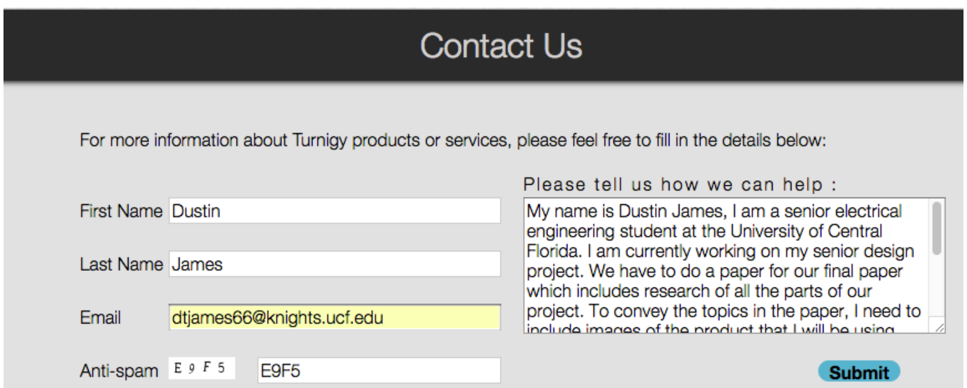
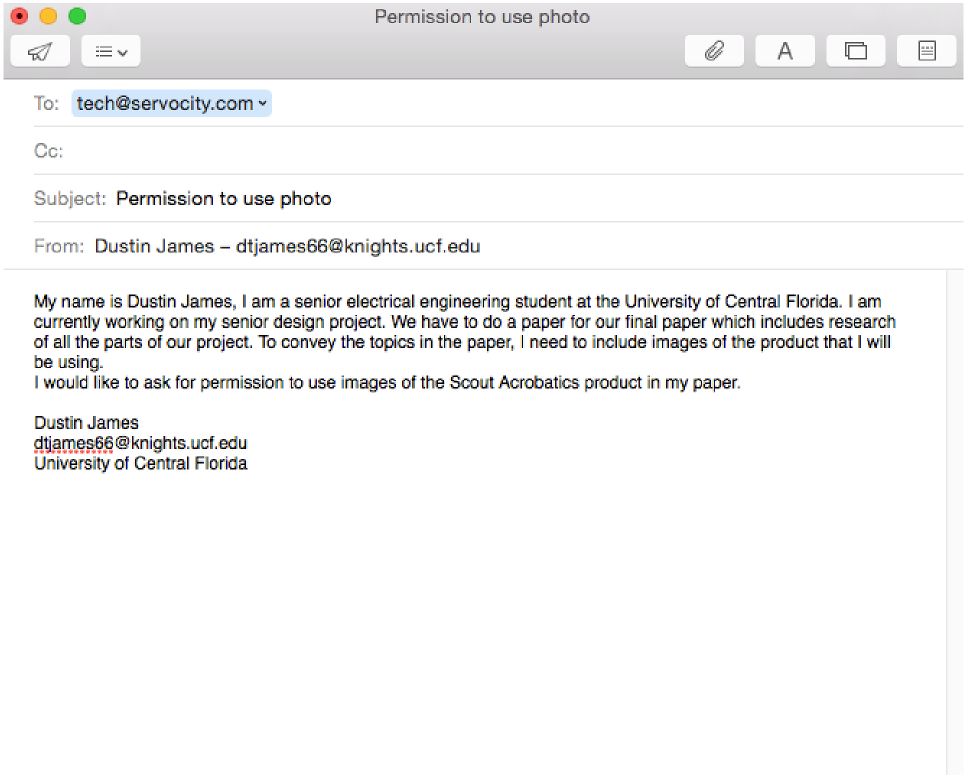


Figure 3.9.2.3 (pending)



Permission to use photo

To: tech@servocity.com

Cc:

Subject: Permission to use photo

From: Dustin James – dtjames66@knights.ucf.edu

My name is Dustin James, I am a senior electrical engineering student at the University of Central Florida. I am currently working on my senior design project. We have to do a paper for our final paper which includes research of all the parts of our project. To convey the topics in the paper, I need to include images of the product that I will be using.
I would like to ask for permission to use images of the Scout Acrobatics product in my paper.

