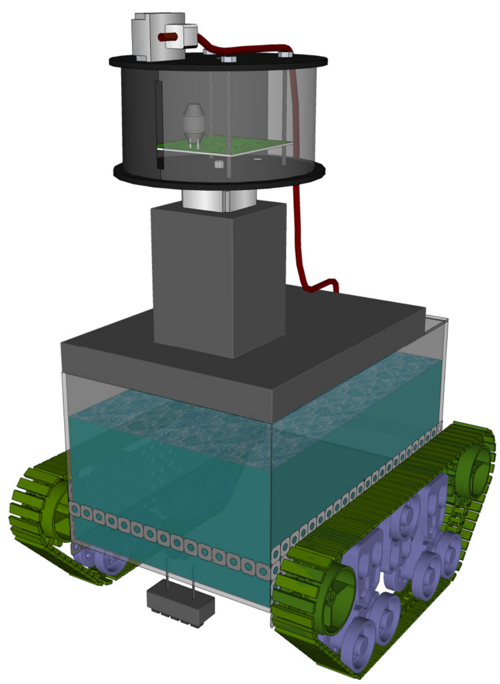
HeatSeekr



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1.0 Executive Summary

The HeatSeekr rover and wireless monitoring unit is a fire detection and extinguishing solution made to showcase how the integration of technologies can add an additional active fire protection module to current fire response systems. HeatSeekr addresses the issues plaguing current fire response methodology, one based on reacting to fires that have already grown beyond control, requiring blanket area responses that can cost hundreds of thousands of dollars in damage to sensitive equipment and other property, not to mention causing widespread panic and chaos in the process. Focusing on breaking the mentality of fire containment being on the scale of households and entire office buildings, HeatSeekr utilizes advanced ultraviolet spectrum particle detectors and wireless communication to meet its goal through a balance of elegance and efficiency.

HeatSeekr incorporates several subsystems in its multiphase operation. The rover is a thirty pound, multilayer, tread-driven combination of the fire extinguishing system, the navigation system, and "The Overlord" master processor. Each system is controlled by its own microprocessor, and performs tasks in parallel with other systems, allowing the rover to navigate a hallway and constantly monitor the area for fire emissions simultaneously. The microprocessors communicate through the master processor over I^2C, allowing data to be exchanged between them and procedural decisions to be made.

The fire extinguishing system consists of a fire sensor, water pump, two stepper motors allowing for near 360° coverage for fire detection and water coverage, a microcontroller, and a water sensor to monitor remaining water levels. The navigation system contains an infrared-sensitive transistor-based line follower and address reader, allowing the HeatSeekr to navigate within a set track placed in its coverage environment and to recognize room codes printed adjacent to the track as it patrols. The navigation system also controls two motors that constitute the tread-based movement system, enabling minimal footprint rotations. The master processor parses the various flags set by the slave processors, controls the different states of operations, and outputs the status of the rover through a forty character, two line LCD screen. The master processor is also where the rover communicates with the wireless module, utilizing Bluetooth to send data between the separate systems. The wireless module contains a microcontroller, fire sensor, wireless card, and power pack, serving to monitor individual rooms for the ultraviolet emissions from active flames and alert HeatSeekr should there be any detections - sending both a fire flag and a room code to allow the rover to navigate to the suspected room.

HeatSeekr represents a challenging set of integrations and optimizations that should provide insightful views into the manufacturing pipeline that is engineering. Through a dedication to quality and a sense of innovative exploration, HeatSeekr will revolutionize our current fire protection methodology with an active, intelligent, and robust technology solution to a very old problem.

2.0 Project Description

2.1 Project Motivation

In the modern age of reinforced synthetic materials, the threat of destructive fire remains a danger to residential, commercial, and industrial environments. Since the dawn of civilization, the ability to mobilize and respond to a spreading fire has been developed and engineered to minimize damage to property and life. Over time, these methods have increased in their efficacy and time response, culminating with today's standard four minute response time for firefighters responding to an active fire alarm, and first response fire sprinkler systems that appear within most modern facilities. As it takes time for firefighters to respond to a fire alarm, the first few minutes of a fire's creation are the most critical and vulnerable parts of a fire. If a response is not introduced to a fire quickly, then the fire is capable of devouring entire buildings and spreading to neighboring areas.

The philosophy behind a first response system for fires is to protect against the spread of a fire by limiting its growth, and ultimately removing all radiating heat. A standard procedure used in fighting fires is to contain the spread of the fire within a given area, usually in units of a household or office building. By containing the fire within this unit, the entire area is almost guaranteed to be destroyed by the fire's destructive capabilities and the massive amount of water used by the fire department to extinguish the flame. This contain unit is also very likely to contain valuable assets in terms of technology, data, family heirlooms, and in worst cases lives lost due to a slow detection and response time. Fire sprinklers attempt to reduce the detection and response time of a fire; however, through their standard design operation they tend to cause immense property damage and may destroy more than a fire could have. For example, if a fire were to start in the a server room for a library, the resulting fire sprinkler alarm system could react by dousing the entire floor with water ruining countless books when a fire extinguisher could have been operated and applied directly to the fire's source. A sense of panic from a fire sprinkler system could also trigger a bad evacuation from a building. For example, if a kitchen fire were to break out in a hospital kitchen, the fire sprinklers could potentially destroy any expensive equipment, chemical tests, and cause widespread panic while attempting to move critical or elderly patients through slippery hallways.

Since response time and damage mitigation are key aspects of fire prevention, an active system capable of on the spot fire reduction would be optimal. The HeatSeekr project is designed as a sophisticated means of eliminating a fire in an office building environment and fits this key niche. As fire gives off an extremely unique and strong infrared radiation, a heat sensor could be implemented to detect a fire's flickering patterns and start an immediate response. By requiring minimal human interaction, the HeatSeekr is an attempt to minimize the amount of additional damage caused by other first response fire systems by creating an efficient fire extinguisher that accurately targets a fire's source.

2.2 Goals and Objectives

The primary goal of HeatSeekr is to detect a fire within a building and extinguish the flame before it turns into a large and more severe situation. It is intended to be a fully independent and autonomous vehicle. By creating a mobile robot, the HeatSeekr will be able to navigate through a standard office building to find a fire. The HeatSeekr should be able to be placed in a standby state in a designated location in a building for activation. By using a remote sensor in adjacent rooms, a heat signature from a fire can be properly identified and a wireless signal should be sent to alert HeatSeekr of danger. Once alerted, HeatSeekr should be able to navigate from its standby location directly into the room with the fire using a line navigation system with a room number associated with the remote sensor. Once HeatSeekr has entered the room with the fire, its sensors should begin scanning the room for the location of the fire. Once the fire's source has identified, it should position itself so that it can spray water and extinguish the flame. Once the fire is extinguished, it should be able to await further inspection from human fire fighters that all danger has been removed, or respond to other fires in the building.

HeatSeekr should be able to meet or exceed the following design specifications in a finalized form. In order to be effective, the effective range of the fire detection should be up to 20 feet with a detection coverage of at least 90°. This will allow for a remote sensor to be placed in the corner of a room and monitor across the entire room for any heat signatures. A detection time of less than 30 seconds will be required to create a fast response time to alert HeatSeekr, fire department, and any personnel in the building. Once the alert has been triggered, HeatSeekr should be able to navigate into a room approximately 50 feet away within one minute. This response time is four times faster than the average time of a fire fighter's alert, and should be able to still get to a small growing fire with plenty of time to still prevent any large amount of damage. In order to be successful, HeatSeekr will have to be able to correctly distinguish the difference between a fire source and other signatures that are not on fire. The fire extinguisher system should be able to shoot water at a distance of five feet since the navigational system can move toward a fire source's position if needed. In order to simulate a real life emergency, HeatSeekr should be able to be put onto standby mode for extended periods of time, at least two hours, and still respond to a fire alarm received from the remote sensor. By carrying its own supply of water, a tank should be created to store about two gallons of water. The average small fire does not take too much water to extinguish, and two gallons of water weighs should allow the system to weigh under 30 lbs with dimensions under eight ft^3, so that it can be moved by external sources. Table 1 represents the bare minimum specifications of HeatSeekr to be considered as a successful prototype.

Fire Detection Range	Up to 20 feet
Fire Detection Response Time	Under 30 seconds
Navigational Response Time	Travel 50 feet under one minute
Water Extinguisher Range	Distance of 5 feet
Standby Response Time	Operate after sleeping for two hours
Weight	Under 30 lbs
Total Size	Under eight ft^3

Table 1: Design Specifications

2.3 Flame Detection

2.3.1 Wide Angle Rover Stalk Detector

The rover will incorporate a flame detector in order to detect flames both while summoned by the stationary hanging detector and while it is in a neutral state. The detector itself will be located on an elevated stalk so as to provide an unhindered view of the immediate environment. Incorporated into the stalk are two servos that will allow the detector's field to be swept across the environment in the x and y directions. Due to the detector's omnidirectional detection field, a movable shroud will be implemented that can control the detector's field of view such that two modes of detection will be possible: a scanning mode involving a highly restricted field of view for when the rover is alerted by the stationary hanging detector of a fire, and a passive detection mode for all other operating states that takes advantage of the unidirectional nature of the detector to provide passive fire detection for fires that occur outside of the stationary hanging detector's domain.

- The stalk detector shall be able to initialize fire detection protocol within 2 seconds upon arriving at a designated fire room.
- The stalk detector shall be able to detect a 1 inch fire source at a distance of 16 feet in either mode.
- The stalk detector shall provide at least 300° coverage while in passive detection mode through the use of the x-direction servos and a rotation mechanic.
- The stalk detector shall be able to lock-on to a detected fire within 20 seconds of scanning initialization.

2.3.2 Stationary Hanging Detector

In order to dramatically increase the system's ability to respond to fires in a time span such that they can be controlled, an expandable system of isolated Wi-Fi enabled flame detectors will be deployed in the environment such that the rover can be sent the location of detected fires and travel to them. The stationary hanging detector is intended to be placed on the ceiling of a room with the intent that the 120° detection field of the fire detector can be used to provide near total coverage. Unlike the stalk detector on the rover, the stationary hanging detector will have only the passive detection mode, thus negating the requirement of a shroud.

- The stationary hanging detector shall be able to detect a 1 inch fire source at a distance of 16 feet.
- The stationary hanging detector shall be able to detect fires in a sphere encompassing at least 100° radial centered on the sensor, with the intent of covering a wide portion of a room's floor plan.
- The stationary hanging detector shall not interfere with the stalk detector, having some form of cessation following fire detection.

2.4 Fire Extinguisher

2.4.1 Reservoir, Algorithm, Pump

The fundamental operation of HeatSeekr is to detect and extinguish fires, thus the implementation of an extinguisher is of prime concern. The flame delivery system will incorporate a retardant reservoir, a means of motivating that retardant, an exit nozzle, and a means to direct the flow of retardant. Because the sensory equipment is capable of long distance fire detection and because the specified operating environments for the rover can include larger rooms, it is important to specify a fire extinguishing range that can be reasonably obtained. The capability of the rover to handle multiple fire events is dependent on a suitable water carrying capacity that requires specification. The scanning algorithms that encompass a large portion of the fire extinguisher system should ensure that through proper fire patterns, detected fires should be extinguished within a specified time window. This time window determines the amount of water used per fire, another important specification.

- The fire retardant reservoir shall be able to contain, at max capacity, at least 2 gallons of water.
- The fire retardant reservoir, in concert with proper hose placement, shall be able to utilize at least 95% of its water capacity by means of proper reservoir design and angling.
- The fire retardant pump and fire pattern algorithm shall be capable of a 4.5 meter distance for fire extinguishing
- The fire pattern algorithm shall ensure that fires be extinguished within 15 seconds of extinguishing initiation.
- The pump flow rate, in concert with timely fire extinguishing, shall be adequate enough to ensure less than 1/4th of total water capacity is used per fire extinguishing event.

2.5 Line Detection

HeatSeekr's primary mode of navigation will be a line follower tracking a line based circuit on the floor of the environment. In normal operation a microcontroller will read in data from a line sensor and make corrections to ensure the rover stays on path. This roaming operation functions completely independently of the extinguishing system and the wireless system; those systems are handled by other microcontrollers. When the main microcontroller receives an alert from one of the remote fire sensors, that alert will also contain an address. This alert and address will be given to the navigation microcontroller.

As the rover follows its path, it will read the address in the form of stripes (similar to a bar code) to the side of the line. Once it has read the correct address, it will follow the branching line into the room and send a signal to the main microcontroller.

2.5.1 Path Detection

Due to the static nature of the rover's environment, a line follower will be incorporated to fulfill the navigation requirements of the system. The line follower system will include a permanent track placed into the fire coverage environment that will guide the rover in its travel from room to room. Located on the bottom of the rover chassis, the line follower detector with be afforded a static line of sight that will necessitate a uniform track composition. Algorithms will be developed such that the detector can be used for reasonably straight navigation along the predefined paths, and combined with the room code detector, the system can handle three-way forks in the path correctly, and be able to resume navigation after complete, untracked revolutions of the rover when it reaches path endings.

- The path detector shall be able to function in the variable light environment of the chassis underbelly.
- The path detector shall be able to work in concert with its algorithm programming and the room code detector to allow for at least 30 second transitions from hall-room junctions to the center of a fire flagged room.
- The path detector shall be able to work in parallel with the room code detector, with no physical interference between the two light-emitting systems.

2.5.2 Room Code Detection

The stationary hanging detector will send a room identification number to the rover when it detects a fire. In order for the rover to navigate to these rooms, identification codes will be placed adjacent to the tracks and a separate line follower system will read the code as the rover is in transit to the room. The code will be read as alternating detectable and non-detectable strips in standardized configurations that will be read as clocked signals to the microcontroller. The room code detector will most likely be of similar design to the path detector, and will have similar specifications.

- The room code detector shall be able to function in the variable light environment of the chassis underbelly.
- The room code detector shall be able to read the floor codes with such speed that the navigation of the rover will not be noticeably hindered through a combination of code design and detector to microcontroller interface design.
- The room code detector shall be able to work in concert with the path detector to allow for at least 30 second transitions from hall-room junctions to the center of a fire flagged room.
- The room code detector shall be able to work in parallel with the path detector, with no physical interference between the two light-emitting systems.

2.6 Wireless System

The remote fire sensors will communicate with the main HeatSeekr robot via an RF wireless protocol. Wireless is preferred over wired due to the distributed nature of the remote sensors. It would be impractical to run a cable from each sensor to the mobile robot, both from an operational standpoint as well as an expandability standpoint. Since the remote sensors are to be placed in various rooms throughout a building, all technologies requiring line-of-sight are also impractical. Additionally, since HeatSeekr is intended to be mobile, power consumption must be considered. Preferably the wireless system will utilize the lowest power technology available. The wireless system will operate in a star configuration. All remote sensors will connect directly to the mobile rover. The minimum range for the wireless system is 50 feet through at least two walls. This number allows the rover to patrol an area and respond quickly when a sensor is alarmed. The wireless system will only be used to alert the rover of a fire and where that fire is located. As such, there is no major requirement for bandwidth. The only requirement is that the signal arrives at the rover intact in a relatively short period of time.

Another consideration in designing the wireless system will be the interface between the wireless module and the microcontroller. The microcontroller will have UART, I^2C, and SPI capabilities; therefore the wireless module requires one of these protocols; however I^2C will already be utilized on the rover meaning the wireless module would preferably use UART or I^2C. The last major consideration for the wireless system is cost. Currently, the HeatSeekr rover and two remote sensors are planned to be physically prototyped. This means three complete wireless modules are required. Ideally each wireless module will cost below $15, bringing the total cost for this system to $45. If the price for the perfect module starts getting too extravagant, re-analysis will be required to determine if a less-perfect, but significantly cheaper option exists.

2.7 Water Level Sensor

The water level sensor is used to determine if the water tank has enough water to successfully extinguish a fire. The water level sensor will need to be able to quickly and accurately make this determination. The exact water level is not important, meaning this sensor can very simply be a binary sensor; either the water level is high enough to produce a stream for a calibrated amount of time or the water level is not high enough to sustain a stream for the entire time period. Ideally this sensor will not be continuously polled or complex calculations will be required. The rover will only check its water level periodically and as part of the “preparing to initiate extinguishing” sequence. If any of these checks fail, the rover will go into a fail mode to alert a human that its tank needs to be refilled.

2.8 Power Source

2.8.1 Power Management

One of the main objectives of the project is low power and efficient use of power. Power is a critical part in the design. The microcontroller needs power as well as the servos, the Hamamatsu UVTRON and every other small crucial component on the board. The tricky part of managing the power is to achieve this task without overloading or supplying too little power to any components. A heat sink will need to be added and a regulator to prevent any possible overheating or overloading issues. Independent power supplies might be used to isolate major components. With this separation it will allow us to run one component without worrying about affecting any other components. Rechargeable batteries might be a better choice to help conserve the cost within the budget, not only will this be benefiting to the financial situation but keeping the batteries in rotation will give us the possibility to charge them constantly.

2.8.2 Power Storage

HeatSeekr is a very power intensive project, requiring enough simultaneously supply to operate the two navigational motors, Hamamatsu UVTRON particle detector, wireless module, CNY70 line reader, and LCD display. The chosen battery supply system must be capable of storing a high capacity of energy in order to allow HeatSeekr to operate for several hours of autonomous detection and extinguishing between charges. HeatSeekr has to be very efficient and not waste any power that it doesn't have too. Power needs to move efficiently down the line, so minimum heat waste is lost. Because the highest voltage requirement of an individual component is 12V, the maximum voltage output will be specified in order to account for voltage loss due to the electrical system transport components

- The power storage solution shall be able to provide at least 5000 mA/h for rover operation.
- The power storage solution shall be able to provide at least 14V output before being divided into rails.
- The power storage solution shall not exceed 7 inches in length to facilitate the organizational structure of the rover.
- The power storage solution shall not exceed 5 pounds in storage weight to facilitate lower motor specifications.

2.8.3 Power Charging

HeatSeekr is intended to be used as a passive, constant tool in preventing spontaneous conflagration, and as such, should have a replenishable source of power. Power charging is needed to recharge the power supply, when it gets drained. This will be done by using rechargeable batteries. This will help to save for the tight budget that is on the table. Budgetary concerns dictate that non-rechargeable power supplies will not be considered. Charging will then be done by a permanent charging system on the or by unplugging the batteries and charging them separately, with the following specifications applied to the entire charging process.

- The power charging methods and solutions shall be able to fully recharge the rover in twelve hours.
- The power charging methods and solutions shall guarantee the possibility of at least 50 repeated charging per battery.
- The power charging methods and solutions shall ensure that the lithium polymer battery will shut off before reaching 5% of total capacity.

2.8.4 Power Components

The power components that will be used are regulators. They will be used to step down voltages from the power supply, to different sub-systems on HeatSeekr. There will be a battery, which is the power supply, about 14.8V. 14.8V will be used to account for transmission lost from the power supply to the regulators and also to the sub-systems. There will be three regulators used on HeatSeekr, ranging from 3.3V to as high as 12V. The specifications regarding the regulatory system are two-fold, specifying and addressing noise concerns and power efficiency. The specifications regarding power efficiency mainly dictate that the type of regulator used for HeatSeekr will be switching regulators, in order to ensure that heat dissipation and therefore wasted power will not be a major concern. In order to reduce noise, the power component system shall not require chaining of switching regulators in order to provide the three rails of power used by the various components of the HeatSeekr system, rather, separate switching regulators will be used that each convert the 14.8V output of the power supply to the voltages of the rails: 3.3V, 5V, and 12V.

3.0 Research Related to Project Definition

3.1 Existing Similar Projects and Products

3.1.1 Xfire

The Xfire is a robotic fire extinguisher created from September 2011 to April 2012 by Daniel Stough, Kara Bocan, and Ben Zazcek. It was created as a graduate project for Embedded Design one at the University of Pittsburgh. Its conceptual idea came from the creation of wanting to develop an automated turret that would be able to serve a purpose other than a school project, and was loosely based on patent 5548276 of a heat-sensing fire extinguish in the 1990's.

The hardware used in Xfire includes an Arduino Uno microcontroller, Probotix 280 oz In. 8-wire stepper motor and Probotix Probo stepper motor driver, Anaheim Automation 17Y9304S-LW4 86 oz In. and Probotix SideStep stepper motor driver, Sparkfun ADXL345 accelerometer breakout, Devantech TPA81 Thermopile Array, Maxbotix LV-MaxSonar-EZ2 Sonar Range Finder, SainSmart 4-Channel 5V Module, (x2) 12V Pull Solenoid, 12 Amp ATX Power Supply, Weed Sprayer, Medium Density Fiber (MDF) board and other miscellaneous hardware from home depot to integrate everything together.

The main mechanical design of the Xfire project involves a MDF platform of the turret that is able to rotate to the correct firing position. Once the correct position is acquired, a cheap weed sprayer is then utilized through the stepper motors to aim and discharges water to overcome a fire.

The electrical circuitry of the system was intended to be based off of an 18 series PIC microcontroller; however, the Arduino Uno was chosen for its superior processing power. Since the Xfire project focused mostly on implementing standard communication protocols only, the large user community, simple IDE, and compatible libraries made the Arduino Uno an easy choice over using a less supported and smaller microcontroller. The sensors connected to the microcontroller were mounted to the weed sprayer's nozzle to help identify the best position, along with the range finder for the proper angle needed for aiming the water. The TPA81 thermopile array heat sensor would detect and localize on any possible fire by sweeping up and down to create a thermal picture. The accelerometer was then used to detect the direction of gravity for leveling the water nozzle before starting the extinguisher. The accelerometer and thermopile array connection to the Arduino is through an I^2C bus. The embedded controller also connected to the motor drivers for controlling movement to the stepper motors for the vertical and horizontal angle of the extinguisher. These large motors required high voltages for embedded electronics at 12V instead of the standard 3.3V to 5V. To power the system, a cannibalized power supply for a desktop PC was used to eliminate the need for voltage regulation. Digital signals from the Arduino move the stepper motors in discrete movements. Finally, the solenoids that actuate the water spray are a simple current in a loop of wire pulled on a metal rod. When activated, the rod would pull down with enough force to let the water flow through the nozzle; however, a relay module was required to pass the same high voltage and current to the solenoids that went to the motors. A fully designed schematic is provided in Figure 1 below for simplified viewing. By having this visual representation of a design schematic with actual parts, the design phase for HeatSeekr can be simplified and should closely resemble this schematic. Considering that the HeatSeekr project will have a master and slave configuration, the main controller should be connected to several smaller controllers that will in turn control the specific functions of a system such as moving the navigational motors, or controlling the fire extinguisher pump.

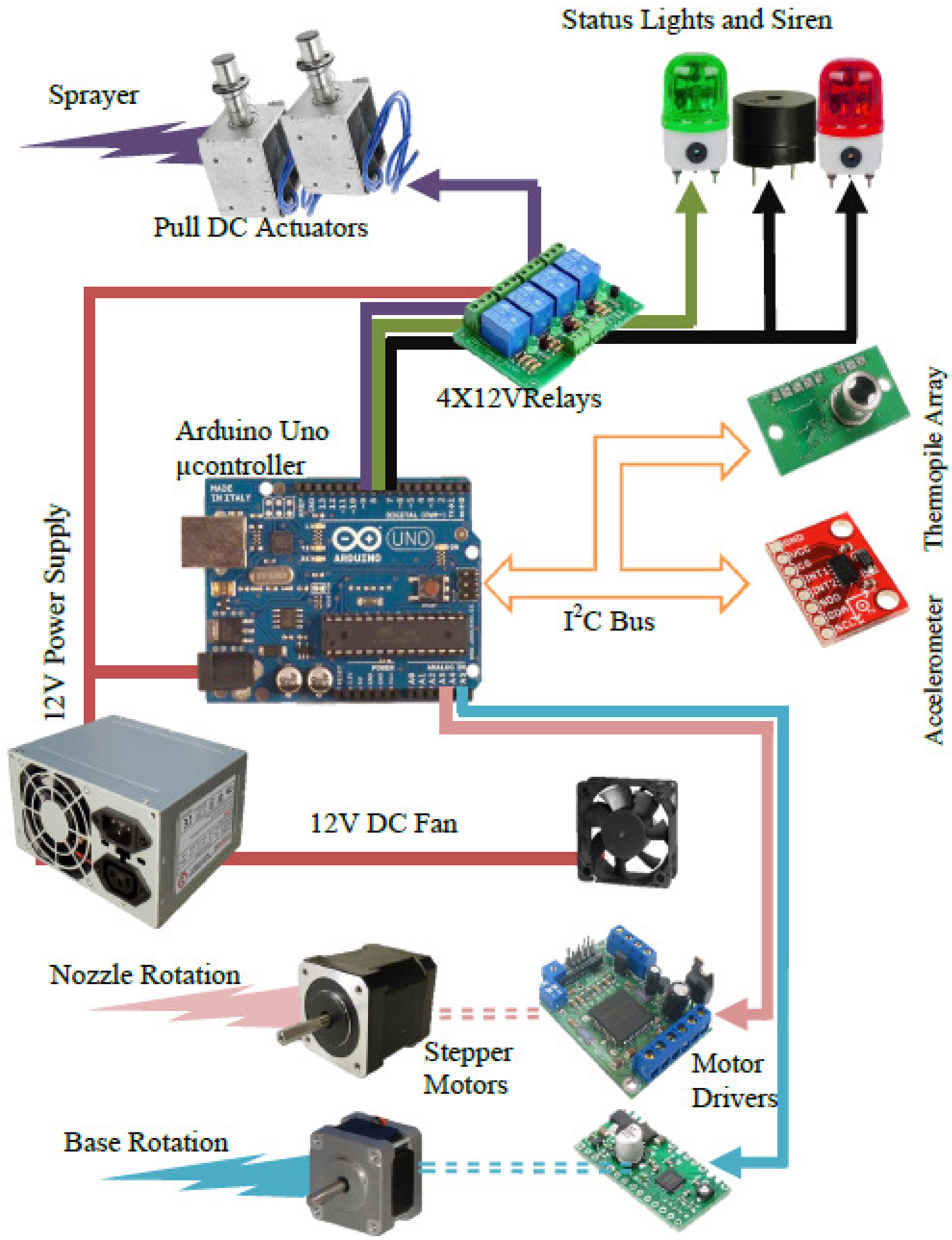


Figure 1: Schematic design for Xfire
Reprinted with permission from Daniel Stough

The coding for the Xfire was all based in C programming with the Arduino IDE "WIRES". The code involves separate classes that each controls a separate part of the project; such as, the Motor Driver, Targeting Controller, Thermal Sensors, Solenoids, Spray Controller, and the Embedded Controller. The Arduino microcontroller is the mediator between the other classes and is able to scan the area, read sensors, locate a target, and begin the extinguisher through use of the other classes. See Figure 2 below for the Xfire UML diagram.