Dustin James
dtjames66@knights.ucf.edu
University of Central Florida

9.2 Citations

- Figure 3.9.2.1 and paragraph titled "3.9.2.1 Ultrasonic Ranging Module HC - SR04"
  - **Ultrasonic Ranging Module HC - SR04. (n.d.). Retrieved November 10, 2015, from http://e-radionica.com/productdata/HCSR04.pdf**
- 3.9.2.2 SeeedStudio Ultrasonic Range Finder
  - **Ultra Sonic range measurement module. (n.d.). Retrieved November 10, 2015, from http://www.seeedstudio.com/wiki/Ultra_Sonic_range_measurement_module**
- 3.9.2.3 Parallax PING Ultrasonic Sensor and figure 3.9.2.3
  - **PING))) Ultrasonic Distance Sensor (#28015). (n.d.). Retrieved November 10, 2015, from https://www.parallax.com/sites/default/files/downloads/28015-PING-Sensor-Product-Guide-v2.0.pdf**

- 3.9.3.4 Devantech SRF05 Ultrasonic Range Finder
  - **Devantech SRF05 Sonar Range Finder. (n.d.). Retrieved November 10, 2015, from https://acroname.com/products/DEVANTECH-SRF05-SONAR-RANGING-MODULE?sku=R271-SRF05**

- 3.9.3.5 Maxbotix LV-EZ1 Mb1010
  - **MaxBotix Inc., High Performance Ultrasonic Rangefinders. (n.d.). Retrieved November 10, 2015, from http://www.maxbotix.com/Ultrasonic_Sensors/MB1010.htm**
- **3.9.3.6 DFRobot URM04 v2.0**
  - **DFRobot URM04 v2.0. (n.d.). Retrieved November 10, 2015, from https://www.dfrobot.com/image/data/SEN0002/URM04V2.0Mannual1.1.pdf**
- Fig. 3.5.3
  - (n.d.). Retrieved November 27, 2015, from http://www.ezdenki.com/graphics/hc-sr04-timing-chart.png
- Fig. 4.11.2.1
  - Single Engine ESC Wiring. (n.d.). Retrieved November 27, 2015, from http://2bfly.com/knowledgebase/electronic-speed-controls/single-engine-esc-wiring/
- Fig. 4.11.2
  - New Wp 1060 BRUSHED HobbyWing QuicRun 1/10 Brushed 60A Electronic Speed Controller ESC 1060 For Free Shipping #HM QR1060-in Parts & Accessories from Toys & Hobbies on Aliexpress.com | Alibaba Group. (n.d.). Retrieved November 27, 2015, from http://www.aliexpress.com/item/New-Wp-1060-BRUSHED-HobbyWing-QuicRun-1-10-Brushed-60A-Electronic-Speed-Controller-ESC-1060-For/2004766373.html?ws_ab_test=searchweb201556_2_79_78_77_91_80,searchweb201644_5,searchweb201560_9
- Fig 4.11.2.2
  - Brushed motor schematic. (n.d.). Retrieved December 2, 2015, from http://www.rcgroups.com/forums/showthread.php?t=1747098
- **3.2** *Scout Robot Kit (637138). (n.d.). Retrieved November 20, 2015, from https://www.servocity.com/html/scout_robot_kit__637138_.html#.VmU4aeODGko*
-
- **3.2.2** *Into Robotics. (n.d.). Retrieved December 1, 2015, from http://www.intorobotics.com/wheels-vs-continuous-tracks-advantages-disadvantages/*
-
- **3.4** *Turnigy. (n.d.). Retrieved November 15, 2015, from*
- *http://www.turnigy.com/*
-