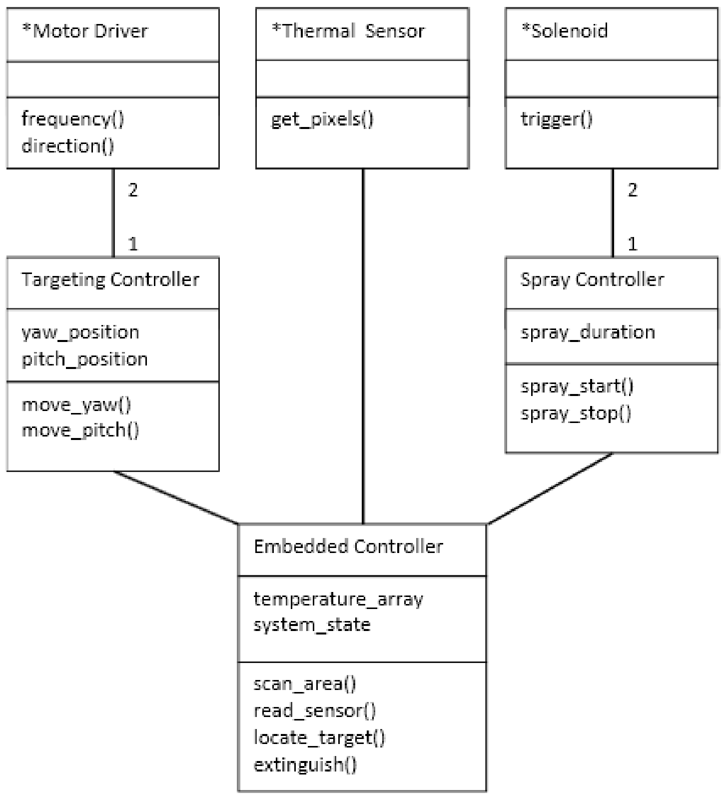


Figure 2: Xfire UML diagram
Reprinted with permission from Daniel Stough

Construction of the Xfire involved many different pieces and large bulky objects, resulting in a large body of about three feet tall and two feet wide. The water nozzle was attached to an aluminum block on the pitch motor shaft and secured with zip ties through milled holes in the aluminum. The standard weed sprayer nozzle was triggered by the two 12v solenoids that were attached on both sides of the nozzle with zip ties. A thin piece of aluminum was attached to a copper rod that was attached to the plunger at each solenoid to depress the trigger of the water nozzle. The thermal sensor that was the key ingredient of locking onto a fire in the infrared domain was specifically designed to respond to a radiant of heat. Once the sensitivity of the sensor reached a certain value, the control algorithm began a conservative sweeping algorithm that would evaluate multiple points over the desired field of view by rotating the sensor along the two axes. By creating a small field of view, the sensor and water sprayer combination was able to localize directly onto a hot spot.

Testing for the Xfire was done through the use of simulating the sequence of events that normally happen during a real life fire emergency. At the beginning of a test, the system was turned on and the heat sensors would begin scanning for large heat signatures. In the lab, the Xfire team used a flat iron to simulate a large enough heat signature for the heat sensor to lock onto. Once the heat source was locked onto, the system determined the precise location of the source and moved the nozzle to aim toward that direction. The water nozzle was set to spray durations of one second to promote a steady supply of water spurts from the nozzle. After each spurt, the device would begin scanning again to search for additional heart sources. This sequence of events was repeated for each simulation trial and the location of the heat source changed sporadically throughout testing.

The results learned from testing showed that system would be able to recognize a heat source and activate the buzzer alarm with a 96% accuracy rating for heat sources within 10 feet. Beyond ten feet, the heat sensor accuracy diminished and the stream of water made contact about 60% of the time. The design setup with the nozzle also showed unexpected limitations in design as the range of motion had to be restricted to 90° in yaw and another 90° in pitch. The drive mechanism also encountered excessive friction during rotation which stalled the motor controlling horizontal movement since it lacked the torque necessary to overcome the created friction.

Overall, the Xfire project is similar in many ways to the HeatSeekr project. Although Xfire is predominantly a stationary platform, the key ideas of using heat targeting sensors and servos to move the extinguisher's water to the correct location of a fire can be directly applied to HeatSeekr. The Arduino Uno microcontroller is incredibly powerful, and could potentially be wasted since HeatSeekr will not be requiring such a heavy computing power. In order to allow the HeatSeekr to be mobile, a different power source will be required as a desktop PC will greatly hinder any mobility. The servos used for Xfire are also quite large, and scaling them down should be able to greatly reduce the amount of voltage required to power the system. The testing procedures that the Xfire went through should be very similar to the testing environment required for the HeatSeekr system. As shown by Xfire's large range in accuracy between searching for a heat signature and actually putting out the flame, it can be assumed that sensing the heat signatures is easier than emitting the water to properly connect with the fire. This could be accounted for the type of pump system that they used and can be accounted for using a stronger pump rather than a standard self-powered weed sprayer. It is also noted that consideration for gravity would greatly improve accuracy of the spray depending on the distance. Once the entire design is complete, calculations for HeatSeekr's design will be able to calculate the amount of force that the water nozzle is emitting from, account for gravity, and then decide the optimal angles and maximum distance for putting out a fire. The testing also showed a large miscalculation in the Xfire's actual design setup as the nozzle would run directly into other objects located around it, and the horizontal motor would stall once it reached a certain turning point as the friction in the chain became too high. To counter these measures, a limiting feature in the fire extinguishers aiming motors should be taken into consideration, and finding a strong enough motor to move the horizontal and vertical positions is an absolute must. The Xfire team also suggested that future work incorporate mechanical modifications to improve performance, using more powerful motors to provide a greater torque to overcome friction limits, improving the vertical support arm that anchors the water nozzle to increase a range in pitch rotation, and creating a smaller custom water nozzle that to avoid collision with hitting the base of the support structures. The team also noted that the system is vulnerable to obstruction by objects in the room which limits the range of detection and operation; however, making the HeatSeekr a mobile device should effectively reduce this issue as it will be able to freely move and navigate on its own.

3.1.2 El Patron

El Patron is a mobile robotic fire extinguisher created in 2001 by Anthony Montoya Jr., Ivan Olguin, and Randy Sena. It was created as a junior design class with the task of creating a mobile robot capable of competing in the Trinity College Fire Fighting Home Robot Contest. The objective of this competition was to navigate through a maze, detect a flame, and extinguish the flame using various sensors. The main goal of the project was to develop the group's teaming skills, oral and written communication skills, and the ability to decompose a large problem. El Patron placed 21st in the national competition out of 71 entries and placed third at their local competition. The main processing board was a Motorola 68HC12 that had each subsystem interfaced with it. The subsystems that integrated with the main board were a system for white line sensors, wall sensors, fire sensors, fire extinguisher, and maze navigation including a return home routine.

El Patron used two flame detectors including a Hamamatsu ultra violet flame detector known as the UVTRON R2868 and its companion driving board for operation, and a PN168 phototransistor. The main function of the UVTRON was to scan each room and determine if there was a flame present. The accompanying driving board outputs a pulse of different frequencies when a flame is detected, and was interfaced directly to their HC12 processor to communicate with the UVTRON. The secondary fire sensor was used as a binocular vision enhancement to home onto the heat signature of a flame by placing the casing of a pen onto the PN158 phototransistor. To avoid any interference from ambient light, a floppy disk was used as a filter by taking the inside lining of the floppy disk and using it as a shield on the outer edge of each pen case. These shields allowed for more accurate locating on a flame and only affected the far left or right sensors of the robot by having the sensor only pick up reading one side at a time.

The mobile portion of El Patron used a closed loop motor control to implement the speed control of the motors. By using built in encoders on the motors to output a square wave at a frequency, a voltage chip was used to transform that information into an analog voltage for the microprocessor to determine what speed the motors are set to. The microprocessor would then be able to adjust the speed of each motor accordingly. Each motor required two frequency-to-voltage chips and circuitry as the motors contained a quadrature encoder. El Patron also used Maxon DC motors connected to the microprocessor by H-bridge motor drivers. The H-bridges were used to control each motor's speed and direction directly from the microcontroller through insulation. The DC motors used were Maxon 0.87 in 6W motors, and their purpose was to control the navigational momentum of the system. With a 14:1 planetary gear ratio, the robot had enough torque to begin movement and maintain a strong top end speed.

The white line sensor used for line navigation was implemented by searching for a white line located within a foot of the flame's candle base inside the maze it was designed to navigate through. The line sensor was soldered onto a perf board and attached to the main processor for communication. The white line sensor consists of a light emitting diode and a photo transistor. During testing, the line sensor was noticed to have variance and errors occur when ambient light interfered with the sensors and the sensitivity of the sensors had to be adjusted. The wall sensors used to prevent collisions inside the maze were sharp GP2D12 IR sensors.

El Patron is a mobile fire extinguisher robot that was designed to navigate through a maze and put out a fire. Similar to HeatSeekr's design, it had to store all of its components into a small frame and be able to efficiently move to a heat source. Although El Patron was designed to navigate a small maze and put out a candle, its mobile methodology could be implemented into HeatSeekr's finalized design to include obstacle avoidance, line navigation, and heat sensing. The use of the UVTRON was a heat sensor was proved to work exceptionally well, as it detects all fire signatures in a region with high accuracy and contains a helpful driver board. The fact that the El Patron team was able to receive a free sample for the UVTRON experiment proved to be a very good financial investment as well. The line navigation implementation idea could be implemented into the HeatSeekr design by having a verified track for navigation. By installing this line seeker, navigation into different rooms to search for a fire would be quite easy as a simple grid could allow for navigation down a hallway, into a room, then back out into the hallway to the next room.

3.1.3 Heat Seeking Fire Extinguisher

This heat seeking fire extinguisher design was a two person team by Frisco Sembel and Tony Winoto for a senior design project in 2011. The goal of the project was to create an extinguisher with the ability to track fire or moving to the heat source for demonstrational purposes using a modified webcam. The device begins activation when the alarm system goes off and the webcam scans the entire area for any contours, then compares those contours to the next frame to depict whether it is moving or not. Once a fire source is detected, the information can be stored and sorted based on the areas location and size and then a fire source would be able to be extinguished in order of largest to smallest. This projects idea began from the amount of property damage caused by sprinklers in the event of a false alarm or just a small source of fire. Common sprinkler systems can spray water across a large region of a room or even an entire building, which causes an immense amount of damage to multiple electronics. This system is designed to specifically locate only the source of a fire or large heat signature, and attempt to extinguish only that one specific area to reduce property damage from sprinkler systems attempting to prevent property damage from a fire.

The project was divided into two subsystems for a strong vision system and a pulse width modulation (PWM) for servos. A Beagle Board was used to communicate with the IR camera and the PWM subsystem, with servos linked through a shifter for voltage conversion. This modified extinguisher system allowed for tracking and pinpointing a fire source, but only turned on an LED to indicate that a trigger function had been implemented. The robot's key features included a portable fire extinguisher system with fast fire detection, low power consumption, and a modular system.

The main control and process of the project relied on the Beagle Board-xM as a microprocessor. The image processing algorithm designed for the project took a large amount of time and processing power, so the Beagle Board helped to speed up the process over other suitable microprocessors. For software, OpenCV was used as it is a large library of programming functions for real time computer vision. OpenCV assisted with simplifying the image processing algorithm by allowing certain calls to necessary functions to process real time images from the IR camera. The resource abusive functions were involved with capturing images, extracting images per frame, saving an image, and background extraction. The system also had a panning and tilting mechanism for the robotic arm was done through an expansion header on the Beagle Board. The servos used for panning and tilting were HS7954SH motors as they generate a 20kg/cm torque. Since the system was generating a high feedback force from the high pressure extinguisher, the stronger motors were required. Measurements indicate that the finalized version of the project allowed for a camera to view approximately 37° for panning and 30° for tilting. For a complete 360° view, the camera's angle would have to be turned 10 times to cover the entire area. The extinguisher was a modified fire extinguisher tube, with modifications on the release mechanism to be automated. The release mechanism works like a water faucet. When the release signal is set, the valve on the fire extinguisher would trigger and unleash onto the fire. An alarm signal was implemented to start the entire process of fire detection. Once an alarm goes off, a signal would be sent to the control system to start looking for fire sources. The control would then return a feedback signal to turn off the alarm while the search is implemented.

The image processing algorithm used was coded in C++ and used the OpenCV libraries for easier processing of images taken from the camera. The algorithm creates a threshold of images and then identifies which images could be a heat source. Motion contour detection was implemented as a strong technique to distinguish between a fire and other sources, as it compares each image to the shape of a fire. The algorithm was then reduced into finding a positive identification on images that would most associate with a strong heat source. When testing with a light bulb as a heat source to simulate fire, the searching algorithm had a hit rate of about 70% and a threshold value of 0.5. The main challenges with this project were the control of system processes and storing information while the system was running. With increased system storage, the system real time processing would drastically increase in length resulting in a slow responsive time to actually put out a fire. Although it was expected to always take less than 50 seconds to scan at each tilt angle, the finalized result was slower with an average of around one minute per tile angle. When in a bright room, the camera's negative photographic film filter would see a wider range of objects which interfered with the overall effectiveness of the image processing algorithm.

In conclusion, the project needed a sever optimization of the control system and the fire detection algorithm in order to speed up the real life response time of the system. For the HeatSeekr's design, the IR camera proved to be too resource heavy and resulted in about a one minute response time to angle toward and locate a fire. Since this project was not mobile, its response time with aiming would be allowed to be a little slow; however, since HeatSeekr is mobile, it is expected to take a longer time to navigate to a room's location and then scan for the fire. This slow response time is incredibly poor and even requires more processing power and resources than originally expected for the project.

3.1.4 FireFighting Robot

The FireFighting Robot was created by Shoaib Afandi, Jaime Austin, Asim Behera, and John Porterfield as a senior design project for Oklahoma State University Engineering. It was designed to follow all rules and regulations of the Trinity College competition. The competition's specific challenge is to create a computer controlled robot that can navigate through a model floor plan of a house, and find and extinguish a lit candle within the shortest amount of time. The robot was designed to be sound activated by having an external alarm emit a certain frequency to start the robot's navigation rather than use a start button or switch.

The FireFighting Robot was designed to have a round shape to avoid any sharp edges and not get stuck on corners of the maze. All pieces of the robot's infrastructure were designed to fit within the chassis so that no external pieces would protrude. The design involved an upper deck and lower deck, with final dimensions of 11 in x 9.8 in x 9.8 in. To ensure that the robot was as light as possible, a servo was used as they are extremely light and small when compared to a heavy DC motor. Three sets of power supplies were used, resulting in 5v for the processor, 10v for the servos, and 18v for the extinguishing motor and were all applied through use of 18 AA batteries and two 9v batteries for the extinguisher motors. The extinguishing circuit was initially designed to use two standard computer case fans to blow out the candle; however, they were proved to not be strong enough to consistently diminish a candle's flame through testing. A DC motor from a remote control car was then installed with the fan blades, and consistency increased dramatically.

Some initial problems with the system were that rounding the corners of the chassis was difficult to implement. The servos were also too small and could easily break, while the wheels were too thin and would cause the robot to jitter instead of moving in a straight line. Since the motors were upgraded to DC motors, the higher torque caused the robot to rotate at time which reduced alignment. The sonar sensors were receiving too much feedback from the top deck of the robot, and the flame sensor was not able to center onto a candle's flame.

The initial problems with the FireFighting Robot were fixed by hacking the servos by removing small protrusions to implement a fully rotational servo. Replacing the servos would have been a better option; however, since the team was on a budget they had to void their warranty and create a quick fix. The sonar sensors used for the alarm system would receive interference by the top deck of the robot because the sound waves would hit the chassis and give incorrect readings. By lowering the sonar sensor with a bracket, the system was able to accurately indicate alerts. The flame sensor's range was originally too far, and was simply painted over with black paint with only a small opening on the sensor to trigger a response when the flame is directly in front of the sensor.

The Hamamatsu UVTRON used for flame detection indicates the intensity of a flame by reading the frequency of pulses from the UVTRON itself. The UVTRON's range is about 5m, which proves it has very accurate reading even at large distances across a room. However, due to its high sensitivity the UVTRON is capable of detecting a flame from any direction and needs to filter out light from its periphery. By creating a small box with an opening in front of the UVTRON, the robot was able to correctly identify a flame and locate its position for extinguishment.

A white line sensor was implemented in the maze, with doorways marked with a white line and the candle being surrounded by a white circle. By using a right and left sensor, the robot was able to read these white lines to navigate the floor plan and also align itself to a specific rotation. This was implemented by using an Optek PB745 reflective object sensor which uses an infrared LED and phototransistor Darlington pair.

Overall, this FireFighting Robot showed a large amount of insight into the amount of problems that could be involved in testing and simple fixes for them. Although the UVTRON's range of detection was incredibly broad, a simple fix of painting the sides of the bulb and placing a box around it repaired that issue. The wheel navigation system was shown to be ineffective as it had issues stalling, and since the HeatSeekr design is going to be carrying a heavy load of about two gallons of water a stronger tire system will need to be implemented. The idea of creating a sound sensor to start the robot from a frequency emission instead of an on and off button could be implemented into the HeatSeekr for use as an early response system. For navigating through a building, using the line navigation system to detect a solid line as a doorway and a circle as a stopping point to search for a fire could prove as an easy way for testing purposes and implementation.

3.1.5 Conclusion and Implementations for HeatSeekr

By combining all of the beneficial traits of each individual project into one, the HeatSeekr can become a fully functioning mobile fire extinguisher robot. Some of the key features that stood out throughout each individual project were the use of the UVTRON as a strong heat source sensor, ensuring that the motors chosen have enough torque to properly move a system, the implementation of a wireless device for activation, and insight into coding issues and simplifications.

The Xfire project displayed a great working demo of a stationery unit that uses a water system to extinguish a fire. They used a standard weed sprayer nozzle from HomeDepot and heavily modified it for automatic release. The system still had to be manually pumped before activated; however, so the HeatSeekr would need to implement a steady motor operated device for the sprayer mechanic. A standard fish tank water pump is capable of pumping a steady stream of water through a tube similar to a weed sprayer; however, it could have its inputs installed onto a board to be operated by a microcontroller to allow for a completely human free environment. The Arduino Uno processor used by Xfire is an incredibly powerful system; however, it could be replaced by several a smaller microcontrollers such as an MSP430. These controllers could be hooked up in a master and slave combination to allow for each processor to control a specific subsystem of the entire project. Since the motors used for Xfire were also designed to support an incredibly large structure, smaller motors could be implemented. Smaller motors can reduce the overall size of the design, reduce the amount of resources required for operation, reduce costs, and increase efficiency with HeatSeekr. The testing environment for Xfire also provides a large amount of initial testing ideas with the extinguisher system for the HeatSeekr project. Assuming that HeatSeekr runs into the same issues as Xfire with being able to detect a fire but not getting the range calibrated correctly, the testing results from this project could provide quick and easy solutions to any problems encountered. Implementing a stronger pump than the weed sprayer should also be able to drastically reduce the amount of error in targeting the fire extinguisher by releasing a stronger steady stream rather than the small compressed amount of water that fits the sprayer. Miscalculations in the initial design for Xfire also backfired when the aiming mechanics for the nozzle interfered with the positioning of the rest of the system, and implementing a mechanical limit for the nozzles would be required. The error with physical objects obstructing the Xfire's visibility can also be reduced by implementing the mobile navigation system to dodge any obstacles if needed. For example, if a fire is located underneath a table and a chair is interfering with the sensors, then the HeatSeekr could potentially navigate around the table to perceive a better location for dousing the fire with water.

El Patron was a mobile fire extinguisher that serves the purpose of demonstrating a smaller version of the Xfire that can put out small candle flames. By implementing the design strengths of the Xfire's powerful extinguisher system with El Patron's mobile navigation, the foundation for the HeatSeekr design can be set. Designed to contain all of its components within a small frame, El Patron is a sleek and circular robot capable of navigating around corners without any systems protruding from it in a nice case. By incorporating this idea into the HeatSeekr, a larger version can be made that is also sleek and mobile. The use of the Hamamatsu UVTRON appeared to provide great accuracy for fire detection, and should be incorporated into the design of HeatSeekr. By implementing an already known working system, the HeatSeekr's heat sensor should be tested much easier than investigating new methods and ensuring that they work with a high rate of accuracy. Although El Patron was only designed to extinguish a candle, the Xfire spray system could still be implemented to extinguish a larger fire by carrying a tank of water on its chassis. Since a gallon of water weighs roughly eight lbs, the amount of power used in the navigational motors will have to be strong enough to support a heavy load to ensure mobility. The white line navigation system used by El Patron could also be implemented into HeatSeekr's finalized form, as navigation to a certain room in a building will require certain navigational signals to be sent to the robot. By using a standard line follower system with set inputs such as a line for a doorway and circle for a fire search location, the HeatSeekr should be able to easily navigate from one room in a building to another.

The Heat Seeking Fire Extinguisher project gave the perspective of using an IR camera designed from a Logitech webcam modified with a floppy disk film. This type of heat sensor proved to work; however, its overall rate of success was much lower than expected. In order to ensure a successful test, the UVTRON from El Patron appears to provide a stronger sensor that can even be provided for free from Hamamatsu for students. The slow response time with the image processing algorithm also suggests that the UVTRON is faster at processing data for an alert on a fire's location, and since HeatSeekr is going to be navigating to the room and then detecting for the fire a speedy response time will be required. The idea of exploring a fire extinguisher that carries an actual full sized fire extinguisher was promising; however, the system appeared to be too bulky, heavy, and messy to be effective. The proposed idea of using a water tank similar to Xfire with a fish tank pump still appears to provide a stronger spray system with customizable dimensions.

Finally, the FireFighting Robot showed a large amount of insight into the amount of issues that testing of a prototype can involve. By taking into account all of the errors that the FireFighting Robot team encountered, the HeatSeekr prototype should be reduced of overall errors in testing. This robot also introduced an interesting idea of incorporating a wireless signal for startup. By creating a wireless signal that turns on the HeatSeekr, the overall resources used in powering the HeatSeekr can be drastically reduced as it will only activate once an alarm is triggered. Although the FireFighting Robot used a frequency emission to turn itself on and off, a Wi-Fi or Bluetooth signal could be incorporated to connect to an antenna on the main design for the HeatSeekr as an alarm. If this route is incorporated into HeatSeekr's finalized design, a remote sensor system will have to be implemented that can detect a fire in a certain room, and then relay the location of the fire to the HeatSeekr to turn on and navigate to that room. The FireFighting Robot also used a UVTRON for heat detection like El Patron, and it had similar success in locating heat signatures throughout testing. The only issue that their system ran into was that the UVTRON was too powerful, and would often capture too much ambient light in a room that would interfere with the signal. To prevent this, the FireFighting Robot painted part of their UVTRON to remove ambient lighting from the sides and created a box with an opening to amplify the amount of light coming in from directly in front of the project. For HeatSeekr's design, a simple UVTRON shield can be implemented that replicate this idea and amplify light in the forward direction of the HeatSeekr. The line navigation system also showed how certain issues were not taken into account for in the design phase, and resulted in the wheels building up too much tension and stalling. To prevent this, the HeatSeekr should use stronger motors as it will be carrying a heavier load through its navigation system. The wheels should also be replaced by tank treads as they increase the amount of terrain that can be navigated and equally distribute the weight of the system across the entire breadth of the tire treads. The line navigation used for the FireFighting Robot is again very similar to El Patron's design, and used a straight line at doorways to simulate entering and exiting a room. Once inside a room, finding a localize spot by a white circle to start sensing for the fire would again be a favorable idea.

By investing all of these projects, it is clear that the HeatSeekr is going to be carrying a heavy load of water weighing roughly 16lbs from two gallons of water. This water will be designed to spray through a tube with some kind of fish tank pump, and motors will be in control of moving the X and Y axis for aiming. In order to properly align itself with a fire, a heat sensor similar to the Hamamatsu UVTRON will need to be incorporated to be highly accurate. This UVTRON sensor could be mounted above the X axis and allow for one motor to control both the aiming of the nozzle and the aiming of the heat sensor, similar to the Xfire project. In order to navigate to the fire, a line navigation system will have to be implemented that detects colors and patterns on the floor in order to determine its current location, and where it has to go. To control movement, strong motors will have to be implemented onto the HeatSeekr's chassis and move a tank tire tread system for optimal navigation. The tank treads will provide better support through the system as all the weight is evenly distributed and less likely to stall than the wheels have in other smaller projects that carry less weight. Finally, a wireless signal alarm could also be implemented into the system for a wakeup alarm. The HeatSeekr could stay in a standby mode to reduce the amount of energy used on the system, and then awake when the alarm goes off. This would allow for a stronger sense of practicality as the sensor would be able to be placed in a room and scan for the fire instead of forcing the HeatSeekr to navigate into a room, scan, and then precede to another room when there could be a fire somewhere in the building already.

3.2 Microcontroller

3.2.1 ATmega328

The ATmega328 is a microcontroller board by Arduino. It has 14 digital input and out pins, six analog inputs, a 16MHz ceramic resonator, a USB connection, power jack, ICSP header, and a reset button. The operating voltage is 5V, with a recommended 7-12V for input voltage, 14 Digital I/O pins, six analog pins, a DC current of 40mA per I/O pin, 32KB flash memory, 2kb SRAM, 1kb EEPROM, and a clock speed of 16MHz. Its physical dimensions are 2.7 inches long and 2.1 inches wide.

Arduino is an open source platform based on a simple I/O board and a developing environment that uses the Wiring language. This allows for development as a stand-alone interactive object or connection to a computer. One of the key features of using an Arduino board is the amount of support and community assistance available. The open source IDE is available for free download from the Arduino website, and there are several communities that assist developers with Arduino hardware questions, IDE development, and testing purposes.

The available communication for the Arduino revolves around the USB connection to a computer. The board does include a serial monitor that allows for simple textual data to be easily sent to and from the Arduino board for ease of use. Additional SoftwareSerial library data allows for serial communication on any of the Arduino's digital pins, and supports I^2C (TWI) and SPI communication.

For the purposes of the HeatSeekr, the Arduino has been deemed as too powerful and potentially wasteful. Because of the high flash memory, SRAM, and clock speed, it is estimated that its resources will be wasted. By attempting to utilize as many resources without wasting power, a smaller microcontroller would be favorable.

3.2.2 MSP430G2553

The MSP430 is a 16-bit microcontroller platform of ultra-low power RISC from TI. It is most widely used for its low power and portable applications. Its key features include seven low power modes, customizability to specific applications, up to 512KB of flash, and up to 18KB of RAM.

The MSP430 different low power modes allow for the microcontroller to sleep while its peripherals continue to work without a power draining processor. It is also capable of wakeup times below 1µs; which, allows the microcontroller to stay in sleep longer and minimize average power consumption.

The main advertised applications of the MSP430 include metering, portable medical, data logging, wireless communications, capacitive touch, personal health and fitness, energy harvesting, motor control, and security and safety. For the HeatSeekr, portability, wireless communication, motor control, and security and safety are key departments that need to be supported by the microcontroller chosen.

The portability of the MSP430 allows the reduction of design complexity which would allow for a more polished final product. It also has shown use amplifying and filtering through data in the medical field as an EKG-based heart-rate monitor. This could be transferred to the amplification and filtering of data returned through the sensors and servos for detecting a fire and acquiring a target trajectory.

The wireless communication of the MSP430 would allow for the proposal of using a navigation system devised around having a wireless system communicate with the main robot to help navigate to a certain room. Asset tracking, industrial monitoring and tamper detection, personal wireless networks, and alarm and security systems are all completed using a single-chip radio-frequency. If implemented, this would allow the HeatSeekr to track its progress through navigation of an office building, detect if an outside source is tampering with its security features, and alert an operator through wireless communication if desired.

The MSP430's security applications include saving power through smoke detectors, thermostats, and glass breakage systems by utilizing the ultra-low power consumption. Since the HeatSeekr is considered a security device, the ability to save power for emergencies like a smoke detector is a highly valued quality.

Finally, the MSP430's ability to control stepper motors will be required to drive the vehicle to its position, and also to correctly position the extinguisher up to a flame. The MSP430 is suggested to connect two UC3717A integrated circuits a bipolar stepper motor. The integrated circuits use an H-bridge circuit for driving a single winding in a bipolar stepper motor, and depending on the number of pins available to the number of stepper motors used, additional MSP430s may be required.

The MSP430 community also has assistance with choosing an IDE, code examples, developer packages, open source projects, and software tools for assistance. As a highly used microcontroller, the community has a helpful forum that provides numerous tutorials.

3.2.3 Conclusion

Overall, the MSP430 meets all of the specific requirements of the HeatSeekr project. It requires little power to operate, has the ability to suspend into sleep mode and quickly awake itself, is highly portable and secure, easily connects and controls stepper motors for various tasks, and has the capability of wireless communication for navigation and alert purposes. Depending on the overall process power required of HeatSeekr and the amount of I/O pins needed, two or more MSP430's could be required. If more than one controller would be used, a microcontroller could be devoted specifically to the navigation or extinguisher blocks and pass data between them.

3.3 Flame Detection

The ability of the rover to identify and combat flames centers on a means to detect fire. Several methods of fire detection were researched, and each option provided a very different set of challenges, requirements, and abilities. One important consideration for each of the detection systems was that the processing power required to perform the specified functions could be handled by an MSP430 or similar level microprocessor. Another consideration was that the chosen system would be robust in its ability to discern fires from other sources of heat or infrared. This is mostly due to the fact that the environment of the rover's operation could include heat sources in kitchens, infrared leakage from fluorescent bulbs that are common in office and retail environments, directed sunlight from windows, and other sources of infrared that could mimic fire to an unintelligent system. Three fire detection methods were eventually discussed.

3.3.1 Infrared Camera

The first fire detection system considered involved a SEN-08773 CMOS IR camera module. The camera itself is a black and white 500x582 optical device that included a board that would output an RCA signal and ran on 12V. The camera with board is projected to cost $34.95, and detailed documentation is readily available. A summary of the SEN-08773 CMOS IR camera module's specifications is presented in Table 3.

Item	Specification
Price	$34.95
Interface	RCA
Size	1.5 in x 1.5 in x 1.2 in
Operating Voltage	12V at 90mA
Resolution	500 x 582

Table 3: SEN-08773 CMOS IR camera module Specification Summary

The implementation of the infrared camera would involve mounting the camera on an elevated stalk so as to give it visual access to the area immediately surrounding the rover. The camera would be connected mechanically to two servos that would control horizontal and vertical movement to allow the camera to pan through the environment.

The advantages of the infrared camera system were unique to the other considered options. The system did not rely heavily on servo-driven scanning in order to detect fires; rather it incorporated a relatively large field of view and relied on software to discern applicable infrared sources. This capability afforded the system a much faster response time, as the other options required automated scanning of the entire upper sphere of the 3-D plane in order to locate flagged fires. When considering fires outside of point sources, this would have led to dramatically faster extinguishing of fires as well, as additional scanning would not be necessary to cover wider fires. Assuming implementation of flicker and edge detection algorithms, the system would also satisfy the requirement for robust fire distinguishing, as infrared sources would require flicker and differential edge disturbance characteristics of flames in order to be positively identified and acted upon, minimizing false detections. Considering the stationary hanging unit, the camera represents a possible means of wide area coverage in that it would not require a servo system to compensate for its low field of view.

This option presents numerous challenges that eventually led to its abandonment. The camera first and foremost had an RCA output, which would require an analog to digital converter in order for the signal to be manipulated digitally by the microcontroller. This presented an entire field of study that, when compared to the other options, simply was an inefficient use of time. Using an infrared camera would also require a robust software suite to be written so that the infrared images it transferred to the microcontroller could have detected flames isolated and centered upon. Previous users of this technology relied on the OpenCV C++ libraries to incorporate edge detection and flicker analysis so that only infrared sources that mimicked flames would be responded to. This represented a significant increase in required computing power as the OpenCV libraries would not run on the level of microcontroller being considered for the project. In a similar vein, the amount of data sent by the camera represented a prohibitive memory and computation condition, as the required resolution and frame rate of the camera would require inefficient amounts of storage for what is accomplished more readily by subsequent considered systems.

3.3.2 Scanning IR Thermometer

The second fire detection system considered involved the $99.50 Daventech TPA81 Thermopile Array, an advanced infrared thermometer that has the incredibly useful bonus of using an I2C interface, allowing for easy information exchange with the MSP430G2553. This sensor includes an array of eight infrared detectors in a 1.2 in x 0.71 in package, and runs on only 5V. Documentation specifies that the thermometer is capable of resolving a candle at 7 feet, making sure to mention that at 7 feet, a candle and a human are resolved as the same temperature above ambient. A summary of the TPA81 Thermopile Array's specifications is presented in Table 4.

Item	Specification
Price	$99.50
Interface	I2C
Size	1.2 in x 0.71 in
Operating Voltage	5V at 5mA
Effective Range	7 feet
Field of View	41° x 6°

Table 4: Daventech TPA81 Thermopile Array Specification Summary

The implementation of the infrared thermometer would involve mounting the array into a shroud to limit its field of view, specified as 41° x 6°. The shrouded array would then be mounted on an elevated stalk and fitted with servos to control horizontal and vertical movement. Software would be developed to incorporate a scanning mechanic to allow a systematic sweep of the environment in rooms that have been flagged as containing fire.

By connecting the output hose of the extinguishing system to the block holding the shrouded array, the servos that control thermometer movement could also be used to center the extinguishing hose, limiting the computational and physical requirements of separate systems.

The scanning infrared thermometer presents several advantages to the infrared camera option. The I2C interface presents an immense decrease in development time, as the values for each of the 8 thermal detectors would be read in digitally to the microcontroller and be made immediately available for computation. This also negates the necessity of any image processing by virtue of the simplified detection scheme, and subsequently relegates the system into the level of desired microcontroller processing power.

The challenges inherent to the IR thermometer revolve mainly around its indiscriminate detection criteria and the lack of means to address these issues. Many elements of a standard office or industrial environment would emit enough infrared radiation to trigger a fire response from the thermometer-equipped rover, such as heating elements used in kitchens, manufacturing, or even heated beverages. The specifications make note that a human being is registered at the same temperature as a candle at 7 feet, presenting a humorous though serious design flaw when false extinguishing is considered. In the infrared camera system, these false positives, or type 1 errors can be mitigated through an investiture into processing power by utilizing image processing to detect characteristic edge and flicker perturbations of fires. No such methods of control are possible with the indiscriminate data received from the infrared thermometer, and the scope of the project would be meaningfully reduced through its implementation.

3.3.3 Hamamatsu UVTRON Flame Sensor

The third fire detection system involved the $34.95 Hamamatsu UVTRON Flame Sensor R2868, a sensor that utilizes a very sensitive ultraviolet detector to detect the faint ultraviolet radiation given off by active flames. The sensor itself requires 325V for operation and outputs an analog voltage, but an additional driving circuit C3704 board ($49.94) is available that functions as a high voltage power supply, lowering the input voltage to 5V at 3mA and also functions as an analog to digital converter for the sensor, outputting serial data. The board and sensor combination have a 2.4 in x 2.4 in x 0.40 in footprint. The specified sensitivity is enough that a cigarette lighter flame can be positively detected at a distance in excess of 16 feet, and this capability is not hindered by sunlight, as the sensor is insensitive to visible light and has a very narrow spectral sensitivity in the UV range. The UVTRON has a very wide field of view, encompassing the portion of a sphere corresponding to 120° x 120°. A summary of the UVTRON Flame Sensor R2868's specifications is presented in Table 5.

Item	Specification
Price	$84.90
Interface	Serial
Size	2.4 in x 2.4 in x 0.40 in
Operating Voltage	5V at 3mA
Effective Range	16 feet
Field of View	120° x 120°

Table 5: Hamamatsu UVTRON Flame Sensor Specification Summary

The implementation of the UVTRON would physically be very similar to the infrared thermometer in that its rover incarnation would be mounted in a shroud outfitted with servos to allow sweeping detection of a flagged fire environment. The UVTRON would be placed on a mounted stalk that also housed the extinguisher output, simplifying the combination of detection and aiming. The outstanding field of view and increased range of the UVTRON allows for the articulating shroud design and the possibility of the stationary hanging unit. Similar to the implantation of the infrared camera, the UVTRON can be used to allow for passive detection while the rover is navigating a non-fire-flagged environment. The shroud used in the scanning mode can be articulated in a non-interfering position when in passive mode to take advantage of the wide field of view, allowing the rover to set its own fire flags should a fire arise away from a stationary hanging detector. The implementation in the stationary unit would involve positioning the sensor such that the 120° x 120° axial field of view would be centered on the floor of a room, allowing for near complete coverage of a five meter radius from the sensor. Because no scanning mechanic would be required for the stationary hanging unit, no servo, shroud, or sweeping algorithm are required, making the stationary unit incredibly simple, requiring only a power source, microcontroller, and the sensor in order to perform a unique and important task.

The UVTRON has many advantages over the other considered options, mainly due to its unique detection method and increased specifications. The UVTRON shares the infrared thermometer's advantage of decreased computational requirements for positive fire identification, requiring only a scanning algorithm and a loop breaking flag to stop the scan when the detector is centered on a suspected fire source. The increased detection range of the UVTRON is more in line with the desired specifications: indoor environments can quickly exceed 7 feet in an office or industrial building where having passive fire protection without human interaction would be the most helpful. The UVTRON's specific band of ultraviolet detection does not require any additional processing to disregard false positives, as the only other major sources of ultraviolet radiation in the specified band are corona discharges in high voltage coil applications - an unlikely component of most offices and warehouses. This specification makes it a much more appealing choice to the infrared camera, as extensive processing was required to isolate detected infrared sources. The lack of infrared detection also allows the UVTRON based system to be used in environments with heating elements such as kitchens and industrial manufacturing plants, as these sources of infrared radiation will not be detected by the UVTRON as they would be by the infrared thermometer and infrared camera.

3.4 Fire Extinguisher

The ability of the rover to extinguish flames is highly dependent on the method of fire extinguishing used. Many aspects of design are impacted by the choice in fire extinguisher, including stepper-motor power requirements, navigational requirements for various ranges, drop-and-swap functionality for non-refillable canisters, and firing algorithms. Desired characteristics of the fire extinguishing system included ease of purchase and replenishment, as the rover will be subjected to many tests, long range accuracy, simplicity in implementation with regards to firing patterns, mechanical concerns, actuator requirements, and relative safety.

3.4.1 ABC Dry Chemical Canister

The first fire retardant considered was an ABC dry chemical canister. Containing pressurized monoammonium phosphate and being activated through actuation of a lever, the canister represented an all-in-one solution for fire extinguishing, with all elements of the system contained within a pre-packaged unit. Many different units were offered, but what was considered specifically was a 2.5 lb multi-purpose product by Kidde, the FA110. The FA110 was available for $26.99 from Amazon, and could have been purchased in bulk for repeated testing. Implementation of the FA110 would involve securing it to the chassis of the rover and fitting it with a throttle actuator that could depress the lever required to release the dry chemical. A hose would be attached to the dry chemical emitter and affixed to the vertical servo to allow it to be aimed.

The FA110 dry chemical canister presents several advantages in its implementation. The extinguisher system is contained in one subsystem and requires no additional parts to be purchased. This makes its implementation into the project a simple matter of securing it to the platform and attaching an actuator. Comparing it to other options, the motivator for the fire retardant is self-contained, the storage unit for the fire retardant is self-contained, and the fuel monitor is self-contained. The FA110's fire retardant is also a much more comprehensive extinguishing agent than water. ABC dry chemical is able to handle class A, B, and C fires, or fires dealing with ordinary organic material, fires dealing with liquid and gasses, and most importantly electrical fires. This is ultimately the strongest advantage for the FA110, as implementation into an industrial or commercial environment could greatly benefit from a means to handle electrical fires. The stream from the FA110 is also already slightly coned, meaning that precise aiming is not required, greatly simplifying the hardware and software requirements of implementation. Compared to a water pump, which fires a highly gravity affected and coherent stream of retardant, the FA110 lofty dry chemical liberally attacks a wide cone of area.

The challenges inherent to the FA110 are mainly a result of the testing requirements of the project, and the implementation methodology. The FA110's dry chemical fire retardant is held under the pressure in the canister - a requirement for the self-contained firing apparatus. This unfortunately makes refilling the system very difficult to be done cheaply and quickly. The prototype testing as outlined requires several firing tests to determine the efficacy of various algorithms related to firing patterns and extinguisher range. While a very superior fire retardant, the dry chemicals used in the FA110 are simply too cost prohibitive to be used in a from-scratch project requiring prototypes and testing; in the absence of a refilling module, each canister would cost $26. The implementation of the project is assumed to be a prototype, and a refillable fire extinguishing system, while perhaps less effective at extinguishing fires, would be a better test of algorithms and hardware configurations.

3.4.2 Water Pump

The second fire extinguishing solution considered centered around the MCP355 Swiftech PC liquid cooling pump, available from Swiftech for $83.95. The MCP355 is intended for use with high load PC cooling systems, and as such runs on the same 12V available in a pc, has a very high pressure output of 14.7 feet (on full load), a medium discharge rate of 120 GPH, and takes up just 2.4 in x 2.4 in x 1.5 in. The implementation of the MCP355 in the rover system would take the form of a water reservoir, entry tube from the reservoir to the MCP355, exit tube form the MCP355 to the vertical stepper motor, and relay control from the MSP430 to the power input of the MCP355. The reservoir is envisioned to take the form of an acrylic cubic rectangle serving as the base on the chassis for the electronics, holding between two and three gallons of water, enough to run the MCP355 at full power for 1 minute. With an average fire extinguishing time of 15 seconds, this implementation would allow for four fires to be extinguished per charge.

The MCP355 presents several advantages in its implementation. The liquid used in the MCP355 is very useful for type A fires, and because type A fires involve organic material such as paper and plastic, the retardant would be excellent for a commercial or industrial environment. The MCP355's impressive pressure output of 14.7 feet indicates that it can project water through 14.7 feet of PC cooling heatsink, implying very high pressure and thus very long range for fire extinguishing. This coupled with the medium flow rate of water translates to constant water coverage for longer time on detected fires, a good characteristic for long range, high accuracy fire extinguishing. Running on 12V is a very good bonus, as the pump can be run directly from the 12V rail in the power system. The notion of a refillable reservoir is perhaps the most important advantage of the MCP355 over the other considered options. Water is essentially freely available, encouraging many attempts during testing of firing algorithms, pump voltages, environments, and demonstrations. Considering the alternatives cost roughly $26 per fire extinguishing, this aspect of design is weighted most heavily.

The challenges inherent to the MCP355 are mainly a result of the intended work environment versus the utilized fire retardant, and the method of delivery required for specifications. The fire retardant used in the MCP355 is rated only for type A fires. Unfortunately, type C fires, or fires involving electrical equipment, are also found in commercial and industrial environments, and the fire retardant used in the MCP355 is actually quite dangerous to use for type C fires as it conducts electricity. This is a fairly important consideration, and reflects an example of the prototypical nature of the project taking precedence over real world applicability. The method of delivery for the MCP355 is also very exact and gravity affected, making long distance fire retardation slightly inefficient with respect to amount of water used. Because the water stream will be more curved as the distance of the fire increases, it will be necessary to incorporate movement algorithms to accompany hose activation in order to spread the stream of water over an area. This translates to increased water usage.

3.4.3 Aiming Servos, Reservoir, and Pump

3.4.3.1 Medium Stepper Motor - PM42M

As the aiming servos will be required to accurately move the extinguisher nozzle small margins of a degree and be relatively small and weightless, the PM42M appeared to be a strong candidate. With high torque output, superior running quietness and stability, step angle of 7.5° , 48 steps, and with a small dimension of 1.7 in diameter by 0.78 in high with 2 in between holes it appears to be a great candidate for moving the extinguisher's nozzle. The PM42M has 48 steps per rotation and 7.5° per step. This rotation has a drawback of a large angle and a drive voltage of 24V, and coil resistance of five ohms if Bipolar and 80 ohms if unipolar with constant voltage.

Because the HeatSeekr is attempting to be a portable, highly accurate, and low resource driven device, this high voltage drive of 24V for a 7.5° turn is a major drawback to that specification. Another issue would be a measure of accuracy for the extinguisher with this 7.5° turn. It is expected that this large turn will require the HeatSeekr to waste water as it continues to spray over or under the expected mark, or require further maneuvering to prevent water waste. To prevent this, a motor with a smaller degree turn will be required. A summary of all features can be seen in Table 6 below for easy reference.

Step Angle	7.5°
Drive Voltage	24 V
Current/Phase	500 mA
Coil Resistance	80 ohms unipolar or 6 ohms bipolar
Torque	4.0 N/cm
Price	$7.95

Table 6: PM42M Specifications

3.4.3.2 NEMA 16 Step Motor - 39BYG302

This Nema four wire 16 step motor is a small step motor that has 200 steps per revolution and a step angle of 1.8°. The small step angle of 1.8° is the smallest that standard stepper motors vary in, and would be the optimal value to accurately hit a small fire source with the extinguisher. With a small dimension of 0.98 in by 0.511 in, it will fit easily onto the HeatSeekr project without impeding with any of the other components and still look quite polished. With such a small frame and step angle, the NEMA 39BYG302 appears to be a good fit for the HeatSeekr project. A summary of all features can be seen in Table 7 below for easy reference.

Step Angle	1.8°
Current	0.32 A
Resistance	15.0 ohms
Holding Torque	1.0 N/cm
Control wires	4
Price	$12.95

Table 7: 39BYG302 Specifications

3.4.3.3 Probotix HT23-180-8

The Probotix step motor is a middle ground between the medium stepper motor and the NEMA motor. It has a step angle of 1.8° with 200 steps per revolution. It has a holding torque of 185oz-in in parallel and series, or 127 in unipolar. It weighs 0.7 kg with a length of 2.2 in and eight wires. Because this model has eight wires to control stepper movement, it will take up a large amount of GPIO pins on the microcontroller. A summary of all features can be seen in Table 8 below for easy reference.

Step Angle	1.8°
Current	2.5 A
Resistance	1.23 ohms unipolar or 0.62 ohms parallel
Holding Torque	180 oz/in
Control wires	8
Price	$33.95

Table 8: HT23-180-8 Specifications

3.5.3.4 Conclusion

For HeatSeekr, the Nema 16 step motor 39BYG302 is the most practical of all listed stepper motors for the extinguisher's aiming system. This type of a stepper motor was chosen as the programming code for the aiming system will be able to reset its position back to an initialized location by counting the amount of steps that it traveled. Its small degree turn of 1.8° will enable for higher accuracy when attempting to put out a flame. The motor has an input of four wires to control movement, which will need to be connected to an H-bridge to communicate with the microcontroller correctly. The motor uses a current of .32A and a holding torque of 1N/CM.

Two of these motors will be bought from Circuit Specialists from their website for $12.95 each, resulting for a total of $25.90. They will be attached to the extinguisher system to control the X and Y plane rotation. This will enable the HeatSeekr to spray water toward any direction and adjust for distance as needed by adjusting the X and Y plane motor accordingly with a margin of error for 1.8° as accounted for the degree turn. This small margin of error can be reduced by positioning the HeatSeekr closer or further away from the target by using the navigational system as needed. Both motors will require two separate H-bridges to properly communicate with the extinguisher system's microcontroller. Spark fun provides H-bridge stepper motor drivers for $2.35. These H-bridges fulfill all of HeatSeekr's needs and allow for complete control over the motors as they are designed for stepper motors. They can increase a voltage of 4.5v up to 36v, and can generate a continuous current of up to 1.1A.

3.5 Navigation

3.5.1 Treads

For navigational purposes, a system of tank treads will be used over a standard wheel system. Due to the nature of the HeatSeekr's navigational paths and high water capacity, the tank treads provide more rough terrain ability and distribution of weight. The steady tread movement should prevent any stalling from transferring from a tile floor to a carpet or moving over any door frames. Similarly, since the tread will be evenly distributed throughout the bottom of the HeatSeekr's chassis, the weight of the system will be transferred more evenly instead of applying a constant force each of the wheels. For proper navigation through terrain, the navigational motors will have to mount into the tread chassis and rotate its gears. Two motors will be needed controlling each side of the tread, as this will allow for turning by only activating one motor at a time instead of both just forward and back movement.

3.5.1.1 Tracked Vehicle Chassis Kit - Tamiya 70108

The Tamiya 70108 vehicle chassis kit is sold by Robot Combat off of their website for $16.49. This chassis is a smaller system with dimensions 6.625 in. x 4.125 in x 2.125 in. and made out of a light plastic material. The system uses a simple motor that does not allow for independent movement of the treads, so a dual motor gearbox would be a required additional purchase to allow for proper vehicle turning. For original estimations of the HeatSeekr dimensions this would be a good size; however, further research shown that it is would be too small and weak to properly move the HeatSeekr at full water capacity and still maintain a centralized center of mass.

3.5.1.2 VEX Robotics Tank Tread Kit

The VEX robotics tank tread kit is sold by Robot Combat off of their website for $29.99. Its standard length is in two preassembled chains of 85 links of 32.75" each. Each link is considered a master link as it is able to be fully removed from the chain to reduce its total length, allowing for greater variability in total length. Each link is also made of delrin plastic, which has impact strength of 1.5 ft-lbs/in., and should satisfy all weight concerns with a full capacity of water. The entire tank tread kit from Robot Combat comes complete with two chains, four tread drive wheels, four double and two single bogie wheel assemblies, 12 bogie support screws and nuts, and instructions for installation on a chassis. Simply put, the tread is attached to the chassis piece by piece and the motor is placed on the other side of the chassis base with the nuts to connect into the wheel drives.

3.5.1.3 Conclusion

Overall, the VEX robotics tank tread kit allows for great customization of tread length for the HeatSeekr's body. The delrin plastic is strong enough to support a heavy load when under the stress of two gallons of water being carried. The tread design will require two separate motors to drive each chain and will be mounted to the drive wheel, and will be expected to drive the entire vehicle forward without any stalling. Since the estimated water capacity will always be carrying one gallon of water weighing eight pounds, the motors are expected to carry 12 pounds each minimum.

3.5.2 Motors

3.5.2.1 Gear Head Motor - GHM-13

The GHM-13 gear head motor provides a small torque value of 231.5 oz-in which converts to 14.468 lb-in. The motor requires a voltage of 12v and has RPM of 152. Weighing at only 7.28oz, the two motors will increase the overall weight of the HeatSeekr by 0.91lbs. Given that the motor already has a low lb-in turn ratio, the chance of having a motor stall during full capacity is very high. A summary of all features can be seen in Table 9 below for easy reference.

Reduction Ratio	50:1
Voltage	12 Vdc
RPM	152
Outside Diameter	37mm
Stall Torque	231.5 oz/in
Weight	7.28 oz
Price	$29.95

Table 9: GHM-13 Specifications

3.5.2.2 Planetary Gear Motor - PGHM-02

The PGHM-02 planetary gear motor provides a high torque value of 388.85 oz-in, which converts to 24.303 lb-in. Similar to the GHM-13, this motor requires 12v to start but has a lower RPM of 65. Weighing 8.9 oz, the two motors will increase the overall weight by 1.1125lbs. With maximum water capacity expected at two gallons, this motor will provide all of the extra strength needed to push the HeatSeekr through the terrain. Each motor can be purchased from Lynxmotion off of their website for $37.95. A summary of all features can be seen in Table 10 below for easy reference.

Reduction Ratio	91:1
Voltage	12 Vdc
RPM	65
Outside Diameter	35 mm
Stall Torque	388.85 oz/in
Weight	8.90 oz
Price	$37.95

Table 10: PGHM-02 Specifications

3.5.2.3 Planetary Gear Motor PGHM-03

The PGHM-03 planetary gear motor is the upgraded version of the PGHM-02 and provides a higher torque value of 499.95 oz-in, which converts to 31.246 lb-in. The motor requires 12v to start but has an incredibly low RPM of only 14. Weighing 9.42 oz, the two motors will increase the overall weight by 1.1775lbs. With maximum water capacity expected at two gallons, this motor provides more than enough strength to push the HeatSeekr through the any kind of terrain. Each motor can be purchased from Lynxmotion off of their website for $39.95. A summary of all features can be seen in Table 11 below for easy reference.

Reduction Ratio	410:1
Voltage	12 vdc
RPM	14 / 410:1
Outside Diameter	1.4 in
Stall Torque	499.95 oz/in
Weight	9.42 oz
Price	$39.95

Table 11: PGHM-03 Specifications

3.5.2.4 Conclusion

Overall, the GHM-13 motor is not expected to perform at optimal levels while carrying a full load; so the PGHM-02 was chosen for its superior torque strength. While the PGHM-03 is the upgraded version for this motor, its low RPM is expected to slow the HeatSeekr down while it is in navigation to its target. Since the HeatSeekr is acting as a pre-emptive strike towards a fire, speed is an important factor in reducing the response time of the system. For this reason, the PGHM-02 is the superior choice as it has the carrying capacity to support a full load and also move at a quicker pace thanks to the increased rpms. The two motors will also each require a MOSFET to derive enough voltage from the microcontroller to run efficiently. The buz20 power transistor will enable proper conversion rates from the microcontroller to each motor and can be bought from Ali express for $2.95 for five pieces.

3.6 Line Detection

The ability of the rover to monitor the fire detection environment and respond to alerts by the stationary hanging unit relies on a means of navigation. Because the environment is envisioned to be static and homogenous, a line follower was decided upon to meet the navigational needs of the rover. Several methods of line detection were researched, and each option provided a very different set of challenges, requirements, and abilities. One important consideration for any of the navigation systems was that the final system should be robust enough to handle gentle curves and corners, as well as be functional in variable light conditions. Two line detection methods were eventually discussed.

3.6.1 CdS Photocell Detection

The first method of line detection considered involved the use of the model 276-1657 cadmium-sulfide photoresistor, a photocell sensitive to the same visible light ranges as the human eye. Priced at $3.99 for a pack of five, this option represents a relatively cheap incarnation of line detection sensor. Being a resistor, this device technically requires only a voltage divider circuit in order to function as a line detector; however, because the photoresistor is sensitive to visible light sources, each photoresistor requires an external LED to reflect light from surfaces in order to work in the low light area of the rover underbelly. A summary of the model 276-1657 cadmium-sulfide photoresistor's specifications is presented in Table 12.

Item	Specification
Price	$0.80
Optical Spectrum	Visible
Size	0.40 in x 0.2 in x 0.080 in
Response Time	Slow

Table 12: Model 276-1657 CdS Photoresistor Specification Summary

The visible spectrum CdS photoresistor and LED combination presents several advantages in its implementation. The visible spectrum photoresistor track requirements are much more lenient than infrared systems, requiring only contrast differences rather than stark black-on-white infrared reflection. This allows for the use of ordinary pigmented masking tape, blue painters tape, or standard black electrical tape to be used. The voltage divider technology required by the visible spectrum photoresistor is also fairly easy to implement, easily working with the MSP430's analog to digital converter, and requiring only the powered LEDs in order to function.