- **3.4.7.1** *LM2576/LM2576HV Data Sheet (n.d.). Retrieved December 1, 2015, from http://www.ti.com/lit/ds/symlink/lm2576.pdf*
-
- **4.5.1** *Step-Down (Buck) LM2576/LM2576HV. (n.d.). Retrieved December 2, 2015, from http://www.hobby-hour.com/electronics/lm2576-step-down-switching-regulator.php*
-
- **5.0** *Search Engine for Standards - NSSN. (n.d.). Retrieved December 10, 2015, from http://nssn.org/*
- Hill, A. (2003). What is an Infrared Sensor? Retrieved November 10, 2015, from http://www.wisegeek.org/what-is-an-infrared-sensor.htm
- Infrared vs. Ultrasonic - What You Should Know. (n.d.). Retrieved November 10, 2015, from http://www.societyofrobots.com/member_tutorials/book/export/html/71
-
- ElecFreaks Octopus Flame Sensor for Arduino. (n.d.). Retrieved November 10, 2015, from http://www.dx.com/p/elecfreaks-octopus-flame-sensor-for-arduino-344800?tc=USD&gclid=CjwKEAiApYGyBRC-g_jIstuduV8SJABCEzhZLR6-Ko365b9OmVmQxF3NUDAS_6X9SAtph1es0ZQSPxoCa3_w_wcB#.VkF17LerSM9
-
- File:Octopus Tilt Sensor D.jpg. (2013). Retrieved November 10, 2015, from http://www.elecfreaks.com/wiki/index.php?title=File:Octopus_Tilt_Sensor_D.jpg
-
- Grove - Flame Sensor. (2015). Retrieved November 10, 2015, from http://www.seeedstudio.com/wiki/Grove_-_Flame_Sensor
-
- Hardware - T.J the FireFighter. (n.d.). Retrieved November 11, 2015, from http://homepages.engineering.auckland.ac.nz/~pxu012/mechatronics2013/group13/hardware.html
-
- Burglar Alarm. (2015, April 20). Retrieved November 11, 2015, from http://burglaralarmves.blogspot.com/2015/04/burglar-alarm-circuit-using-ir-sensors.html
-
- 540 Crawler Brushed Motor 35T. (2015). Retrieved December 4, 2015, from http://store.rc4wd.com/540-Crawler-Brushed-Motor-35T_p_821.html
-
- Multi-Engine ESC Wiring. (n.d.). Retrieved December 4, 2015, from http://2bfly.com/knowledgebase/electronic-speed-controls/multi-engine-esc-wiring/
-
- Robot MarketPlace - Sabertooth 2 x 12 RC Dual Motor Speed Controller. (n.d.). Retrieved December 4, 2015, from http://www.robotmarketplace.com/products/0-SABER2X12-RC.html
-
- (n.d.). Retrieved December 4, 2015, from http://mediatoget.blogspot.chttp://mediatoget.blogspot.com/2011_05_29_archive.htmlom/2011_05_29_archive.html
-
- Aliexpress.com: Acheter Origina lFPV 5.8 G 1000 MW vidéo Audio transmetteur TX RX 5.8 GHz sans fil récepteur pour hélicoptère de dvi récepteur fiable fournisseurs sur Shenzhen Moreshare Group Co.,Ltd. (n.d.). Retrieved December 5, 2015, from http://fr.aliexpress.com/store/product/Free-Shipping-FPV-5-8G-1000MW-Video-Audio-Transmitter-TX-RX-5-8GHz-Wireless-Receiver-for/133124_1438063447.html

"CALCULATING SPACING BETWEEN PCB TRACES FOR VARIOUS VOLTAGE LEVELS." *PCB Trace Spacing Calculation for Voltage Levels*. Web. 4 Dec. 2015.

http://www.kovoelectronics.nl/wordpr/wp-content/uploads/Proto-pooling-voorwaarden.pdf. Web. 4 Dec. 2015.

Smith, Nicholaus. "The Engineer's Guide To High-Quality PCB Design."*The Engineer's Guide To High-Quality PCB Design*. Web. 4 Dec. 2015.

Quick, Victoria. "A Safer Search: Mastering the Firefighter-oriented Search Method." - *My Firefighter Nation*. Web. 2 Dec. 2015.

"PCB Manufacturing US QuickTurn Prototype PCB." *PentaLogix Catalog*. Web. 5 Dec. 2015.

"PCB Specification Selection." *Online PCB Quote*. Web. 5 Dec. 2015.

- "Standard via Sizes?" *Pcb*. Web. 5 Dec. 2015. <http://electronics.stackexchange.com/questions/5951/standard-via-sizes>.