The challenges inherent to the CdS photoresistor are mostly the result of the environment of the rover. CdS photoresistors require constant environmental lighting conditions in order to function correctly with a digital threshold check. Because the rover is designed to be implemented in commercial, industrial, and residential environments where windows and overhead lighting may create highly variable lighting conditions, the creation of a very isolated lighting system would become an added concern, becoming very important for the function of the line detector. In past projects, CdS photoresistors were also found to be slow to react, making line detection at 90° turns for example fairly imprecise at moderate speeds. Due to the nature of the environment projected for the rover's use, this inability to react to sharp turns ultimately reflects very poorly on CdS photoresistors for use in this design.

3.6.2 Reflective Optical Phototransistor

The second method of line detection considered involved the CNY70 reflective optical sensor with transistor output, a $0.76 package that includes an infrared emitter, a phototransistor, and an optical shroud nestled together in one component. The package includes four leads, two for the infrared emitter and two for the transistor, and functions by modifying the output current based on the amount of infrared light incident on the transistor, which varies based on the reflectivity of the surface on which the package is placed. Because each package contains an emitter and phototransistor, the device needs only to be powered and have its output fed into the analog to digital converter of the MSP430 in order to function. A summary of the CNY70 reflective optical sensor's specifications is presented in Table 13.

Item	Specification
Price	$0.76
Optical Spectrum	Infrared (950 nm)
Size	0.28 in x 0.28 in x 0.24 in
Response Time	Fast

Table 13: CNY70 Reflective Optical Sensor's Specification Summary

The CNY70 reflective optical sensor presents several advantages in its implementation. The phototransistor is first and foremost much faster in its response time than the photoresistor, allowing for much better turning response to sharp route changes such as 90° turns. The fact that the phototransistor is sensitive to infrared emissions rather than emissions typical of daylight allows the already shrouded device to function in all variations of light environment. This is compounded by the included daylight blocking filter which ensures that only the emitted 950 nm wavelength of the infrared emitter will excite the phototransistor. The compact package allows for much easier implementation of an optically isolated system, allowing for an array of four to five packages to be used in tandem and in close proximity, increasing the smoothness of the line follower.

The challenges inherent to the CNY70 reflective optical sensor are minor, and reflect a strong product with specific implementation goals. The infrared emission system relies on the selective reflectivity of the chosen surface and track. Because many commercially available masking tapes are often transparent to infrared, care must be taken to ensure that the track composing the line of the line follower is optically opaque to infrared emissions. Of particular note is the optical transparency of electrical tape, which would have worked perfectly for the photoresistor system, but is optically transparent in the infrared spectrum. Thankfully, simple black printer ink or the line created from a permanent marker has worked for previous groups as an optically infrared-opaque surface through which the phototransistor-emitter system can function.

3.7 Wireless System

The world of wireless communication contains a plethora of RF protocols to choose from. Several technologies were explored for this project, including IEEE 802.11 (Wi-Fi), IEEE 802.15.1 (Bluetooth), and IEEE 802.15.4 (ZigBee). The protocols will be judged on the availability and price of a suitable module, how that module can interfaced with the MSP430 microprocessor, power consumption, and over all ease of implementation.

The first protocol analyzed was the IEEE 802.11 b/g wireless LAN. Multiple Wi-Fi modules were found that operated at the same voltage as the microcontroller, 3.3 volts, and had both UART and SPI bus interfaces. According the data sheet for the Roving Networks RN-171, "the module only requires four connections (PWR, TX, RX, and GND) to create a wireless data connection," making this module incredibly easy to implement. This module utilizes "4-µA sleep, 38-mA Rx, 120-mA Tx at 0 dBm" according to the datasheet, making it a viable option regarding power consumption. Several modules supported ad hoc mode relatively easily, allowing for an easy implementation of the star network layout. However, most modules did not include an antenna on board; therefore either a wire antenna or an antenna trace will be required on the final PCB. The cheapest module discovered, the Roving Networks RN-171, was $29 without an antenna. Table 14 displays a summary of the important specifications for considering this module. After including the cost of an antenna this price exceeded the anticipated budget for this portion of the project. Therefore the IEEE 802.11 protocol has been rejected as the wireless system for HeatSeekr.

Item	Specification
Protocol	802.11 (Wi-Fi)
Mounting type	Surface mount
Cost	$29
Antenna	None
Interfacing protocol	UART
Standby power consumption	4µA

Table 14: Roving Networks RN-171 Wi-Fi Module Specification Summary

The next protocol assessed was IEEE 802.15.1 (Bluetooth). Several modules were found that had UART interfaces, which is the most preferred interface for the wireless system for this project. According to the datasheet for the Roving Networks RN-42 Class 2 Bluetooth module, this device uses 26 µA in sleep mode, 3 mA while connected, and 30 mA when transmitting. While this device doesn't sip power in sleep mode, when compared to the RN-171, its transmitting and receiving power ratings are significantly lower, making this chip more favorable for low power use. This module also includes an antenna trace on its PCB. An antenna onboard removes an entire area of failure for testing as it will have been fully tested before its introduction to HeatSeekr. Table 15, below, displays the approximate maximum distance two RN-42's can sustain transmission while the number of walls between the devices increases. These values were obtained from the RN-42 datasheet.

Obstruction	Distance
One wall	55 feet
Two walls	60 feet
Three walls	36 feet

Table 15: Range Characteristics from Roving Networks RN-42 Datasheet

The sharp drop in range as the number of walls increase changes the network layout slightly. Instead of all sensors being in constant communication with the mobile rover, each sensor will need to retransmit the information of the alarmed sensor until the

HeatSeekr rover acknowledges the alarm. This modification is required as it's very likely the rover will go out of range of every sensor except the ones in its immediate vicinity. This repeating transmission isn't a major concern since in the current design implementation the rover will have to complete its patrol loop to arrive at the alarmed sensor anyway. At most the rover will need to travel one full circuit if a remote sensor alarmed just as the rover passed it, at least the rover will be arriving at a remote sensor as it begins to alarm. Several modules found were significantly cheaper than the Wi-Fi modules as well as antenna PCB traces were much more commonly found for Bluetooth modules than Wi-Fi modules. The specific module examined was the Roving Networks RN-42. A summary of the specifications for this module are displayed in Table 16. The price, low power, and ease of implementation, combined with the onboard antenna, make this protocol the most promising for the wireless system so far.

Item	Specification
Protocol	Bluetooth
Mounting type	Surface mount
Cost	$15.95
Antenna	PCB trace
Interfacing protocol	UART
Standby power consumption	26 µA

Table 16: Roving Networks RN-42 Bluetooth Specification Summary

The final protocol examined was the IEEE 802.15.4 (ZigBee). Figure 3 displays an overview from TI of the various wireless standards discussed thus far.

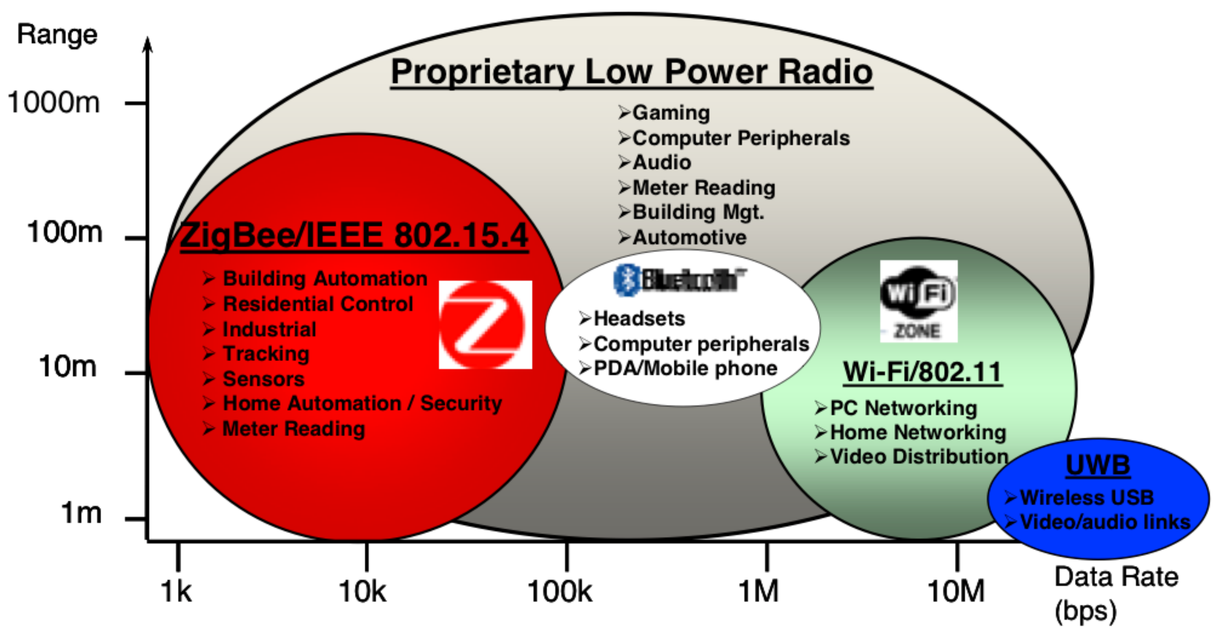


Figure 3: Specification of Various Wireless Standards *(permission pending)*

As this graph shows, the ZigBee protocol appears to be a great application for HeatSeekr. According to its specifications, ZigBee offers a very wide range, allowing it to easily cover a practical area for HeatSeekr to patrol. Additionally it offers a slower date rate, which should make implementation and debugging easier. Most modules researched utilized SPI to communicate with the microcontroller, which is not among the preferred interfaces. However, these modules absolutely sip power; according to the data sheet of the TI-CC2520, it uses less than 1 µA when asleep, 18.5 mA when receiving, and 25.8 mA when transmitting at 0 dBm. Table 17 displays a specification summary of this TI-CC2520. The lack of an antenna combined with the SPI-only interface causes this protocol to become less than ideal for implementation.

Item	Specification
Protocol	Zigbee
Mounting type	Surface mount
Cost	$6.05
Antenna	None
Interfacing protocol	SPI
Standby power consumption	1 µA

Table 17: Texas Instruments TI-CC2520 Specification Summary

Initially, HeatSeekr was going to utilize Wi-Fi for its RF sub-system; however after researching into these various technologies, it has been determined that Wi-Fi would not be the most appropriate option for HeatSeekr. Instead, this project will utilize Bluetooth for communication. Bluetooth has been chosen due to its low power consumption, ease of implementation, and pre-existing PCB trace antenna. Specifically, the RN-42 Bluetooth Transceiver from Roving Networks will be the chip implemented in HeatSeekr due to its low cost, fully documented Bluetooth modes, and ease of implementation.

3.8 Power Management

3.8.1 Voltage Regulators

In order to achieve power distribution throughout the HeatSeekr system, several voltage regulators will be needed. Feeding the different subsystems of the heat seeker with the full, unmodified power from the batteries would destroy all of the small, yet crucial, components in the system. Meanwhile, the larger components would be damaged through intense heat damage and poor heat dissipation, thus decreasing their operability and dependability. Although smaller, precisely personalized batteries would be appropriate for the setup, they would unfortunately prove inefficient in the long run. These inefficiencies include bulkiness, heat dissipation, and also a lack of engineering innovation. A voltage regulator is used to disregard a certain amount of output voltages from a wide range of input voltages depending upon the voltage regulator’s specifications. The first type of voltage regulator considered was the linear voltage regulator.

Linear voltage regulators are beneficial because they easy to implement for driving devices that require very low power. Their reputation comes from the fact that they are very simple to use and are fairly inexpensive to purchase. The only undesirable aspect to the linear voltage regulator is that because of the way that it functions, some inefficiency occurs. The linear voltage regulator works by using the difference between the input voltage and the output voltage while the rest is dissipated as waste heat. As anticipated, the greater the difference between the input and output voltage, the more heat the voltage regulator will produce. Certain linear voltage regulators waste more power during the step down of the voltage than the resulting power supply to the intentional device. The usual efficiency of a linear voltage regulator is about forty percent, with some efficiencies reaching as low as fourteen percent. This poor efficiency tends to generate a lot of waste heat which needs to be dissipated through large and expensive heat sinks. The ineffectiveness also translates to a decline in battery life, which is very critical in HeatSeekr's design.

The second type of voltage regulator considered was the switching voltage regulator, characterized by its operation method of using small amounts of power from the input voltage and then re-transmitting this power to the output. This process occurs via the use of an electrical switch and a controller which regulates the flow of energy that is transferred to the output. The loss of energy in these small pieces is smaller than the loss that occurs in a linear voltage regulator. Therefore, switching voltage regulators can achieve 80-85% efficiency compared to linear regulators. This productivity is also less reliant on the input voltage. Switching voltage regulators can power beneficial loads from high input voltages. Switching voltage regulators are mostly seen in small mobile devices where high efficiency is needed and also where low power consumption is desired. Such devices range from cell phones, digital cameras, laptops and tablets.

Although the switching voltage regulator outperforms the linear voltage regulator in efficiency, it lacks the frugal, if not elegant simplicity. Switching voltage regulators include a complex circuitry design which makes them very unpopular with hobbyists. The switching voltage regulator also works better with respect to high input voltages and driving loads over 200 milliamps (mA). The use of a linear voltage regulator for those circumstances becomes unreasonable. Sometimes the use of isolated battery cells is often used to relieve these issues; one battery pack for the high voltage devices and another battery pack for the low voltage devices thus splitting the distribution. This also means that these two separate battery packs will need to be recharged at constant intervals. Simultaneously, certain switching voltage regulators can step up voltages which a linear voltage regulator can never attain. There are a number of different ways to determine if a linear or switching voltage regulator is needed for a certain specific application. From the research that was conducted, if the linear voltage regulation solution tends to waste less than 0.5 W of power, then a switching voltage regulator would not be necessary, especially due to their increased price. Conversely, if the linear voltage regulation tends to waste several watts of power from the system, then a switching voltage regulator is the better option. The equation to calculate wasted power is below:

$$P_{wasted} = (V_{in} - V_{out}) * I_L$$

For example, if the main power supply on HeatSeekr was a 24 volt lithium-ion polymer (LiPo) battery and it was used to drive different sub-systems, and amongst them was a microcontroller which drew about 3 milliamps (mA) of current and different heat sensors which drew about 40 milliamps (mA) and let's assume both the microcontroller and these sensors ran off of 5 volts. In addition to that, a 5 volt linear voltage regulator was used to step down the voltage to 5 volts from 24 volts. The same equation described above would turn into the following:

$$P_{wasted} = 24V - 5\ V * 3\ mA + 40\ mA = 0.817\ watts\ (W)$$

In this instance, a switching voltage regulator would prove favorable over a linear voltage regulator due to the fact that more than 0.5 W of power is being wasted. Of course, a remedy to this situation would be to decrease the voltage of the lithium-ion polymer battery pack. If two servos were added, a situation drawing on average 0.375 A and running off of the same 24 volt voltage supply, the equation produces:

$$P_{wasted} = 24v - 5v * 3\ mA + 50\ mA + 375\ mA + 375\ mA = 19.703\ watts\ (W)$$

As one can see above, 19.703 W is a significant amount of wasted heat. Without a large, bulky heat-sink attached, the linear voltage regulator would get hot enough to possibly de-solder itself or even damage the printed circuit board. Even with an attached heat-sink, wasting 19.703 W of power is needless and inefficient for the battery pack. A switching voltage regulator would most likely be able to reduce power loss down to a low 0.5 watts W.

3.8.2 3.3V-5V Input Adjustable Switching Regulator

A 3.3 voltage regulator will be needed for the microcontroller. The PTH04070W switching regulator is a possible option for this operation, because it is low-cost and highly integrated, providing up to 3A of current. The benefit of this switching voltage regulator is that it occupies less printed circuit board space than standard linear voltage regulators. This particular switching voltage regulator also provides an output current at a much higher efficiency with a decrease in wasted heat. This design enhancement effectively eliminates the need to include a heat sink. According to the manufacturer, Texas Instruments (TI), the fact that they are small sized, highly efficient, and low cost makes these components more useful for a variety of applications. The input voltage range of the PTH04070W switching voltage regulator ranges from 3V to 5.5V, thus allowing operation from either a 3.3V or 5V input bus. This feature is highly useful because several components will require different input voltages like the sensors, Wi-Fi module and micro-controller.

The use of highly advanced switching mode technology allows the PTH04070W to step down to voltages as low as 0.9 volts from a five volt input with typically less than one watt of wasted power. Moreover, the output voltage of this switching voltage can be effortlessly adjusted to any voltage over the range of 0.9 volts to 3.6 volts using a single external resistor. Several operating features of the Texas Instruments PTH04070W switching voltage regulator include an on/off inhibitor, an output overcurrent protection system, and an under-voltage lockout (UVLO) mechanism.

One of the possible uses of this switching voltage regulator will be a 3.3 volt regulator that will service the microcontroller, WIFI module and the range finder. The WIFI module will converse with the main HeatSeekr robot through an RF wireless procedure. HeatSeekr is envisioned to be portable, therefore power consumption must be carefully considered. Consequently the wireless system will utilize the lowest power technology obtainable. This regulator can also drive the MSP430 microcontroller which will be the main communicator for all smaller sub-systems on HeatSeekr. Table 18 below shows the specifications for the considered PTH04070W.

Item	Specification
Price	4.30
Temp range	-40 C to 85 C
Efficiencies	Up to 94%
Input voltage range	3 V to 5.5 V
Output voltage	0.9V to 3.6V
Max output current	3A at 85 C

Table 18: PTH04070W Specifications

The on/off output inhibitor on pin 5 can be used whenever it is required for the output voltage from the switching voltage regulator be turned off. The device functions normally when this inhibit pin is opened. A transistor is used and, once turned on, applies a low voltage to the "Inhibit" control pin which then in turn disables the output of the switching voltage regulator. Once the transistor is turned off, the regulator will perform soft-start power-up sequence. From there, a regulated output voltage is created within twenty milliseconds. The circuit diagram displayed in Figure 4 displays the placement of the above-mentioned transistor

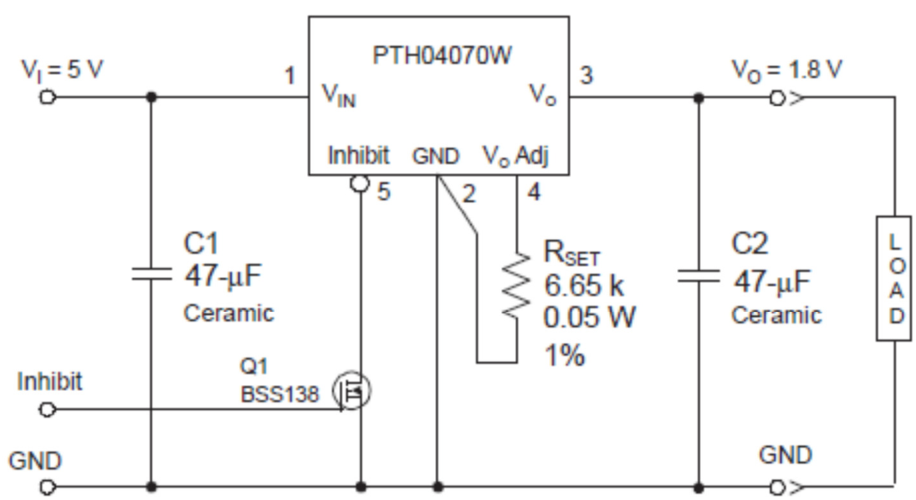


Figure 4: On/Off Inhibit Control Circuit (*Permission pending)*

Figure 5 illustrates the typical rise in the output voltage post transistor shutdown. (Q1)

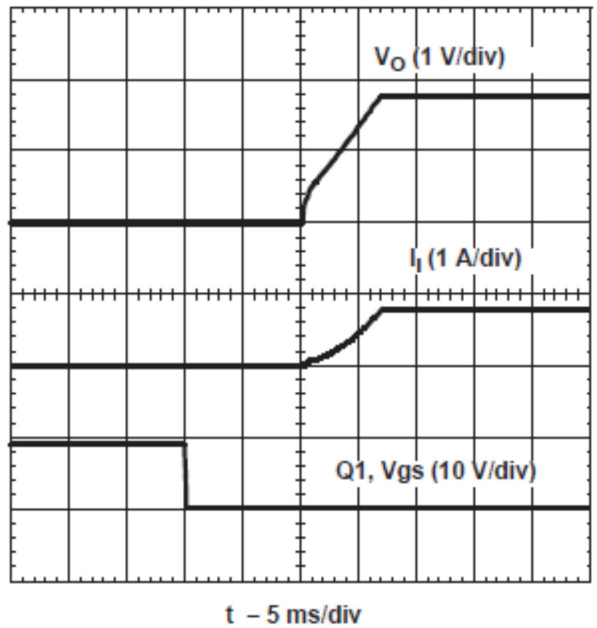


Figure 5: Power up Response From Inhibit Control (*Permission pending)*

The output overcurrent protection system protects against load faults with a continuous current limiting characteristic. Under this load fault condition, the PTH0407W's output current is not allowed to exceed the current limit value. Any attempt to draw current in excess of this limit causes the output voltage to be reduced. Current is then continuously supplied to the fault until it is removed from the system. Once removed, the output voltage will quickly be restored. The under-voltage lockout (UVLO) mechanism on the PTH0407W switching voltage regulator incorporates an electronic circuit which is used to turn off any power in the event that the voltage drops below the regulator's operational value. Due to the high integration possibilities of this product, Texas Instruments recommends a wide range of use for this switching voltage regulator; from high-end consumer products to test and measurement applications along with telecommunications.

Figure 6 indicates the efficiency versus the output current of the 5V input voltage Texas Instruments PTH04070W switching voltage regulator.

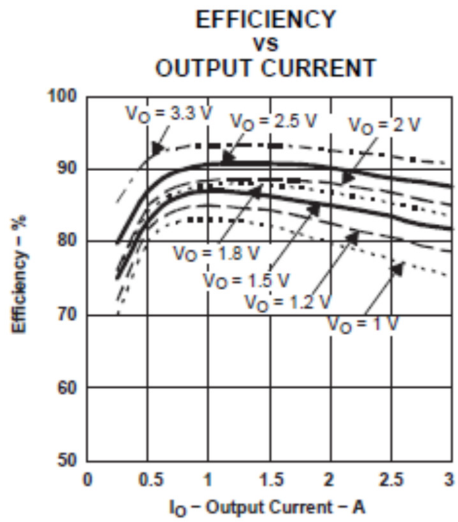


Figure 6: Efficiency vs. Output Current (*Permission pending)*

The graph illustrated in Figure 7 demonstrates the characteristics of the power dissipation versus the output current of the 5V input voltage Texas Instruments PTH04070W switching voltage regulator.

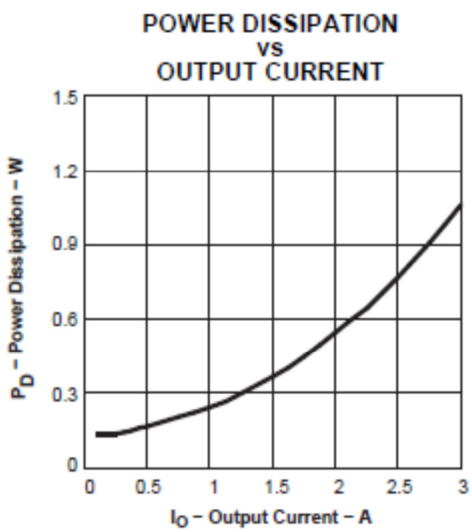


Figure 7: Power Dissipation vs. Output Current (*Permission pending)*

The Texas Instruments PTH04070W switching voltage regulator provides a range of output voltages. The adjustment of the device must be accomplished in the following manner. The $V_{oadjust}$ control pin (pin 4) is used to set the switching voltage regulator. The adjustment range of this device is from 9V to 3.3V. Adjustment of this device need the addition of a single resistor external to the device, R_{set}, which must be directly connected to the $V_{oadjust}$ and GND pins. Table 19 provides the external resistor values for a number of commonly desired output voltages along with the real voltage that said resistors will produce.

Vo (Required)	Rset (k) Standard value	Vo (Actual)
0.9	Open circuit	0.9
1	84.5	1.001
2	4.87	1.999
3.3	0.475	3.298

Table 19: Standard Values of R_{set} for Common Output Voltages

If other output voltages are desired besides the common ones above, then the value of the resistor can be calculated using the following equation.

$$R_{set}=10k\Omega *((0.891v)/(V_{out}-0.9V))-(3.24k\ \Omega)$$

The value of the non-standard resistor can also be selected by referencing Table 20 below:

Vo Required	Rset	Vo Required	Rset	Vo Required	Rset
0.9	Open	1.475	12.3	2.55	2.16
0.925	353	1.5	11.6	2.6	2
0.95	174	1.55	10.5	2.65	1.85
0.975	116	1.6	9.49	2.7	1.71
1	85.9	1.65	8.64	2.75	1.58
1.025	68	1.7	7.9	2.8	1.45
1.05	56.2	1.75	7.24	2.85	1.33
1.075	47.7	1.8	6.66	2.9	1.22
1.1	41.3	1.85	6.14	2.95	1.11
1.125	36.4	1.9	5.67	3	1
1.15	32.4	1.95	5.25	3.05	0.0904
1.175	29.2	2	4.86	3.1	0.81
1.2	26.5	2.05	4.51	3.15	0.72
1.225	24.2	2.1	4.19	3.2	0.634
1.25	22.2	2.15	3.89	3.25	0.551
1.275	20.5	2.2	3.61	3.3	0.473
1.3	19	2.25	3.36	3.35	0.397
1.325	17.7	2.3	3.12	3.4	0.324
1.35	16.6	2.35	2.9	3.45	0.254
1.375	15.5	2.4	2.7	3.5	0.187
1.4	14.6	2.45	2.51	3.55	0.122
1.425	13.7	2.5	2.33	3.6	0.06

Table 20: Calculated Set-Point Resistor Values (*Permission pending*)

3.8.3 5V Switching Voltage Regulator

A 5V regulator will be needed for sub-systems like the drive system and the different sensors that will be on HeatSeekr. The DE-SW0XX family of switching voltage regulators is intended to be the simplest method for incorporating this style of regulator to support the project. This switching voltage regulator allows a high input voltage of up to 30V and the ability to step it down to 5V in a compact and efficient manner. The efficiency of this part is typically 83% but can reach up to 87% efficiency, a relatively impressive figure. This is achieved while maintaining the through-hole style pin setup of the TO-220 package. Another advantage of the DE-SW050 switching voltage regulator is that it possesses integrated decoupling capacitors which provide simplified integration and a significant decrease in the price of materials needed to integrate this component. Figure 7 displays the relative size of the DE-SW0XX family of switching voltage regulators when compared to a standard linear voltage regulator in the TO-220 through-hole package. A US quarter was included to aid the visual comparison.

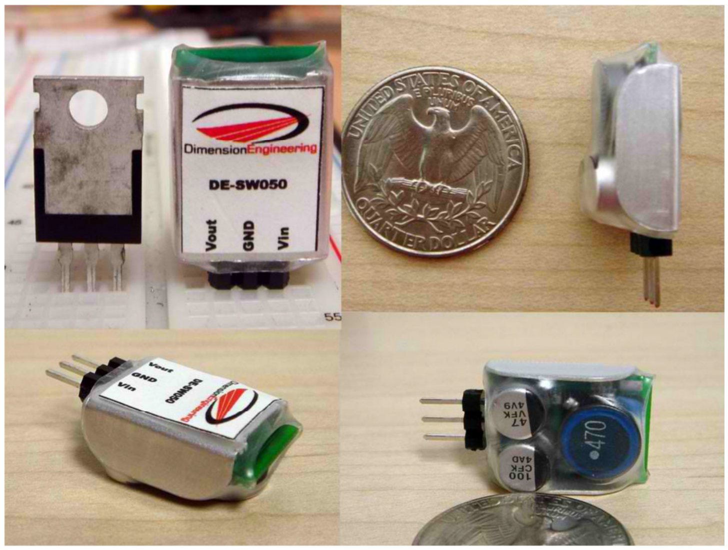


Figure 7: Depiction of the DE-SW050 Switching Voltage Regulator
(*Permission pending)*

The efficiency of the DE-SW050 switching voltage regulator is appealing enough to warrant sacrificing the slightly larger dimensions, 1.1 in x 0.63 in x 0.43 in (L x W x H) when compared to the TO-220 through-hole package. Figures 8 and 9 portray the efficiency versus the input voltage and the efficiency versus the output current, respectively, of the DE-SW050 switching voltage regulator.

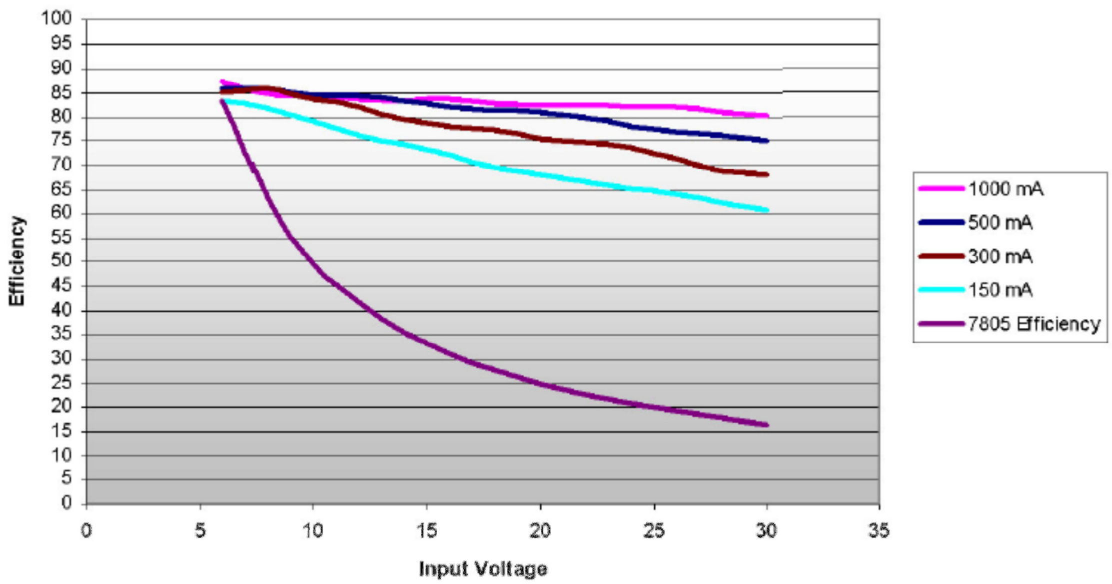


Figure 8: Efficiency vs. Input Voltage (*Permission pending)*

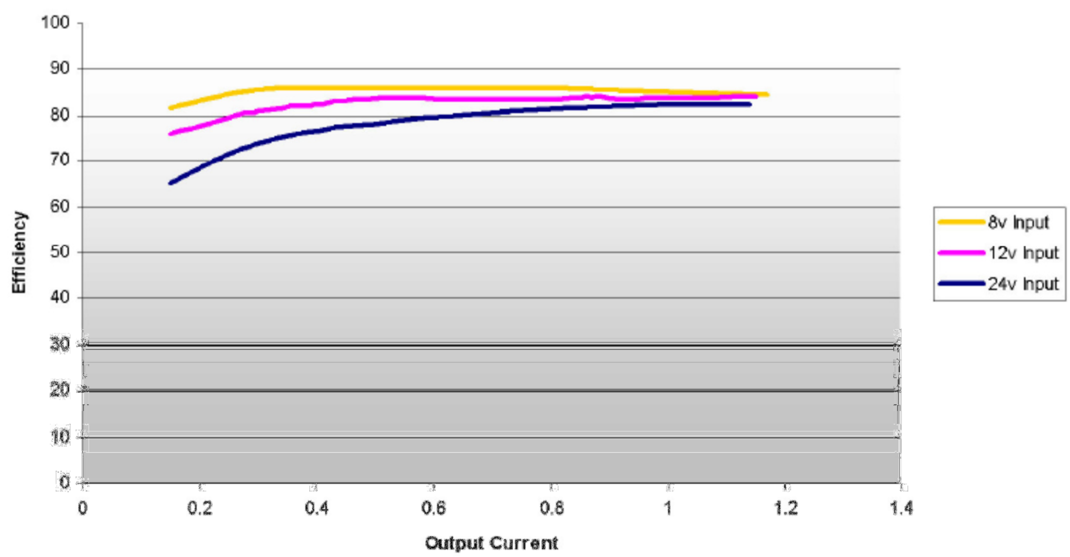


Figure 9: Efficiency vs. Output Current (permission pending)

The DE-SW050 5 volts regulator can service different sensors, servos and the drive system on board. The sensors consist of a water level sensor, a remote sensor which involves of a mixture of numerous sub-systems on the main HeatSeekr rover combined into a reduced package. The Remote Sensor will consist of a UVTRON Flame Detector with a driver board that is being driven by a 12 volts switching regulator. The 12 volts switching regulator will also be driving the pump mechanism that will be extinguishing the fire, and also the drive motors that will allow for HeatSeekr to move. Table 21 below shows the specifications of the DE-SW050 5.5 switching regulator.

Item	Specification
Price	$15.00
Temp range	-40 C to 85 C
Efficiencies	Up to 87%
Input voltage range	Max 30V
Output voltage	1.3V to 5V
Max output current	1.25A peak

Table 21: DE-SW050 Specification

3.8.4 3.3/5 Volt Switching Regulator

Another consideration is the Murata Power Solutions 78SR Switching Regulator. This model comes in two versions, a 3.3 volt output and a 5 volt output. As these two voltages are two of the three rails required, one of each of these regulators are being considered for HeatSeekr. These regulators were designed as drop in replacements for the LM78XX series linear regulators. These regulators require a V_{in} between 8 volts and 32 volts; therefore the 14.8 volts supply by the Tenergy battery pack can be directly connected to these regulators. These regulators are able to output up to 2 amps, which is expected to be plenty of current for the minor systems driven by these power rails. The datasheet for these regulators advertise extremely low noise. This low noise and completely self-contained package result in no requirement of the traditional inductors and capacitors that traditionally surround a switching regulating IC. The lack in requirement of these components results in saving valuable space and minimizing complexity in the overall design. In addition to the simplicity, these regulators can be sufficiently cooled from the ambient air, resulting in heatsink required. The lack of a heatsink is vital for multiple reasons. The first reason is that heat generation is an indication of inefficiencies. As a component increases in temperature; more power is being drained from the battery that is being wasted instead of going towards powering something useful. The second reason heatsinks are to be avoided is to cut down on weight. Since HeatSeekr is mobile, its run-time is solely based on the drain on the batteries and as more weight is added, more power is required from the batteries, resulting in a shorter run-time. One consideration to note is that these regulators do not provide voltage isolation between the input and output. As a result, if something incredibly abnormal occurs on one rail, both of these rails will be affected. Table 22 provides a specification summary for these two regulators.

Specification	78SR-3.3/2	78SR-5/2
Input Voltage	8-32 Vdc	8-32 Vdc
Output Voltage	3.3 Vdc	5 Vdc
Switching Frequency	20 mV @ 333 kHz	20 mV @ 476 kHz
Efficiency	90% @ 1 A	90% @ 1 A
Cost	$13.18	$13.18

Table 22: Specification Summary of the Murata Power Solutions Switching Regulators

3.8.5 12 Volt Switching Regulator

The Innoline R-78C12-1.0 DC/DC Converter is a viable option for HeatSeekr's 12 V rail. According to the datasheet, this regulator requires a V_{in} between 8 volts and 42 volts. This regulator is able to output up to 1 A, which will be sufficient for HeatSeekr's drive motors. This regulator shares many similarities as the Murata 78SR. For example, this regulator has been designed as a drop in replacement for 78XX linear regulator as well as not requiring a heatsink. This regulator is specified as being 96% efficient. The inclusion of this regulator along with the Murata 78SR would completely eliminate the requirement of all heatsinks, resulting in HeatSeekr having an extremely high power efficiency. The R-78C12-1.0 is able to automatically recover for a direct short circuit without any ill effect. Table 23 provides a specification summary for this regulator.

Specification	R-78C12-1.0
Input Voltage	15-42 Vdc
Output Voltage	12 Vdc
Switching Frequency	350 kHz
Efficiency	96%
Cost	$8.79

Table 23: Specification Summary of the Innoline R-78C12-1.0

3.9 Batteries

Of primary concern for any mobile, autonomous unit is power storage. HeatSeekr addresses these concerns with a thorough analysis of available battery solutions, focusing on advantages and applicability. Plugging HeatSeekr into a wall outlet is not a practical solution for the purposes of the project, especially if the rover portion is required to move around to accomplish its goals. This is why a portable source of power is obligatory, and also the reason why most robots rely on batteries to get their power. Because of recent technological advancement in portable electronics, battery innovation has dramatically increased within the last two decades. Batteries will be considered on the basis of their size, output voltage, capacity, relative safety, and longevity.

3.9.1 Nickel Metal Hydride (NiMH)

Nickel metal hydride batteries are analogous to Ni-Cd batteries. The minimal voltage of Nickel Metal Hydride is similar to nickel cadmium batteries, which is about 1.2 volts. There is an internal resistance that exists within the Nickel Metal Hydride batteries that produces high current surges, a specification that will require adaptive design to address. The positive electrode contains nickel, but unlike Ni-Cd batteries the negative terminal doesn't have cadmium; it uses a hydrogen-absorbing alloy, making NiMH a cleaner option with regards to implementation into the HeatSeekr on a larger scale. NiMH batteries are best for applications such as camera flashes, RC vehicles and power tools, indicating that the longevity required for HeatSeekr is a concern.

The charging voltage ranges from 1.4–1.6 V/cell. A constant-voltage charging method cannot be used for automatic charging. When fast-charging, it is worthwhile to charge the NiMH cells with a smart battery charger to avoid overcharging, which can damage cells and can be dangerous. This is an important safety consideration regarding implementation into the HeatSeekr system, requiring a specific charging apparatus and methodology.

A fully charged cell supplies an average 1.25 V/cell during discharge. A complete discharge of a cell to the point where it goes into polarity reversal can cause permanent damage to the cell, indicating that any NiMH battery considered for HeatSeekr must have auto-shutoff functionality if no design concessions are made to accommodate this fact. This condition can occur in the arrangement of 4 AA cells in series, where one cell will be completely discharged before the others cells due to small differences in capacity among the cells. When this occurs, the good cells will start to drive the discharged cell in reverse, which can cause permanent damage to that cell. Figure 10 displays the charge discharge graph of the NiMH battery. Careful appreciation of the limits of the NiMH batteries capabilities from this graph will shape design of the power system should the NiMH architecture be adopted.

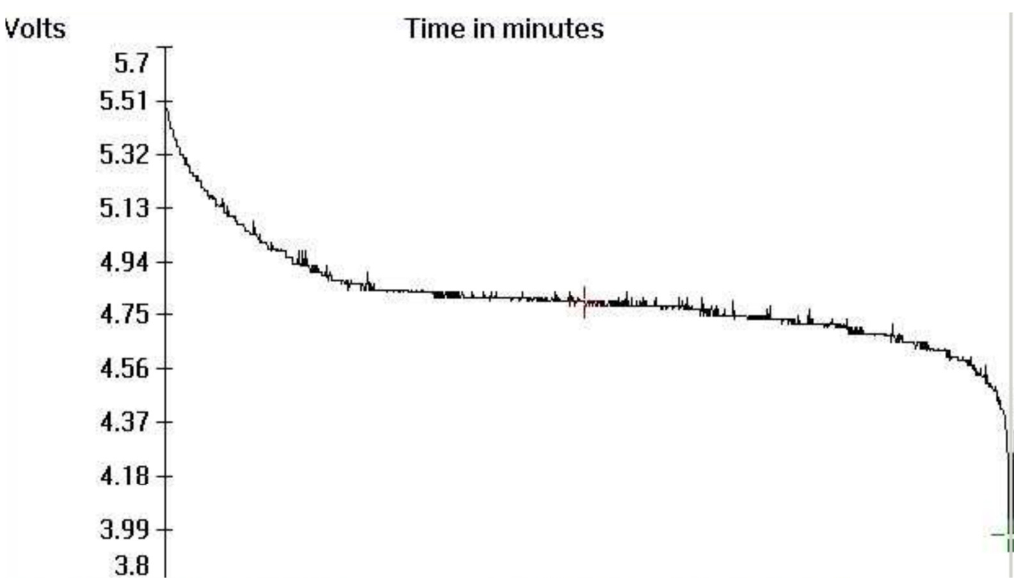


Figure 10: Charge/Discharge graph of Ni-MH batteries *(Permission pending)*

The Ni-MH battery system presents several advantages in its implementation. The specific method of construction negates the memory effect seen in traditional battery design, allowing for increased flexibility regarding recharging schedules and facilitating repeated testing of the power system and other systems as a whole. Ni-MH batteries represent an economically feasible solution for long-term implementation, as they have relatively longer life than comparable batteries. This lessening of budget concerns is significant if HeatSeekr is to be widely adopted. Ni-MH batteries also present an ecofriendly power solution, having few if any toxic emissions. Compared to other batteries, Ni-MH requires only nickel and eschews heavy metal pollution sources.

The disadvantages present in the Ni-MH battery solution stem mostly from the chemical processes by which it functions and the resulting impacts on necessary performance as required by the specifications of the project. Ni-MH represent significant difficulty in obtaining full-charge detection, leading to potentially hazardous situations of over charge and requiring significant monitoring infrastructure to be invested into the project paradigms. Ni-MH batteries also do not respond well to frequency charge and discharge cycles, preferring 500 cycles for optimal performance. An ironic consideration, Ni-MH batteries produce significant levels of heat while charging, representing fire hazards in the type of envisioned autonomous charging scenarios that HeatSeekr may be subjected to. Finally the Ni-MH battery solution suffers from a 30% loss in initial charge if disused for a month, representing a significant limitation in testing and design.

3.9.2 Lithium-ion

Lithium-ion is a part of the rechargeable battery types in which lithium ions move from the negative electrode to the positive electrode during discharge, and back when charging. A Li-Ion battery uses an added lithium compound as the electrode material, compared to the metallic lithium used in the non-rechargeable lithium battery, leading to safety concerns for the HeatSeekr project. Lithium-ion batteries are relatively common in consumer electronic devices, representing a widely available source of batteries and a familiarity with conventions that aids in their implementation. They are one of the most popular types of rechargeable battery for everyday electronics because they have the best energy densities, no memory effect, and a slow loss of charge when not in use.

Charging lithium ion batteries involves applying a current until the voltage limit per cell is achieved. The charging current is then reduced to enter a mode of balance where the state of charge of the individual cells is balancing by an electronic circuit until the battery is full balanced. Due to its internal resistance, a voltage of 4.2 volts needs to be applied in order to correctly charge a 3.7V battery. These specifications limit the applicability of designing custom charging stations for the HeatSeekr, requiring adherence to commercially available charging units. Lithium ion batteries prove to be sensitive to high temperatures; heat causes them to degrade at a higher rate than usual. This specification represents a significant prototype concern, as the battery should be located away from potential sources of heat. Being a fire-fighting rover, the HeatSeekr system will be forced to accommodate the heat concerns of the lithium ion battery should it be implemented. If a lithium ion battery is completely discharged it becomes ruined, representing a significant design consideration if the chosen battery does not include an auto shutoff capability.

In theory the life span of a lithium ion battery should be forever but due to cycling and temperatures performance, the life span is affected. Manufacturers consider environmental conditions and because of that the average battery lifetime is between 300-500 discharge/charge cycles. Similar to the properties of a mechanical device, life span decreases with the increase of use, an important consideration due to the fact that

HeatSeekr is intended to be a passive, constant fire protection system. Exposure to high temperatures and high charge voltage has also proven to be quite harmful to the cycle life of lithium ion batteries. Figure 11 displays the discharge rate at a fixed temperature.

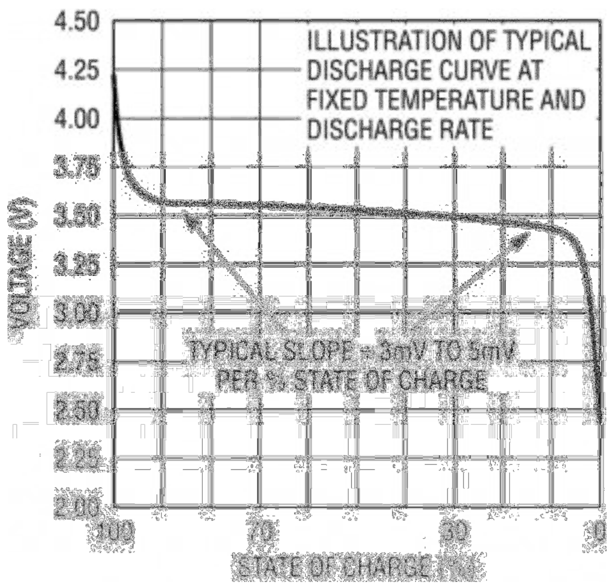


Figure 11: Lithium-ion Battery (*Permission pending*)

Lithium ion batteries present several advantages to their implementation. Because of their concerted design, lithium ion batteries are capable of very high energy densities, limiting their structural impact on the rover system and allowing greater flexibility where time tables are concerned. Implementation of the lithium ion battery system is enhanced due to the lack of priming requirement in their first use. The lifetime per charge of the lithium ion battery system is enhanced by their ability to prevent self-discharge, representing longer run times. Because of the simplicity inherent to their construction, and the relative stability of the platform, as discussed above, the lithium ion battery system requires significantly less maintenance than other battery systems. Should the need arise, lithium ion batteries can also provide high current to the rover. This may be a useful characteristic where the navigational motors are concerned.

The disadvantages present in the lithium ion battery solution stem mostly from the chemical processes by which it functions and the resulting impacts on necessary performance as required by the specifications of the project. Mentioned earlier was the fact that lithium ion batteries are irreparably damaged should they be allowed to reach empty charge. Thus, the lithium ion battery itself much provide a protection circuit in order to maintain safe voltage and current limits if the design does not directly address them. In terms of long term feasibility, lithium ion batteries eventually become subject to an aging effect if they are not stored in proper conditions at the various discharge cycles. Regarding budgetary concerns, lithium ion batteries are often more expensive to acquire, as they experience significantly increased manufacturing costs.

3.9.3 Nickel-Cadmium

Nickel-Cadmium (Ni-Cd) is, a common rechargeable battery, used by numerous electronic devices, such as laptops, tablets, etc. This type of battery is also recognized for its “memory effect“, which allows this kind of battery to lose its charge at an increased rate as it ages. Ni-Cd batteries are made up of two chemical elements, Nickel, in the form of Nickelic Hydroxide, and Cadmium, a heavy metal that could represent a significant environmental impact should the HeatSeekr platform become widely adopted. A third element is used as electrolyte; it is typically a solution of Potassium Hydroxide (KOH).

Battery manufacturers recommend that new batteries be charged slowly for 16 to 24 hours before use. The reason is that charging the battery slowly brings all cells in a battery pack to an equal level of charge. This is very important because each cell within the nickel-cadmium battery may self-discharge at its own rate which weakens the overall charge, an important design concern. Additionally, during long storage the electrolyte tends to gravitate to the bottom of the cell and the initial trickle charge helps redistribute the electrolyte to remove dry spots on the separator.

Ni-Cd batteries have a flatter voltage vs. time curve during discharge. This means that the voltage will remain relatively constant throughout the entire discharge life of the battery. Figure 12 demonstrates this unique voltage vs. time curve, providing a useful graphical insight into the design implications of the Ni-Cd battery solution.

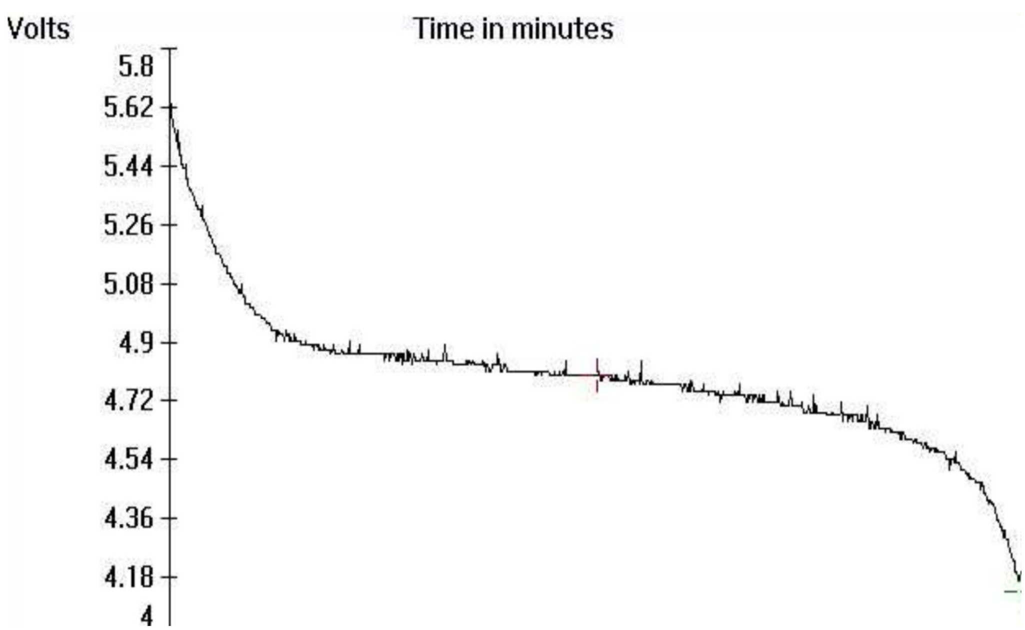


Figure 12: Nickel-cadmium Battery Discharge (*Permission pending*)

Nickel cadmium batteries present several advantages in their implementation. Due to their construction and methods of energy conversion, nickel cadmium batteries are capable of very long life cycles, allowing them to be part of a feasible long term power solution for an envisioned HeatSeekr revolution. Their ability to function at very cold temperatures is an advantage for winter conditions when heating elements can lead to accidents involving unmonitored fires – the perfect implementation of the HeatSeekr platform. The chemical composition of its electrodes and electrolyte afford the nickel cadmium battery solution a lower overall self-discharge level relative to other battery solutions, allowing for longer use on individual charges and increased time tables for performance. Another very important advantage of nickel cadmium batteries is their uniform voltage supply over changing discharge levels. This implies a very useful steady voltage level source for the MSP430 microcontrollers, important due to mandatory resets and the watchdog timer requirements.

The disadvantages present in the nickel cadmium battery solution stem mostly from the physical impacts of the chemical processes by which it functions and the resulting impacts on necessary performance as required by the specifications of the project. Nickel cadmium batteries are first and foremost incredibly heavy per storage capacity unit when compared to other considered battery solutions. This disadvantage heavily impacts many areas of HeatSeekr design, including motor requirements, stepper motor performance, chassis and tread design, and other unforeseen impacts of the increased weight. Nickel cadmium batteries also require increased maintenance when compared to other batteries because of their susceptibility to the memory effect and the false bottom effect. These disadvantages result from incomplete discharging, a condition that the HeatSeekr rover will commonly encounter as it will not be allowed to cease operations when not near a charging station.

3.9.4 Lithium Ion Polymer (Li-Po)

Lithium batteries are found in many electronic devices, such as tablets and laptops. When comparing the lithium battery to the Ni-MH or Ni-Cd batteries, it is evident that the lithium battery has greater storage capacity, while simultaneously, maintaining the same size and weight. Nevertheless, over the past years, lithium batteries have migrated to the hobby trade, and are now used widely in RC car helicopters, and more. Because of their light weight and high battery capacity, they are perfect for RC helicopters and airplanes, because they deliver a much lengthier flight time than the outdated Ni-MH and Ni-Cd complements, meaning that for the HeatSeekr project, they may have perfect applicability.

Li-Po batteries must be charged prudently. The basic procedure is to charge at constant current until each cell reaches about 4.2 V; the charger must then gradually reduce the charge current while holding the cell voltage at 4.2 V until the charge current has dropped to a small percentage of the initial charge rate, at which point the battery is considered one hundred percent charged. Some manufacturers specify 2%; others 3%, nevertheless other values are also possible. The difference in achieved capacity is within minutes. These design characteristics will be important should any custom charging stations be eventually realized.

Li-Po has a unique, near flat, discharge characteristic. The voltage of the pack will remain fairly linear up until it starts reaching its critical voltage point. It is Because of this characteristic that it is possible to detect when the battery is running low. When the cell voltage drops to around 3.0 volts per cell, the load should be remove from the batteries to prevent damage. Over discharging the battery will shorten the lifespan of li-Po batteries. Commercial batteries such as those found in laptop computers have protection circuits that prevent this problem. However, raw battery packs, such as those used in the radio control industry do not have any protective circuits built into them, implying that their use will require significant design considerations to be made. Some radio control components such as speed controllers will have some limited protection, meaning that its use in the HeatSeekr platform will require some forms of these protections. It is important to properly monitor these batteries especially if they are powering critical systems. Figure 13 display the discharge curve that makes the lithium polymer battery such an appealing option for implementation. The relatively uniform curve is beneficial for proper microcontroller operation.

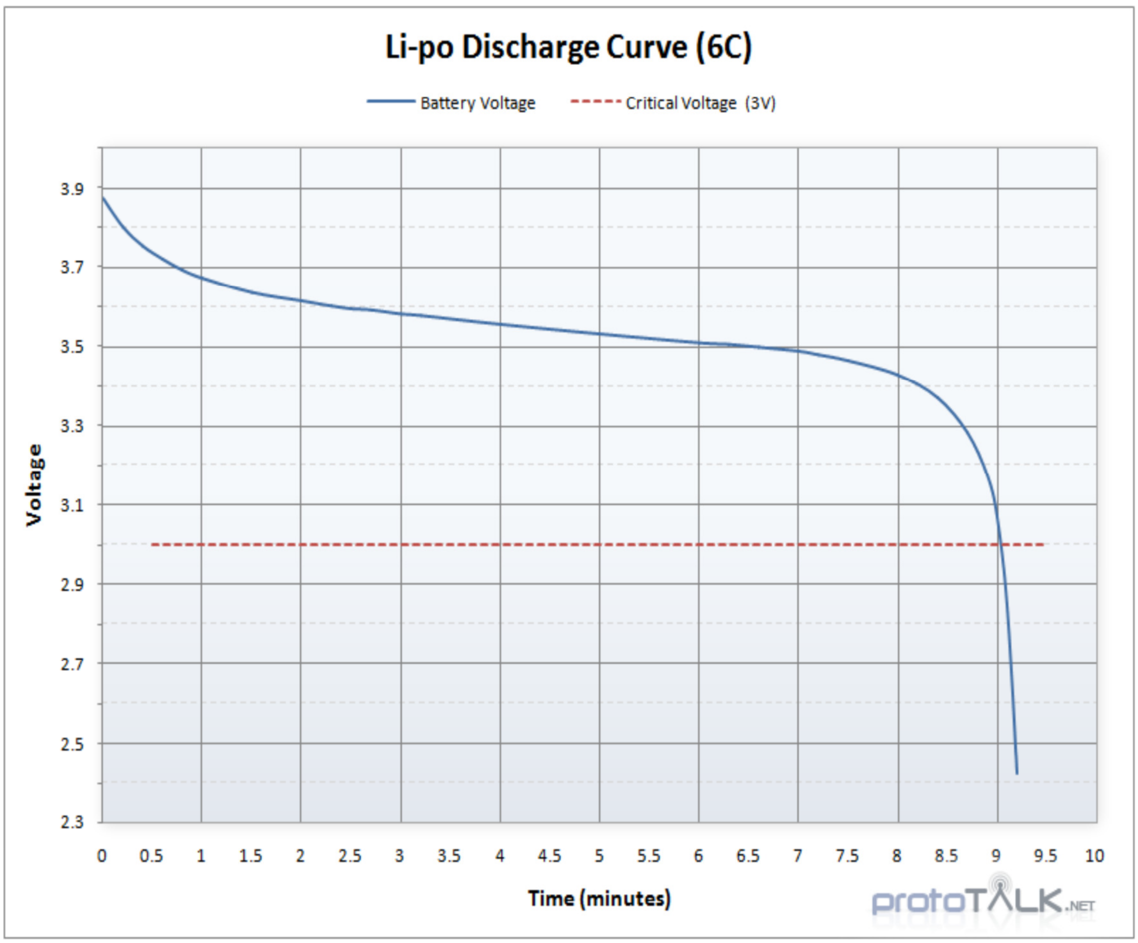


Figure 13: Voltage over time use graph for lithium polymer batteries
(*Permission pending)*

Lithium polymer batteries present several advantages in their implementation. The simplicity of their manufacture and compacting processes affords the lithium polymer platform with incredibly thin profiles and lighter overall battery weights. These specifications are paramount in the design of HeatSeekr, as weight considerations determine many component choices and implementations. Along with the advantageous weight, lithium polymer batteries come in many size options, allowing them to be fit to the HeatSeekr system's requirements. Due to the compartmentalization of the various sub systems, space may become limited, and a flexible battery will prove to be very advantageous. Lithium polymer batteries are finally very safe systems to implement, presenting decreased chances of electrolyte leakage and a heft resistance to overcharging. Because HeatSeekr is specified to work in commercial areas, safety of its use remains a primary concern among the various parts and components.

The disadvantages present in the lithium polymer battery solution stem mostly from the physical impacts of the chemical processes by which it functions and the resulting impacts on necessary performance as required by the specifications of the project. Compared to lithium-ion systems, lithium polymer batteries have noticeably lower energy density and decreased cycle counts. Energy density is tied to the weight of implementation, and remains a prudent concern. Lithium polymer batteries are also relatively expensive to acquire, due to their elemental constitution and expensive manufacturing process. Lithium polymer batteries represent a challenge in implementation so far as standards are concerns, due to the lack of standardized sizes and capacity configurations, a specification stemming from the discussed the custom, high volume consumer applications that lithium polymer batteries are commonly used in. Compared again to lithium-ion battery systems, lithium polymer batteries fundamentally represent a higher cost-to-energy ratio, stemming from a combination of their other disadvantages.

The most appropriate battery found was a Tenergy 14.8V 5500mAh lithium-polymer battery pack. This battery pack contains internal protection circuitry, ensuring the battery pack does not drop below 7.2 volts. This is circuitry is crucial as dropping the battery voltage too low will destroy the battery, rendering it unable to be recharged. Additionally, since this circuit is inside the battery, HeatSeekr will not be required to monitor its consumption. This greatly simplifies the entire power management system in both physical components and code for the master processor. According to the datasheet, this battery can be discharged at a maximum

3.9.5 Battery Protection

Due to variances in the supply of voltage to the battery, and unpredictability regarding backflow of current from HeatSeekr's components, a method of protecting the battery is vital for long-term function. To achieve this, a protection circuit module was considered. There are two methods for implementing a lithium polymer battery utilizing a Protection Circuit Module, the first of which is located in Figure 14. First, the Protection circuit module may be imbedded in the charger pack. While on the charger, the battery will have the standard protection offered by the Protection circuit module including overcharge protection, short circuit protection, charge current limiting, and balancing function for each cell.

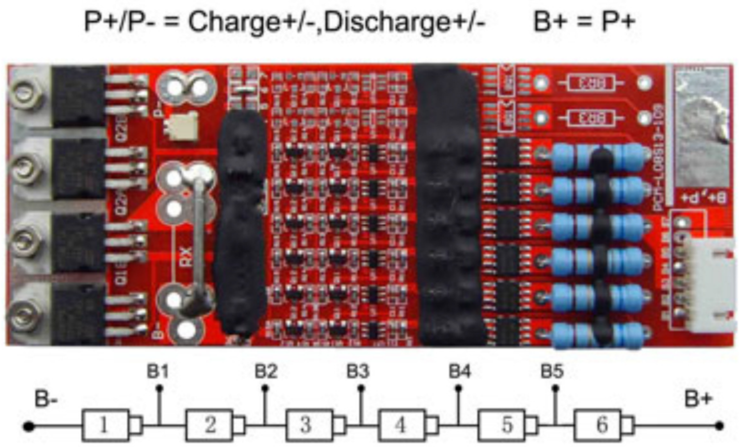


Figure 14: PCM Configuration *(permission pending)*

This method, however, will not be able to protect the battery once it is removed from the charger. This means that the battery itself has few or no attached active circuit elements, which will monitor its operation. The advantages and disadvantages of this system are shown below in Table 24.

Advantages	Disadvantages
Reduced battery weight	No active protection during use
Uses only one PCM	Increased safety risk
Reduced cost for multiple batteries	Reduced battery performance/loss of life

Table 24: Advantage and Disadvantages for Configuration One

Second, the Protection circuit module can be permanently attached to each individual battery pack. This system is generally used in rechargeable lithium batteries that have multiple cells. The advantages and disadvantages of this system are shown below in Table 25.

Advantages	Disadvantages
Full active battery protection	Increased battery weight/complexity
Increased system safety	Batteries will require separate PCM

Table 25: Advantage and Disadvantages for Configuration Two

In conclusion HeatSeekr will not use a charger mechanism to take advantage of the on-board protection circuit module. The price of the batteries with the protection circuit module on-board is prohibitively expensive, and the advantages of having the Protection Circuit Module onboard of the battery are negligible; nevertheless, safety is an important key challenge in the design project, and backflow prevention will be built utilizing other methods outlined in design sections.

4.0 Project Hardware and Software Design Details

4.1 Microcontroller

The MSP430G2553 microcontroller is part of Texas Instrument's ultra-low-power microcontrollers. It features a powerful 16-bit RISC CPU, 16-bit registers, two 16-bit timer_A, 24 touch-sense-enabled I/O pins, and universal serial communication interfaces including I^2C. The recommended operating condition during operation is a standard min to max voltage during program execution of 1.8V to 3.6V. It also has a flash storage of 16kB, and RAM of 512 bytes for all processing needs. The microcontroller comes in a TSSOP package that is able to accommodate either 20 or 28 pin connections. For HeatSeekr's purposes, four MSP430G2553 microcontrollers will be used for the navigation system, extinguishing system, remote sensor, and master processor. Of those systems, two microcontrollers will be required to have the 28 pin accommodations for the master processor and the extinguisher system, while the smaller remote sensor and navigation system only need the 20 pin accommodation. The master and slave system incorporated will use I^2C to efficiently transfer data throughout the entire system. The remote sensor system is designed to communicate back to the master controller through use of Bluetooth communications between the remote sensor and an array receiver attached to the master system.

The control of HeatSeekr is divided among three embedded processors. One processor controls everything relating the navigation. This processor monitors the line following sensors and controls the drive wheels to ensure the rover stays on the line. This processor also watches the address reader, allowing the rover knows what rooms it is around. Another processor will control the extinguishing system on the rover. This processor will monitor the water level and UVTRON. It will also control the aiming of the water jet and activate the water pump when necessary. Controlling these two processors is the master processor. This processor will be responsible for wireless communication, running the LCD screen, and directing the other two processors. Due to the required number of GPIO pins, this processor will be in a 28-pin SMD package. This package allows the entire Port 3 to be dedicated to the LCD panel while Port 1 will be used primarily for standard interfacing with this processor and Port 2 will be used for testing I/O. Figure 15, below, displays the schematic of how this processor will be connected. The Bluetooth module (Roaming Networks RN-42) will connect to this processor via its UART interface. Three other pins on the RN-42 will be connected to this processors Port 1. These pins will allow the processor to monitor the status of the RN-42 and reset it if necessary. The other connections to this processor are the programming jumper and the LCD connector.

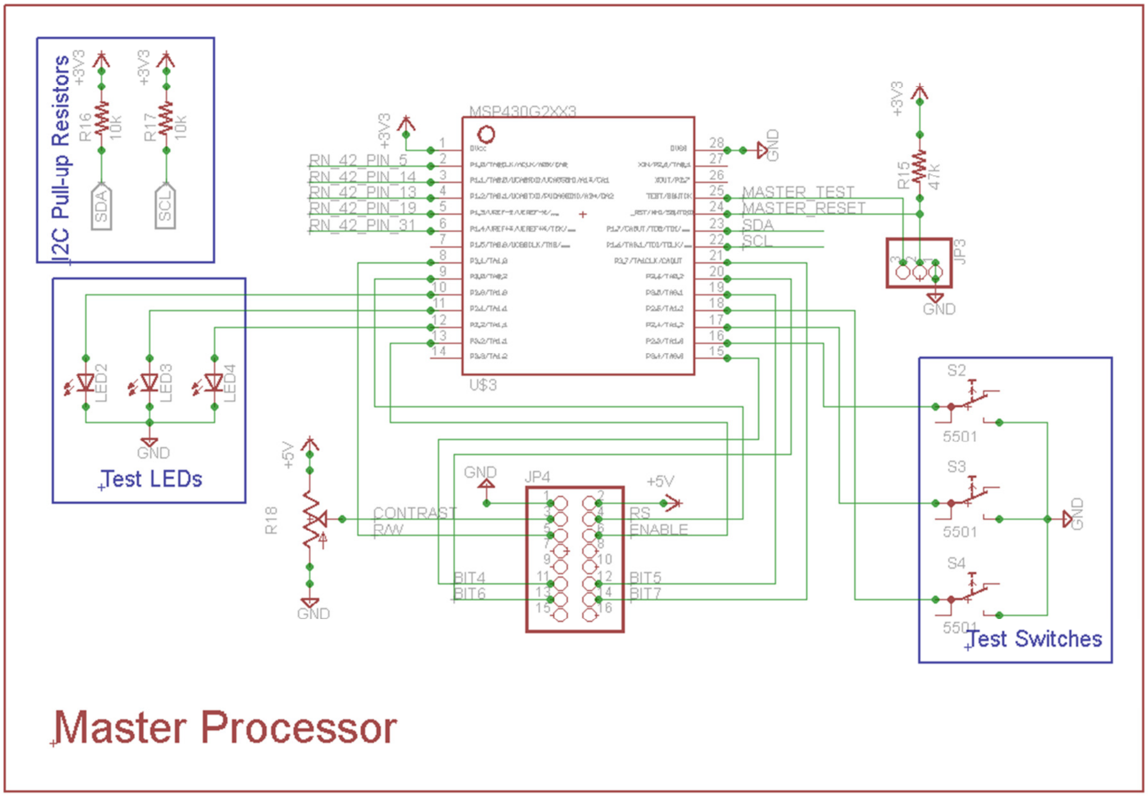


Figure 15: Schematic of the master processor

Since this processor is the I^{2}C master, the 10 kΩ pull-up resistors will be placed near it. I^{2}C was chosen due to its simplicity and small GPIO requirement. I^{2}C was chosen because there will be a total of only three devices that need to communicate and the communication is extremely simplistic. When the fire signal is received from the remote sensor, the master processor will tell the navigation system the address to arrive at. It will then periodically poll the navigation system for its status. Once the navigation system has arrived at the given address, it will change its response to the master processor. Once the master processor knows the rover is at the correct location, it will tell the extinguishing system to begin searching for, and extinguish, a fire. During this time the master processor will periodically poll the extinguishing system for its status. This polling will allow the master processor to know if the water has run low or when the fire has been extinguished. The pseudo-code for this entire processor is displayed below in Figure 16. Each time the navigation system is contacted, it will tell the main processor if the rover is currently moving and the last address it read. This information will be stored in global variables on the main processor for other functions to utilize. If the rover is currently moving, it will display ‘Roaming’ on the LCD. After the navigation system status has been checked, the main processor will poll the extinguishing system for its status. The main processor will store the fire detection status, the extinguishing status, and the water level status in global variables for all functions to see. If the water level is reported to be too low, the LCD will display ‘Low water!’ and the CPU will go to sleep. By design there is no wakeup method for this sleep, meaning a human will be required to refill the tank and reset the processor. Next, the main processor will check the status of the remote fire sensor. If a fire is detected, the LCD will display ‘Fire at [address]!’ and the main processor will tell the navigation the address to go to and it will wait until the rover has arrived at that address. Once the rover is no longer moving, the master processor will tell the extinguishing system it's clear to locate the fire and extinguish it. The main processor will then wait until the fire is extinguished, at which point it will display 'Fire extinguished' and wait for a human to reset it.

```
Initialize UART
Setup RN-42
Initialize I²C
Initialize LCD

main_function(
navigation_status_check()
if(moving == 1)(
display 'Roaming' on the LCD
)
extinguishing_status_check()
if(water level == low)(
display 'Low water!' on the LCD
put the CPU to sleep                // CPU will stay asleep until a human manually resets it
)
remote_sensor_status_check()
if(remote_fire ==1)(
send 'address' to navigation system
display 'Fire at [address]!' on the LCD
while (moving == 1)(
navigation_system_check()
wait 10 seconds
)
send 'okay to fire' to extinguishing system
while (extinguishing ==1)(
extinguishing_system_check()
wait 10 seconds
)
display 'Fire extinguished!' on the LCD
put the CPU to sleep                // CPU will stay asleep until a human manually resets it
)
)

navigation_status_check(
Set I²C slave address to navigation processor address
Send command to report status
Listen for status response
Set global variable 'moving'
Set global variable 'last address'
)
```

```
extinguishing_status_check(
Set I²C slave address to extinguishing processor address
Send command to report status
Listen for status response
Set global variable 'fire'
Set global variable 'extinguishing'
Set global variable 'water level'
)
```

Figure 16: Pseudo-code for the Master Processor

4.2 Flame Detection and Extinguisher

4.2.1.1 Flame Detection Hardware Configuration

The flame detection hardware configuration for the rover consists of the Hamamatsu UVTRON particle detector, the C10807 driving circuit also from Hamamatsu, and the MSP430 microcontroller. The Hamamatsu UVTRON particle detector is a two polar port sensor that requires 350 V for optimal operation, and when properly configured outputs a number of pulses corresponding to the intensity of incident ultraviolet light. The C10807 driving circuit from Hamamatsu is a multiple input multiple output circuit board that functions to reduce the operating voltage of the UVTRON particle detector to only 12 V.

The inputs to the C10807 that will be used for this project are the ports labeled A and K, denoting soldering points for the anode and cathode of the UVTRON particle detector. Because of the incredible ramp in voltage occurring in the C10807 in order to drive the UVTRON particle detector, positioning of the UVTRON through soldered wires instead of direct soldering to the board is discouraged, as the high voltage power supply function of the C10807 creates a high impendence between the ports of the board and the anode/cathode of the UVTRON particle detector. Thus for the purposes of the project, prototyping will work around the UVTRON particle detector's anode/cathode being soldered directly to the C10807's A and K ports, and the size/shrouding concerns that result from this decision. Thus, concerning hardware, the UVTRON particle detector and the C10807 driving board are considered to be a unified component.

This union results not only in a 12 V requirement instead of a 350 V requirement, but also in altered output signals to the MSP430. The C10807 driving board includes a signal processing circuit with two outputs, the first of which being the port labeled "1," defined as an open collector output. Port 1 outputs a series of pulse signals of amplitude 5 V and a pulse width of 10 ms. This pulse width can be extended through the use of a capacitor, but because the UVTRON particle detector/C10807 driving board assembly will constantly be sweeping, and because of the high clock rates achievable on the MSP430, it is prudent to use the shortest pulse width. Port 2 of the C10807 signal processing circuit utilizes a constant 5 V signal with pulses of amplitude set to ground and with pulse widths of 10 ms - essentially an inverse of port 1. For simplicity, port 1 will be used.

The C10807 driving board's Port 1 output will be soldered to port P1.0 of the MSP430, requiring only one input to relay information regarding fire intensity. Port P1.1 of the MSP430 will be used to control the output of an LED in order to aid in testing and as a 3rd party's indication of positive fire detection. Figure 17 depicts the completed UVTRON interface with the MSP430, as well as the testing LED and button.

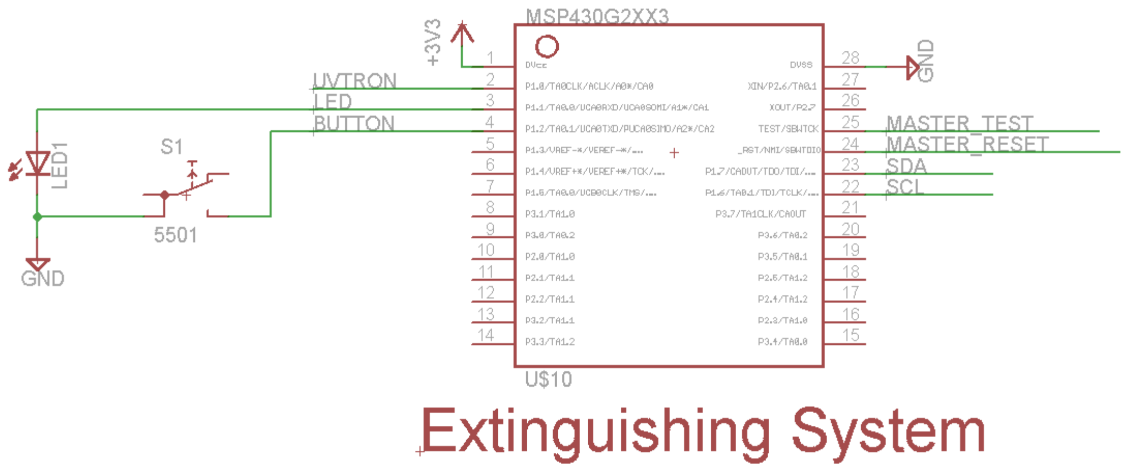


Figure 17: Schematic representation of UVTRON interface with MSP430 and testing peripherals

4.2.1.2 Extinguishing Hardware Configuration

The fire extinguishing hardware configuration for the rover consists of the MCP355 Swiftech PC liquid cooling pump, the y-radial stepper motor, a relay, and the MSP430 microcontroller. The MCP355 is a power driven device, requiring only its operating power specifications to function. This being the case, the pump portion of the fire extinguisher is remarkably easy to initiate, requiring only a switch in the form of a relay to toggle its power supply. The y-radial stepper motor is controlled through a function call in the MSP430, and follows a simple vertical sweep

The relay used to control the power to the MCP355 water pump is connected to pin P1.3 of the extinguishing microcontroller. The relay serves to control access to the 12V power rail for the MCP355. Connected to the y-radial stepper motor, the water pump access hose is manipulated by function calls as specified previously.

4.2.2.1 Flame Detection Algorithm

In order to best meet the specifications, it was decided that the Hamamatsu UVTRON flame detector would be chosen to meet the fire detection needs of the project. The UVTRON's C3704 board outputs a 10 ms width pulse output that corresponds to detected sources of ultraviolet radiation. The specifications for the sensor indicate that there is a background pulse allowance that must be accounted for in order to prevent false positives. Thus the flame sensor outputs a frequency varying signal whereby higher frequencies denote higher sources of ultraviolet radiation and lower frequencies indicate adjacent sources or simply background radiation.

The integration of the UVTRON and the MSP430 then relies on a method for counting the pulses emitted by the C3704 board and comparing the measured count to a predefined threshold. This is most readily accomplished through the MSP430's Timer_A capture function, which measures the period (and therefore frequency) of a signal by counting the time between rising edges of the signal. The capture function works by using a known clock source to count the number of detected pulses. By ensuring that the known clock is higher than the amount of pulses generated by the C3704 board in 1 second, a fairly accurate estimation of the frequency is possible, and the ability to compare frequencies to predefined thresholds is assured.

From the UVTRON specifications, it was determined that small flame sources roughly 1 meter from the UVTRON will result in signals of 3 pulses per second from the C3704. For comparison, the background signal frequency is under 24 pulses per hour, ensuring that the known clock rates the MSP430 is capable of generating will be more than sufficient to accurately capture fire detection frequencies.

The requirement of the frequency counter in light of the very low background signal frequency is due to the fact that when the UVTRON is in the vicinity of a fire but not pointing in its exact direction, it will still pick up UV radiation from the fire that reflects off surfaces in the immediate area. Experimental testing with the UVTRON will allow for a precise frequency threshold to be calculated; this threshold will be unique to this project because it depends on the shroud design, scanning speed, known clock rate, and reflectivity of the environment.

4.2.2.2 Extinguishing Algorithm

As outlined in the hardware configuration, the hose of the extinguisher will be mounted on the same servo driven platform as the UVTRON detector. This means that the x-radial position of the hose, for the purposes of extinguishing, is in line with the fire once the fire has been detected and the sensor stops scanning. The same loops used for scanning will be used for the extinguishing algorithm, namely, the stepper motor controlling y-radial position will cycle through 90° of movement reflected by a function call to the stepper motor function for moving upwards 45° and then downwards 90°, and then upwards 90° again.

Upon reaching the center of a room, the fire detector will sweep a near 360° radial distance. Upon positive identification of the flame, the sensor will cease the sweep and remain pointed at the fire. The fire extinguisher then is primed to begin the aforementioned algorithm, beginning the y-radial sweep with the stepper motor and then setting pin P1.3 to high and activating the relay, powering the MCP355 water pump. The MSP430 will monitor the status of the UVTRON, and when the UVTRON particle detector no longer senses a flame, pin P1.3 will be reset and the extinguisher will cease.
Figure 18 contains a pseudo-code representation of the discussed algorithm methodology.

```
Configure Timer A to perform an interrupt every 10 seconds
Configure Timer B to count the frequency pulses from the UVTRON
Configure I2C

main_function(
Check water level
if (water level == 'Low')(
Put the CPU to sleep
if (remote_fire ==1)(
wait until master processor gives 'Okay to extinguish'
while (local_fire != 1)(
sweep X stepper motor
)
turn on water pump
while (local_fire == 1)(
sweep Y stepper motor
)
set local_fire=2
)
)

timer_A_interrupt_received_function(
Determine frequency of pulses from the UVTRON
If frequency > threshold(
Set local_fire = 1
Return to main_function
)
Return to main_function
)

interrupt I2C(
wakeup CPU // depending on how program got here, it may not be sleeping
receive status of the rover from the master processor
send 'water level'
send 'local_fire'
)
```

Figure 18: Pseudo-code for the Extinguishing System

4.2.2.3 Scanning Algorithm

The flame detector functions by determining the output frequency of the C3704 board and comparing it to an experimentally determined threshold value. The design of the rover and its intended use require that the flame detector's field of view be swept horizontally through the environment to accurately guide the extinguishing hose. This will be accomplished through the use of programmed loops that sweep through a range of horizontal values for a set vertical value, and upon completion of this sweep repeat the horizontal sweep until a fire is detected. These sweeps will call functions in the MSP430 written to control the stepper motors as outlined previously. The functions deterministically manipulate the horizontal and vertical values such that a return to a predefined location is possible, ensuring that the sweeping sensor's location will be known.

4.2.3 Aiming Control

Two Nema 16 step motors, model number 39BYG302, will be used to rotate the X and Y plane of the extinguishing system's nozzle. To do this, the X plane motor will be securely attached to the bottom of the UVTRON's mounting plate. This will enable the X plane to freely move right and left at 1.8° turns, and point the UVTRON in the correct direction. Once the UVTRON is properly aligned with the fire, the Y plane will be able to move up or down accordingly to douse the fire in water. The Y plane motor will be attached directly to the fire extinguishers nozzle so that each step will allow for an incremental change in spray distance. The software installed onto the extinguisher system's controller will enable the system to rotate the X plane for proper alignment and continue to run the up and down motion of the Y plane to ensure the flame is put out. Once the UVTRON has confirmed that the fire has been subdued, the software counter for the stepper motors will allow for confirmation of their location and reset them to a standard position. An overview of the 39BYG302's specifications can be seen in Table 26 below.

Step Angle	1.8°
Current	0.32 A
Resistance	15.0 ohms
Holding Torque	1.0 N/cm
Control wires	4
Price	$12.95

Table 26: 39BYG302 specifications

Both motors will be connected to the extinguishing system's microcontroller by use of two H-bridges. As shown in Figure 18, the motor wires will connect their control wires to pins two and 19 on each bridge. The bridges will then transfer the data back to the MSP430G2553 and connect to pins eight to 14 and 15-19. The bridges will allow for proper transfer of voltage and current from the microcontroller to the stepper motors when instructed to do so through software.

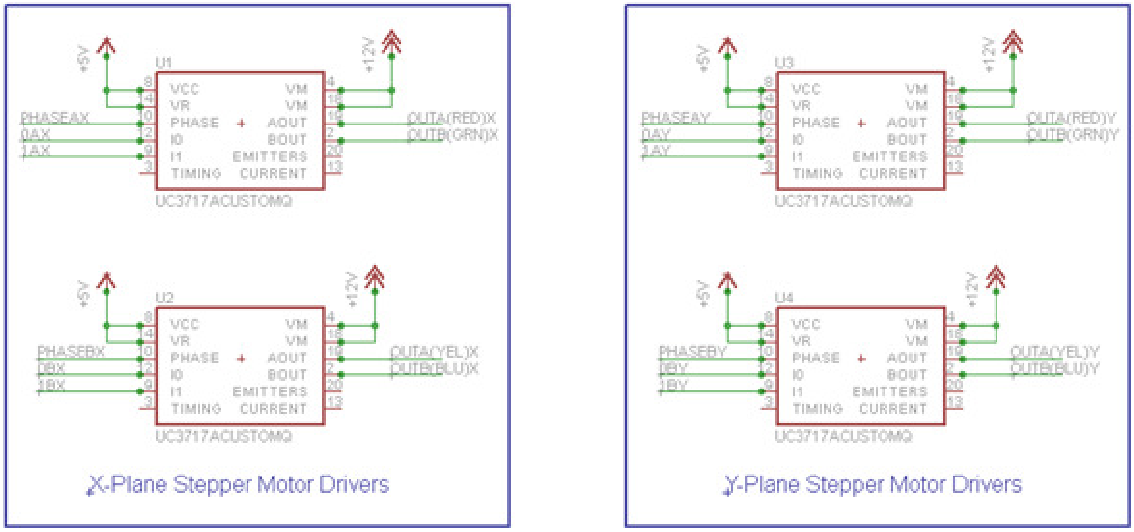


Figure 18: Motor connections from Extinguishing System Schematic

4.3 Line Follower and Navigation MCU

4.3.1.1 Line Detection Hardware Configuration

The line follower hardware configuration for the rover consists of a five member array of the CNY70 reflective optical sensor with transistor output and the MSP430 microcontroller. The CNY70 reflective optical sensor is a four polar port package consisting of an infrared emitter and transistor, each comprising two of the four total ports. It should be noted that the emitter and transistor are, for all intents and purposes, separate circuits within the same package, and thus comprise two isolated nets. The infrared emitter is essentially a diode, and the transistor has collector and emitter ports, thus it is important to note the polarity of connections regarding these two elements. The diode requires 5V to run efficiently, and requires between 25 to 50 mA of current, thus 200 Ω resistors will be placed on a leg of each diode circuit, with the anode leg of the diode connected to the 5V power rail.

The transistor portion of the package can thankfully function on the same 3.3V used for the MSP430, and will have the collector port connected to the 3.3V power rail. The intensity of infrared light modifies the output current of the transistor, and this is the value that should be measured. Because the output of the transistor will be fed into an MSP430 port acting as an analog to digital converter, the current will be read in terms of voltage on a resistor through which the output current flows. In order to produce output voltages that comply with the logic level signal input of the MSP430, a resistor value was chosen that would convert the typical output current into 3.3V. The emitter port will terminate in a grounded 6.8k Ω resistor in order to satisfy this requirement. Figure 19 depicts the line detection hardware configuration schematic, detailing the CNY70 array's interface with the navigation microcontroller.

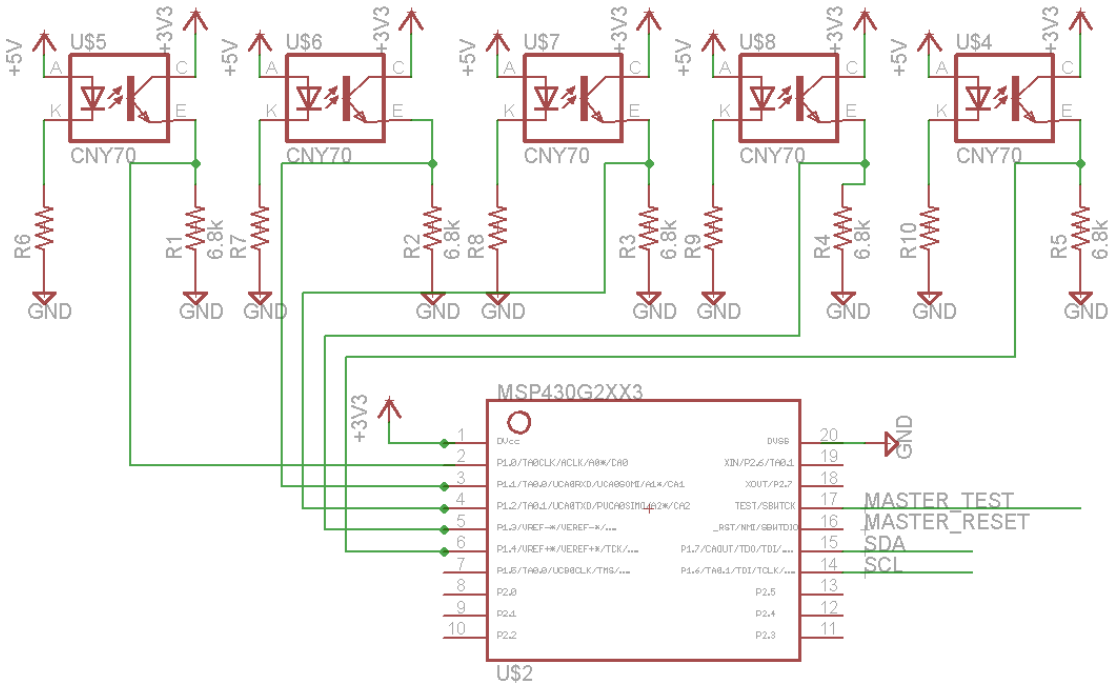


Figure 19: Schematic view of CNY70 array to MSP430 interface

The portion of the transistor circuit that interfaces with the MSP430 is on the emitter leg, before the grounded resistor. A trace will connect this area to the designated port on the MSP430. There will be five CNY70s arranged in an array, and each will have a trace connecting their emitter leg to the designated ports, which will be P1.0 through P1.4

4.3.1.2 Address Reader Hardware Configuration

The address reader hardware configuration for the rover consists of one CNY70 reflective optical sensor with transistor output and the MSP430 microcontroller. The address reader is in essence a replica of the line detector with an array of only 1 element, with the principle difference between the two subsystems being almost entirely software based. The CNY70 optical sensor of the address reader is separate from the line detector, and will be arranged in the prototype in a similar fashion, though distanced by up to several inches from the line detector array. Following the convention of the line detector CNY70, the emitter leg of the address reader CNY70 will have a trace taken before the grounded resistor and be connected to port P1.5 of the MSP430. Figure X depicts the address reader's hardware configuration schematic, detailing the CNY70 interface with the navigation microcontroller.

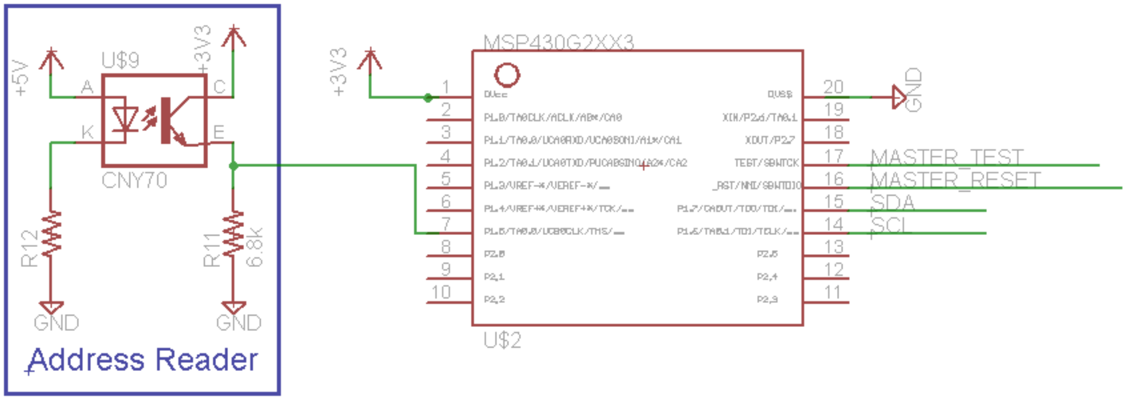


Figure 20: Schematic view of CNY70 array MSP430 interface

4.3.1.3 Navigation Hardware Configuration

Navigation will be driven by a standard tank tread design in order to equally distribute the weight of the water tank. The VEX motion robotics tank tread kit has a maximum length of 32.75in per chain, tread width of 1.5in, and is made of delrin plastic which is strong enough to support the expected weight of the system with a full load of two gallons of water weighing 16.682lbs. The kit is to be purchased from the Robot Marketplace for $29.99 off of their main website. With a chassis frame of size 12.592in x 7.598x, the tire tread length will be set at 12in, which provides a surface area of 18in per chain for a total of 36in. total to evenly distribute the HeatSeekr's weight. Since the system is designed to navigate an indoor environment, the tread is also expected to handle maneuvers from different textures such as tiles and carpets easier than standard wheels would. The treads will be mounted to the bottom of the chassis, and the navigational motors will be inserted into the drive wheels to control movement.

The motors that are going to be controlling motion for the tread system are two separate planetary gear motors, model PGHM-02. The motors are to be bought from lynx motion for $37.95 each. The motors have a stall torque of 388.85 oz-in which converts to 24.303lb-in., which provides excess strength for additional weight and speed for the system. At 65 rpm, the motors should be able to drive the HeatSeekr at a quick speed in order to increase the response time after getting an alert for a fire from the remote sensor system. An overview of the PGHM-02's specifications can be seen in Table 27 below.

Reduction Ratio	91:1
Voltage	12 vdc
RPM	65
Outside Diameter	35 mm
Stall Torque	388.85 oz/in
Weight	8.90 oz
Price	$37.95

Table 27: PGHM-02 specifications

To convert up to the 12v required to run each motor, a BUZ20 MOSFET will be used to increase the power sent from the microcontroller, and can be bought from Ali Express for $2.95 for a pack of five despite only having a need for 2. Each motor is connected to a MOSFET, and then connected to pins eight and nine on the navigation system microcontroller for the left and right motor respectively. When instructed to move by the microcontroller, the motors will use standard tank tread navigation to move by starting both motors at the same time in the same direction. If turning is required, one motor will remain off and the other will begin moving to turn.

4.3.2.1 Line Detection Algorithm

The CNY70 reflective optical sensors that comprise the line detector's five member array output voltages between 0V and 3.3V depending on the amount of infrared light incident on the transistor components of their packages. The ports designated for input from the CNY70s will be defined as inputs into the analog to digital function of the MSP430. What will result when these inputs are converted into digital values are arbitrary numerical values that will have no meaning until threshold values are set. When a CNY70 sensor is situated over a white surface, the digital value representing the analog input will be higher than when the CNY70 sensor is situated over a black surface. Through experimentation, the threshold value corresponding to digital values of black and white sensors will be determined, and the code comprising the algorithm will check each CNY70's digital input value against this threshold value.

A five member array will be defined in the code that will represent the status of each CNY70 sensor. The threshold value will allow the digital value of arbitrary weight to be converted into a binary 1 or 0, where 1 corresponds to the CNY70 sensor being situated over a black surface and a 0 corresponding to the CNY70 being situated over a white surface. The previously defined array will be loaded with the values for each sensor in order, with a sample value being 00100, representing the line being situated at the exact center of the CNY70 sensor array. What will follow is an algorithm applied to each array, with the array value updating upon completion of the algorithm.

An else-if loop will check the array for certain configurations, and if the array meets these conditions, an instruction will be sent to the motors, often informing both to be powered, or only the left or right motor to be powered. These conditions correspond to the possible statuses of the CNY70 sensor array, and due to the relatively closely packed nature of the array, the conditions correspond to every combination of single 1 values and adjacent 1 values; for example, 01000 and 00011, with the former indicating that the rover must adjust by applying power to the left motor to move the line closer to the center of the CNY70 array, and the former indicating that the rover must adjust by applying power to the right motor to correct the line position.

The relative degree of deviation will be noted with a compounding error function, comprising a PID controller. This error function will have the memory of the last three error values, allowing for the response of the motor pair to be adjusted accordingly. An example would be that arrays of 00100, 01100, and 01000 would indicate a gradual left turn, and an array sequence of 00001, 01100, and 00000 would indicate a sharp left turn whereby the array has left the line and must continue left until it finds the line again.

4.3.2.2 Address Reader Algorithm

The CNY70 reflective optical sensor that comprises the address reader's single sensor outputs voltages between 0V and 3.3V depending on the amount of infrared light incident on the transistor component of the packages. Similar to the line detector CNY70 array components, the address reader CNY70's value will be read into the analog to digital converter, compared to experimentally defined threshold values corresponding to voltages from the transistor incident on black and white surfaces, and then finally converted into binary values, where 1 corresponds to the CNY70 sensor being situated over a black surface and a 0 corresponding to the CNY70 being situated over a white surface.

The rover's movement will be designed such that it maintains a constant speed while traversing the relatively straight paths in the hallways between rooms. Before the junction at every room, the room code located adjacent to the track will be made a standard distance from the track such that it will be located directly under the address reader as the rover passes over that section of track. Because the speed of the rover is known, it is possible to imbed information into the room code in the form of alternating stripes of black and white surfaces of equal width and adjacent to one another.

As the address reader is testing for threshold values, it will wait until a long strip of black surface inputs a repeated string of 1's to the address reader. This corresponds to the design of the room code, which is a few inches of non-reflective material followed by the alternating code. This repeated string of sampled 1's indicates a switch in the address reader's code, whereby it will change its sampling rate to a predetermined number of wait cycles. This experimentally determined number of wait cycles is of the required length to determine each individual stripe's color-coded binary value of the address code, and to only sample each stripe once. The number of wait cycles is determined primarily by the spacing of the room code stripes, and the speed of the rover, both of which are to be held constant.

The binary sequence corresponding to the room code stripes is stored in an array, and compared to the array sent from the stationary hanging detector. If the arrays match, the rover executes a programmed right or left turn, depending on the location of the room code. This programmed turn is done without input from the CNY70 line detector array, and programmed to occur a certain number of wait cycles after the code has been read, corresponding to the distance of the room code from the junction. If the arrays do not match, and the rover is at the wrong room, it passes the junction without incident.

4.3.2.3 Line Follower Address Reader Integration Algorithm

The navigational microcontroller is required to simultaneously process information from both the line follower and the address reader in order to correctly determine local and absolute location within the navigation environment. The navigational microcontroller is also responsible for dictating the various combinations of motor output for various conditions of the line follower and address reader. Figure 21 contains a pseudo-code representation of the discussed algorithm methodology.

```
Initialize I²C
Initialize ADC

main_function(
while(1)(
if (fire=1)(
Turn off both drive motors
put the CPU to sleep
)
Turn on both drive motors
set 'moving' = 1
Set ADC to channel 0
adc_function(line[0])
Set ADC to channel 1
adc_function(line[1])
Set ADC to channel 2
adc_function(line[2])
Set ADC to channel 3
adc_function(line[3])
Set ADC to channel 4
adc_function(line[4])

if (line[0] == 1)(
// rover is to the right of the line
turn off left motor
turn on right motor
)
else if (line[2] == 1 AND line[3] == 1 AND line[4] == 1)(
// rover is on top of the line
turn on both motors
)
else if(line[4] == 1)(
// rover is to the left of the line
turn off right motor
turn on left motor

Set ADC to channel 5
adc_function(on_addres)
if(on_address==1)(
read_address_function()
)
```

```
)
)

read_address_function(
adc_function()
address [0] = line
wait 'delay' milliseconds
adc_function()
address [1] = line
wait 'delay' milliseconds
adc_function()
address [2] = line
wait 'delay' milliseconds
adc_function()
address [3] = line
wait 'delay' milliseconds
)

adc_function(
turn on ADC
put CPU to sleep
wake up CPU when ADC is done
if (ADC result > threshold)(
return 1
)
else(
return 0
)

interrupt I2C(
wakeup CPU // depending on how program got here, it may not be sleeping
receive status of the rover from the master processor
send state of 'moving'
)
```

Figure 21: Pseudo-code for the navigation system

4.4 Wireless System

Ideally the wireless system is completely transparent from the microcontrollers. The goal of this project does not revolve around wireless; instead wireless is means to transmit data to achieve the end goal. The RN-42 can be configured to become essentially a black box. A microcontroller can send basic unformatted data out the UART to the RN-42 and the receiving RN-42 will place that same unformatted data on the UART input for the receiving microcontroller. All handshaking and actual formatting of the Bluetooth stack is performed internally and transparently by the RN-42. This module is sold directly by Roving Networks and costs $15.95 each. It is a surface mount device with connection pins on all three sides. Special care will be required while designing the PCB to ensure the antenna trace of the RN-42 is on the edge of, or protrudes from, the board and that no traces run near the antenna in order to avoid interference.

Initially the master RN-42 module will need to be configured by a host machine to switch it out of the default slave mode. The default settings on the slave modules will be used; therefore they will not require any special programming. Configuration is accomplished by pairing the device with a host computer over RS-232 (serial) or Bluetooth, entering command mode, and sending commands to the device via a terminal. The terminal serial settings are listed in Table 28.

Setting	Value
Port	COM port
Baud rate	115200
Data rate	8 bits
Parity	None
Stop bits	1
Flow control	None

Table 28: Serial port settings for programming the RN-42

Upon power up the RN-42 will only be able to enter command mode in the first 60 seconds, therefore the command to enter command mode must be sent relatively quickly upon turning on or resetting the device. Figure 22 displays the commands required to configure the master RN-42 on HeatSeekr rover.

```
$$$
SM,1
---
```

Figure 22: Terminal commands to configure the master RN-42

After configuring the wireless modules they become essentially black boxes for the MSP430 to send data to and receive data from. The pseudo-code for the master processor is displayed in Figure 23. This function will be called periodically as the processor executes and loops the main function. If the wireless module is not connected to another wireless module, the function will exit without changing any variables. If the wireless module is connected when this function is called, that remote module (aka slave) will be asked for its status. If the slave module reports a fire, a global variable will be set so the other functions are aware of the new state. Additionally, the master will retrieve the address the slave is located at. This address will be used by the navigation system to locate the room containing the fire.

```
remote_sensor_status_check (
Check state of P1.3 to determine if wireless is connected
If not connected(
Return to main_function
)
```

```
If connected(
If fire == 2(
UART TX Buffer = 'all clear'
Set fire = 0
Return to main_function
)
If fire == 1(
Return to main_function
)
Ask slave for status
If status == 0(
Return to main_function
)
If status != 0(
Ask slave for its address
Set address = UART RX Buffer
Set fire=1
Return to main_function
)
)
)
```

Figure 23: Pseudo-code for the wireless interface on the master processor

4.5 Water Level Sensor

The purpose of the water level sensor is to ensure the water tank contains enough water to actually put out a fire. This sensor will be used to let the rover know it needs to stop patrolling for fires and alert a human that it requires more water. While there are a plethora of different types of sensors for detecting a water level, HeatSeekr is going to use a fairly simple sensor. This simplistic approach was taken to cut down on the cost and complexity of the rover. The water level sensor is essentially a "ground detection" sensor. One probe, Probe A, is placed at the desired level on the water tank and is connected to the microcontroller and VCC. The other probe, Probe B, is placed at the desired water level an inch away from Probe A and is connected directly to ground. When the probes are underwater, the circuit is closed and the microcontroller will see a logic '0'. When the water level drops, the probes are exposed and the microcontroller will see a logic '1'. This sensor therefore only requires one GPIO pin on the microcontroller while still being able to provide very quick and very reliable measurements.

There are two methods by which this sensor can be implemented. In the first method, a 3 MΩ resistor pulls Probe A high while Probe B is grounded. One of the GPIO pins on the extinguishing microcontroller is also connected to Probe A. Since ideally the circuit will be closed most of the time, there will be a constant current flow across the resistor. This results in a constant 1.1 nA of current drain on the batteries. This method is easiest to implement in design and code; however, its small but present current drain is undesirable. Therefore the second option is to utilize a pull up resistor within the microcontroller instead of connecting Probe A to VCC. The pseudo code for this design is displayed in Figure 24. This second method is preferred since when the microcontroller is not actively reading the value of the water level sensor there is no leaking current.

```
check_water_level_function
Enable internal pull-up resistor on Pin 1
If Pin 1 == 0
Then there is enough water in the tank
Else If Pin 1 == 1
Then there is not enough water in the tank
Disable internal pull-up resistor on Pin 1
```

Figure 24: Pseudo-code for the water level sensor

4.6 Remote Sensor

The remote sensor is a combination of several sub-systems on the main HeatSeekr rover combined into a smaller package. The Remote Sensor will consist of a UVTRON Flame Detector (with driver board), an MSP430G2553, a Roving Networks RN-42, and a small power supply. The schematic for this sensor is displayed in Figure 25. The UVTRON is connected to P1.5 for frequency counting. The RN-42 is connected to the microcontroller via the UART interface, P1.0 to reset the module, P1.3 to check if the module is connected to another wireless module, and finally P1.4 to check if the module is transmitting or receiving data. JP5 is used for programming and debugging the microcontroller. The testing I/O consists of an LED and a push button. During the normal code execution, this LED will illuminate when a fire is detected; however during testing it will be used as an indicator during various debugging procedures, such as illuminating when the RN-42 is connected to the master wireless module. The pushbutton is only for testing purposes. During testing, when the button is pressed, the sensor will act as though it has detected a fire. During normal operation, this pushbutton will be completely inert.

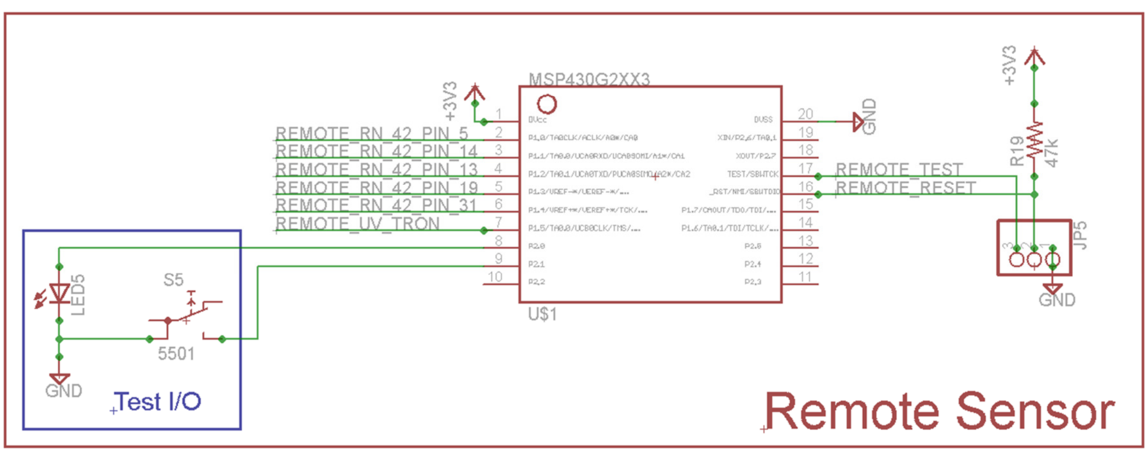


Figure 25: Schematic for the remote sensor

In order to save power, the system will spend most of its time in a sleeping state. Every 10 seconds the microcontroller will wake up and read the output of the flame detector. If there isn't a fire, the device will go back to sleep. If there is a fire, the device will set a global variable. This variable is referenced at the start of the transmit function when the master processor asks for the state of the remote sensor. Figure 26 displays the pseudo-code for the remote sensor. The transmit function will be entered via an interrupt stating the presence of data on the UART receiving buffer.

```
Configure Timer A to perform an interrupt every 10 seconds
Configure Timer B to count the frequency pulses from the UVTRON
Configure UART for interfacing RN-42

main_function(
Place microcontroller in low power mode 3
)

timer_A_interrupt_received_function(
Wake up CPU
Determine frequency of pulses from the UVTRON
If frequency > threshold(
Turn on LED indicator
Set fire = 1
Return to main_function
)
Return to main_function
)

transmit_function(
If UART RX Buffer == status request(
UART TX Buffer = fire
If fire == 1(
Wait for UART RX Buffer == (address request OR 20 seconds pass)
If UART RX Buffer == address request(
UART TX Buffer = address
Wait for UART RX Buffer == 'all clear'
Return to main_function
)
)
If fire == 0(
Return to main_function
)
)
)
```

Figure 26: Pseudo-code for the Remote Sensor

4.7 Power Supply

After comparing the different battery types that were researched, it was evident that many of the considered batteries were inappropriate for inclusion in the HeatSeekr system. Ni-MH and Ni-Cd had to be eliminated, for the simple reason that their specifications were completely outmatched by the lithium-ion and lithium-polymer solutions. Thus it was concluded that the final battery selection would be between the Li-ion and Li-Po batteries.

One of the specifications that were scrutinized was the internal resistance for the last two remaining options. By inspecting Table 29 below, one can clearly see that the Li-Po battery has much higher internal resistance, which means that less current flow at the output. Nevertheless, the table also shows that the capacity of the Li-Po is much higher; because of this the internal resistance can be considered negligible.

The energy density is also another reason why the lithium-polymer is the best choice to integrate into the project. Furthermore, lithium polymer batteries are far more efficient and longer lasting. Because of its many advantages when compared to other battery options, the lithium polymer battery was chosen for inclusion into the HeatSeekr system.

Specifications	**Ni-MH**	**Ni-Cd**	**Li-Po**	**Li-ion**
Energy density (W-hr/kg)	70-90	40-60	130-200	100-160
Capacity (Amp-hr)	2.4	1	12.6	2.8
Internal resistance (mΩ)	200-300	100-200	200-300	100-200
Nominal voltage (V)	1.2	1.2	3.7	3.6
Discharge Rate	Flat	Flat	Flat	Flat
Recharge life	600-1000	500-700	>1000	> 600
Disposal	Recyclable	Non-degradable	Recyclable	Recyclable
Charge/discharge efficiency	66%	70-90%	99.80%	80%-90%
Cost ($/Whr)	2.75	2	2.8-5	2.5

Table 29: Battery specifications summary

Because the power supply that will be used is rated for much higher voltages than the rated voltages for a majority of the parts that will be used for HeatSeekr, it is apparent that an additional design consideration will be needed to maintain the voltage in the circuits at a manageable level for the components. As was discussed in the research section this can be achieved in a variety of ways.

In order to simplify the process, Table 30 was constructed of the parts which are the most susceptible to failures in maintaining proper regulation, as these are all very much mission-critical components. Failure to meet these requirements could result in a catastrophic loss for the rover, and it is therefore imperative that the voltage ranges set forth by these components' data-sheets are met accordingly.

Part	Operating Voltage
Microcontroller	3.3 V
Water level Sensor	2.375 V – 5.5 V
Remote Sensor	4.75 V – 5 V
Servos	6 V – 12 V
UVTRON Flame sensor	5V
Scanning IR thermometer	5V

Table 30: Operating voltage requirements for HeatSeekr's main components

From this table, it is clear that more than one regulator will be needed to accommodate the smaller sub-systems on HeatSeekr. With this in mind, the search can now begin for different possibilities for voltage regulators. Different companies will be looked into including Texas Instrument. However, before specific parts were looked into, it was very essential for us to investigate whether it would be advantageous to use switching regulators, as opposed to linear voltage regulators.

The Tenergy 14.8V 5500mAh lithium-polymer battery pack will serve as the only power source for the HeatSeekr rover. In series with the positive lead of this battery pack will be a physical switch to turn HeatSeekr on and off. When the switch is flipped on, the battery pack will become connected to the 3.3 volt switching regulator (Murata Power Solutions 78SR-3.3/2), the 5 volt switching regulator (Murata Power Solutions 78SR-5/2), and the 12 volt switching regulator (Innoline R-78C12-1.0), resulting in HeatSeekr fully powering on. These three regulators will have their V_{in}'s connected together and three separate power traces will make up the three distinct power rails. Upon application of power, all embedded processors will begin their initializations and begin communicating to establish their initial states. This precaution will be enforced to ensure the individual processors do not try to interpret the value of their sensors before their sensors are stable. For example, the extinguishing system will disregard all input from the UVTRON until the master processor gives the 'all clear' to begin operating. Figure 27 displays the schematic of the power supply.

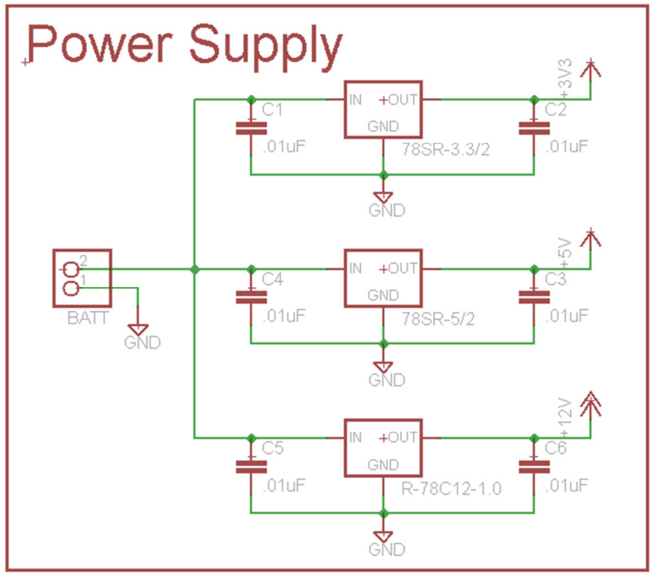


Figure 27: Schematic for the power supply

4.8 LCD Screen

The HeatSeekr rover will contain a 40x2 character Hitachi HD44780 LCD panel. This panel was chosen because it was donated to the project at no cost. This display will be connected to the master microcontroller on the rover. Nikosapi's HD44780 C library for the MSP430 will be used to interface the display with the microprocessor. This library is licensed under the Creative Commons Attribution-NonCommercial-ShareAlike 3.0 Unported license. The library makes utilizing the display incredibly simple. After initializing the display, one simply calls one of the various functions, passing a character or string, and the display will print that character or string. The library allows the display to run in either 8-bit mode or 4-bit mode. HeatSeekr will implement the 4-bit mode to save GPIO pins. While 4-bit mode is slightly slower than 8-bit mode this is not expected to become a hindrance to the rover. One requirement of the library in 4-bit mode is that the LCD panel will need to be connected all on one port of the MSP430. Since many crucial functions (UART, I^2C, external timer) share GPIO pins with Port 1 and some of Port 2 is shared with the external crystal pins, the inclusion of this panel forced the decision to utilize a higher GPIO pin count SMD package for the master MSP430G2553.

The following strings will be programmed to display under their appropriate situation:

- Low battery!
- Fire in room [address]!
- Low water!
- Fire extinguished
- Roaming

5.0 Design Summary of Hardware and Software
5.1 Microcontroller
5.1.1 Hardware Configuration

The chosen microcontroller for HeatSeekr was the MSP430G2553. As an ultra-low power microcontroller, it is optimized to achieve extended battery life in portable applications. It was chosen for its ability to perform at low power levels, control stepper motors, and portability. As shown in Table 31, its parameters provide a modest power for minimal voltage supply and meet the estimated requirements of HeatSeekr's specifications.

Frequency	16 MHz
Flash	16 kB
SRAM	0.5 kB
GPIO	24
Timers-16-bit	2
Low supply voltage ranges	1.8 to 3.6 V
Active power consumption	230 µA
Standby mode consumption	0.5 µA

Table 31: MSP430G2553 Specifications

The microcontroller comes in a TSSOP package that is able to accommodate either 20 or 28 pin connections. For HeatSeekr's purposes, four MSP430G2553 microcontrollers will be used for the navigation system, extinguishing system, remote sensor, and master processor. Of those systems, two microcontrollers will be required to have the 28 pin accommodations for the master processor and the extinguisher system, while the smaller remote sensor and navigation system only need the 20 pin accommodation. The master and slave system incorporated will use I^2C to efficiently transfer data throughout the entire system. The remote sensor system is designed to communicate back to the master controller through use of Bluetooth communications between the remote sensor and an array receiver attached to the master system.

5.1.2 Master System

As shown in Table 32, the master system uses a 28 pin connection to communicate with its multiple systems. The preceding Figure 28 further explains the schematic by explaining what each specific item on the schematic represents.

Pin Number	Connection With
1	Input Voltage
2 - 6	Remote Sensor System Connections
10 - 12	Test LEDs
8, 9, 13, 15, 19 - 21	LED Alert Screen
16 - 18	Test Switches
22 - 23	I^2C Bus to Other Systems
24 - 25	Master Test and Reset
28	Ground

Table 32: Pin Layout Connections

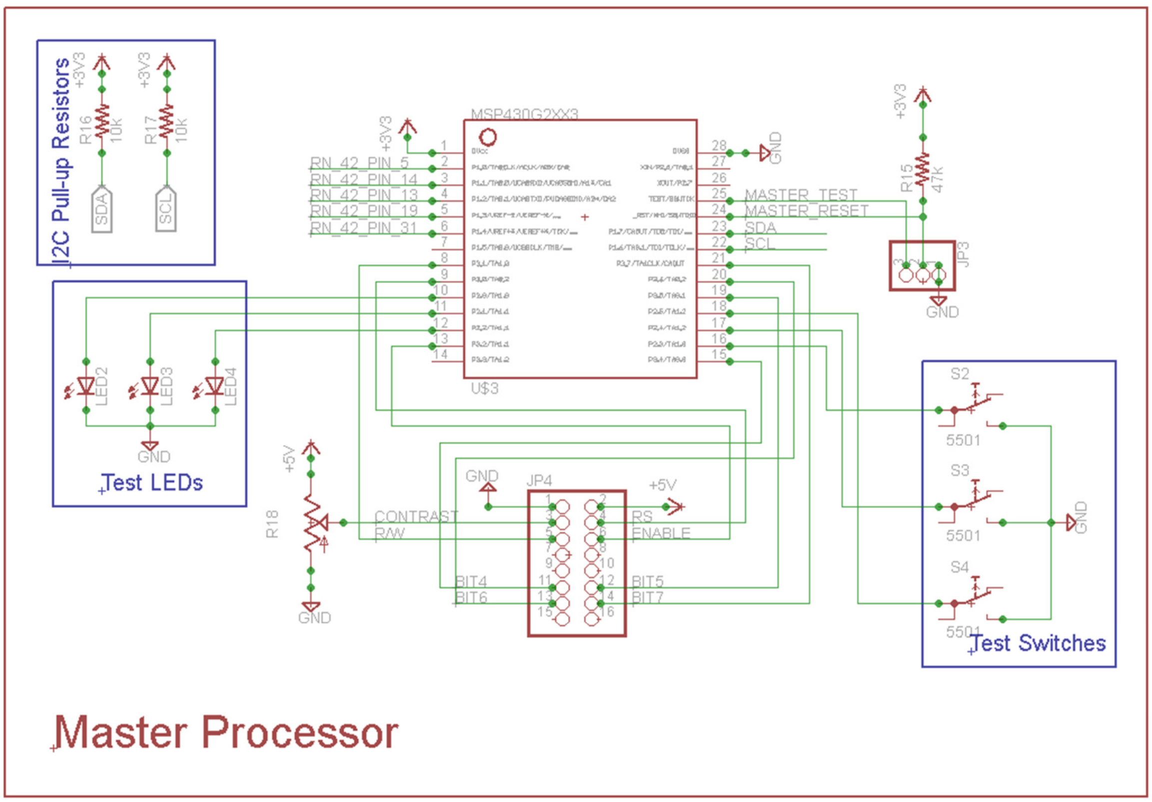


Figure 28: Master Processor Schematic

Pins 2-6 represent the remote sensor system connections for communicating between the Bluetooth enabled remote sensor and the receiving array on the HeatSeekr. The I^2C bus on pins 22 and 23 allows for communication between this master processor and the navigation and extinguisher systems. Finally, the LED Alert screen is a 40x2 character Hitachi HD44780 LCD panel that is designed to display HeatSeekr's current status. Once a status has changed, the LCD will display its current state varying between:

- Low battery!
- Fire in room [address]!
- Low water!
- Fire extinguished
- Roaming

The master processor directs the other two sub-systems and is the heart of HeatSeekr. While the sub-systems are able to function completely independently and without the master processor, they are unable to change whatever state they're in. Figure 29 displays the pseudo-code for the master processor. The master processor periodically steps through communication with each sub-system, exchanging status's and then acting on any new information received.

```
Initialize UART
Setup RN-42
Initialize I²C
Initialize LCD

main_function(
navigation_status_check()
if(moving == 1)(
display 'Roaming' on the LCD
)
extinguishing_status_check()
if(water level == low)(
display 'Low water!' on the LCD
put the CPU to sleep            // CPU will stay asleep until a human manually resets it
)
remote_sensor_status_check()
if(remote_fire ==1)(
send 'address' to navigation system
display 'Fire at [address]!' on the LCD
while (moving == 1)(
navigation_system_check()
wait 10 seconds
)
send 'okay to fire' to extinguishing system
while (extinguishing ==1)(
extinguishing_system_check()
wait 10 seconds
)
display 'Fire extinguished!' on the LCD
put the CPU to sleep            // CPU will stay asleep until a human manually resets it
)
)
```

```
navigation_status_check(
Set I²C slave address to navigation processor address
Send command to report status
Listen for status response
Set global variable 'moving'
Set global variable 'last address'
)

extinguishing_status_check(
Set I²C slave address to extinguishing processor address
Send command to report status
Listen for status response
Set global variable 'fire'
Set global variable 'extinguishing'
Set global variable 'water level'
)
```

Figure 29: Pseudo-code for the master processor

5.2 Extinguishing System

5.2.1 Hardware Configuration

As shown in Figure 30, the extinguishing system uses another 28 pin connection. The extinguisher's main responsibilities involve controlling the UVTRON, X and Y plane motors used for controlling the aim of the water turret, and control over the water pump.

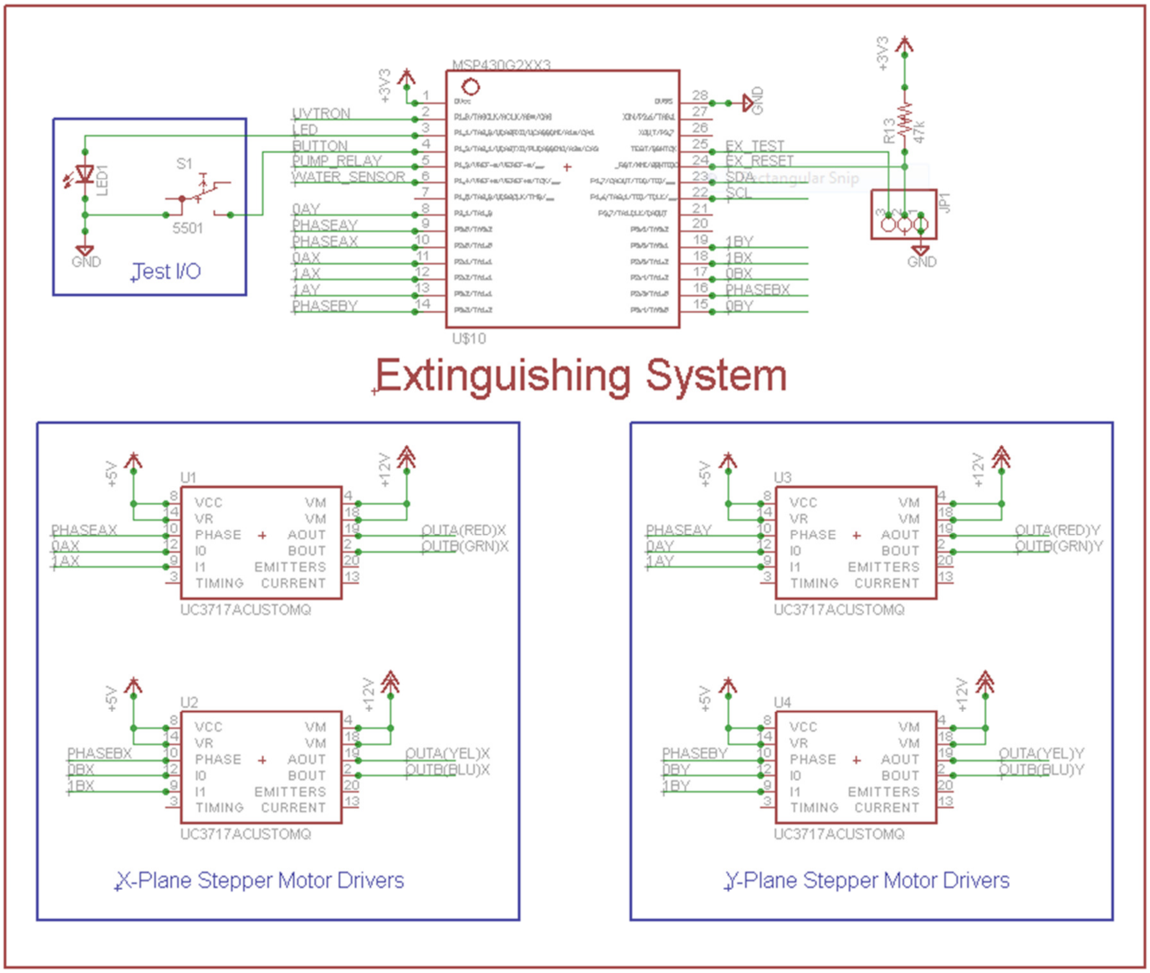


Figure 30: Extinguishing System Schematic

5.2.2 Aiming Mechanics and Algorithms

As shown in the previous Figure 30, Pins 8-19 of the extinguishing system are connected to the X and Y plane motors through use of four H-bridges. Each of these motors is a standard Nema 16 stepper motor model 39BYG302 with a step angle of 1.8° and a control current of 0.32A. The X plane motor will be attached underneath the UVTRON's mounting plate and allow for the UVTRON's direction to change. The Y plane will be connected on top of the UVTRON's shield with the extinguisher's nozzle to maintain the same direction, and rotate up and down to change the overall distance of the water fired from the pump.

Stepper motors were chosen for aiming the water turret at the flame due to their ability to count the number of steps taken and return to a default position without the need of an encoder. Unlike servo motors, the stepper motor's operation in a constant current mode reduces the amount of resources required to operate. This feature should allow the HeatSeekr to effectively extinguish a fire, and reset itself ready for another fire. The pseudo-code to this effect is located in Figure 31.

```
Configure Timer A to perform an interrupt every 10 seconds
Configure Timer B to count the frequency pulses from the UVTRON
Configure I2C

main_function(
Check water level
if (water level == 'Low')(
Put the CPU to sleep
if (remote_fire ==1)(
wait until master processor gives 'Okay to extinguish'
while (local_fire != 1)(
sweep X stepper motor
)
turn on water pump
while (local_fire == 1)(
sweep Y stepper motor
)
set local_fire=2
)
)

timer_A_interrupt_received_function(
Determine frequency of pulses from the UVTRON
If frequency > threshold(
Set local_fire = 1
Return to main_function
)
Return to main_function
)

interrupt I2C(
wakeup CPU // depending on how program got here, it may not be sleeping
receive status of the rover from the master processor
send 'water level'
send 'local_fire'
)
```
Figure 31: Pseudo-code for the Extinguishing System

5.3 Navigation System

5.3.1 Hardware Configuration

As shown in Figure 32, the navigation system only requires a 20 pin connection as it does not have as many functions as the Master and Extinguisher systems. The Navigations system's main features include control of the tread motion, and communication with the line reader.

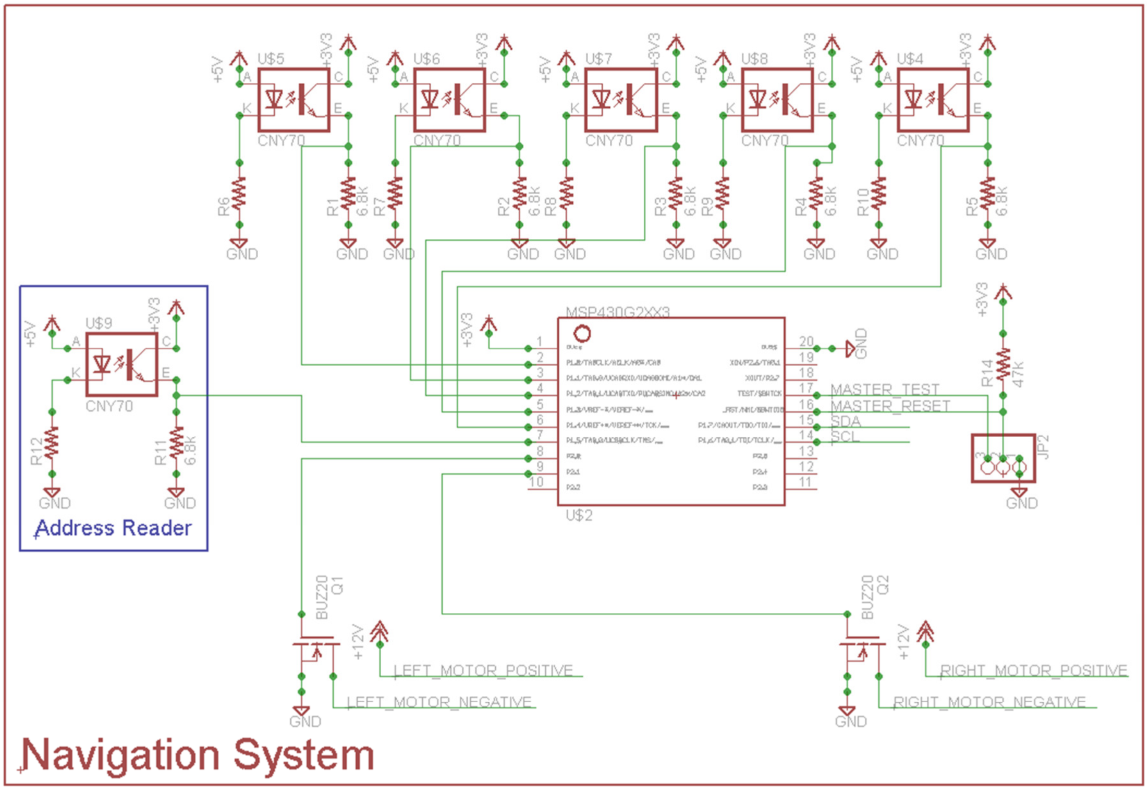


Figure 32: Navigation System Schematic

5.3.2 Steering Mechanics and Algorithm

As shown in the previous Figure 32, pins eight and nine communicate to the left and right motors through the use of a MOSFET to regulate the voltage difference between the 3.3V processor and the required 12V planetary gear motors. The gear motors are planetary gear motors model PGHM-02 created by Lynx motion and provides a torque of 388.85oz-in or 24.303lb-in each. Each motor will be attached underneath the chassis to the tank tread system and installed into the drive wheel to control motion. Steering will be applied to the system by invoking a call from the navigation controller through the MOSFETs to turn them on. For turning, the microcontroller will send a call to specifically one motor and leave the other stopped to allow for sharp turns. A standard DC motor will be installed because the only requirements of the navigation motors will be to move and stop when needed by sending a pulse from the microcontroller directly to the motors input. The pseudo-code guiding the implementation of the steering mechanics, line follower, and address reader is located in Figure 33.

Initialize I^2C
Initialize ADC

main_function(
while(1)(
if (fire=1)(

```
Turn off both drive motors
put the CPU to sleep
)
Turn on both drive motors
set ‘moving’ = 1
Set ADC to channel 0
adc_function(line[0])
Set ADC to channel 1
adc_function(line[1])
Set ADC to channel 2
adc_function(line[2])
Set ADC to channel 3
adc_function(line[3])
Set ADC to channel 4
adc_function(line[4])

if (line[0] == 1)(
// rover is to the right of the line
turn off left motor
turn on right motor
)
else if (line[2] == 1 AND line[3] == 1 AND line[4] == 1)(
// rover is on top of the line
turn on both motors
)
else if(line[4] == 1)(
// rover is to the left of the line
turn off right motor
turn on left motor

Set ADC to channel 5
adc_function(on_addres)
if(on_address==1)(
read_address_function()
)
)
)

read_address_function(
adc_function()
address [0] = line
wait ‘delay’ milliseconds
adc_function()
address [1] = line
wait ‘delay’ milliseconds
adc_function()
```

```
address [2] = line
wait 'delay' milliseconds
adc_function()
address [3] = line
wait 'delay' milliseconds
)

adc_function(
turn on ADC
put CPU to sleep
wake up CPU when ADC is done
if (ADC result > threshold)(
return 1
)
else(
return 0
)

interrupt I2C(
wakeup CPU // depending on how program got here, it may not be sleeping
receive status of the rover from the master processor
send state of 'moving'
)
```

Figure 33: Pseudo-code for the navigation system

5.4 Wireless System

The wireless system will utilize the Roaming Networks RN-42 Class 2 Bluetooth module. This module requires a minor configuration change for the master module; otherwise it will be utilized entirely in its factory configuration. In this configuration, this module connects to the microcontroller via UART and is completely transparent to the microcontroller. Whatever is placed on the UART transmit buffer is sent out the microcontroller, into the RN-42, and over the air to the other RN-42. Whatever data the RN-42 receives is placed on the microprocessor's UART receive buffer. The microprocessor pseudo-code for the master RN-42 is displayed in Figure 34. This excerpt is a function that is periodically called by the main microcontroller. If the wireless modules are in range and connected, they communicate and update each other with their statuses. If the modules are not connected, the function terminates without an error or any indication as it will automatically try again in a short period of time.

```
remote_sensor_status_check(
Check state of P1.3 to determine if wireless is connected
If not connected(
Return to main_function
)
If connected(
```

```
If fire == 2(
UART TX Buffer = 'all clear'
Set fire = 0
Return to main_function
)
If fire == 1(
Return to main_function
)
Ask slave for status
If status == 0(
Return to main_function
)
If status != 0(
Ask slave for its address
Set address = UART RX Buffer
Set fire=1
Return to main_function
)
)
)
```

Figure 34: Wireless function for the master RN-42 Bluetooth module

Figure 35 displays an excerpt of the wireless portion of the pseudo-code running on the remote sensor. This function is entered when the microprocessor detects data on the UART receive buffer.

```
transmit_function(
If UART RX Buffer == status request(
UART TX Buffer = fire
If fire == 1(
Wait for UART RX Buffer == (address request OR 20 seconds pass)
If UART RX Buffer == address request(
UART TX Buffer = address
Wait for UART RX Buffer == 'all clear'
Return to main_function
)
)
If fire == 0(
Return to main_function
)
)
)
```

Figure 35: Wireless function for the remote sensor's RN-42 Bluetooth module

5.5 Remote Sensor

The remote sensor will be placed in a room separate from the rover and will monitor that room for a fire. It contains a Hamamatsu UVTRON, a Roving Networks RN-42, an MSP430G2553, and a power supply. Figure 36 displays the schematic for the remote sensor. When the UVTRON identifies a fire, the LED will turn on and the sensor waits for the main processor to wireless poll its status. Once the remote sensor has given the main processor the fire status, it will wait for an ‘all clear’ from the main processor. This waiting is to prevent the main processor from getting flooded with status updates for the same fire it is travelling to.

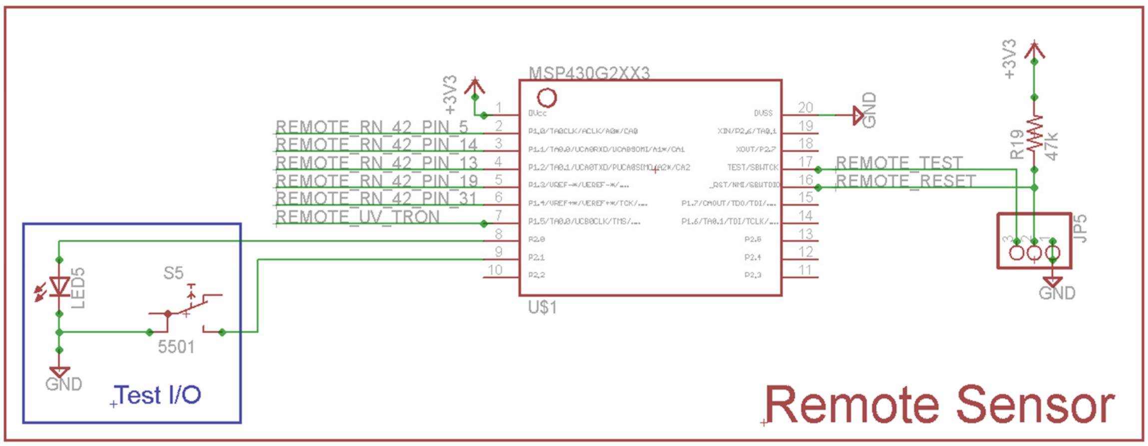


Figure 36: Schematic for the remote sensor

Figure 37, below, displays the pseudo-code for the remote sensor. This module will periodically check the UVTRON to determine if a fire condition exists and updates a global variable. As the HeatSeekr rover makes wireless contact with the remote sensor, this status is transmitted to the rover.

```
Configure Timer A to perform an interrupt every 10 seconds
Configure Timer B to count the frequency pulses from the UVTRON
Configure UART for interfacing RN-42

main_function(
Place microcontroller in low power mode 3
)

timer_A_interrupt_received_function(
Wake up CPU
Determine frequency of pulses from the UVTRON
If frequency > threshold(
Turn on LED indicator
Set fire = 1
Return to main_function
)
```

```
Return to main_function
)

transmit_function(
If UART RX Buffer == status request(
UART TX Buffer = fire
If fire == 1(
Wait for UART RX Buffer == (address request OR 20 seconds pass)
If UART RX Buffer == address request(
UART TX Buffer = address
Wait for UART RX Buffer == 'all clear'
Return to main_function
)
)
If fire == 0(
Return to main_function
)
)
)
```

Figure 37: Pseudo-code for the remote sensor

5.6 Power Supply

HeatSeekr will be powered by a Tenergy 14.8V 5500mAh lithium-polymer battery pack. This battery pack will be connected to a physical switch to power On/Off the entire HeatSeekr rover. This switch will be connected to three self-contained switching voltage regulators. The 3.3 V rail will be established by the Murata Power Solutions 78SR-3.3/2 voltage regulator, the 5 V rail will be established by the Murata Power Solutions 78SR-5/2 voltage regulator, and the 12 V rail will be established by the Innoline R-78C12-1.0 voltage regulator. Figure 38 displays the schematic of the power supply.

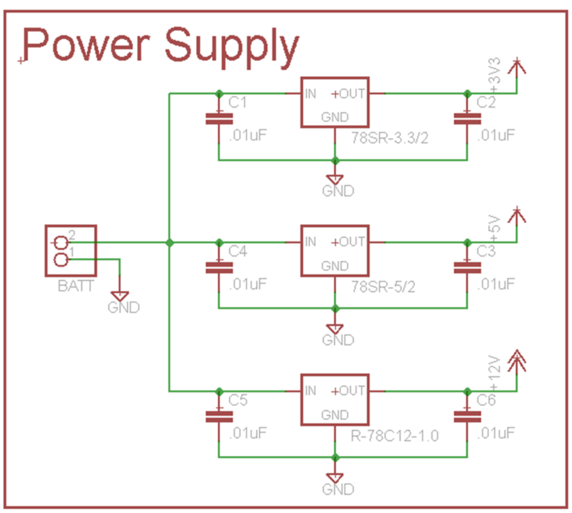


Figure 38: Schematic of the power supply

The power flow chart is shown below in Figure 39. This figure depicts how each individual component will be connected to each rail in the power system. By quantitatively analyzing the power consumption of these devices, the total current draw for each regulator can be determined to ensure all devices are within their specifications.

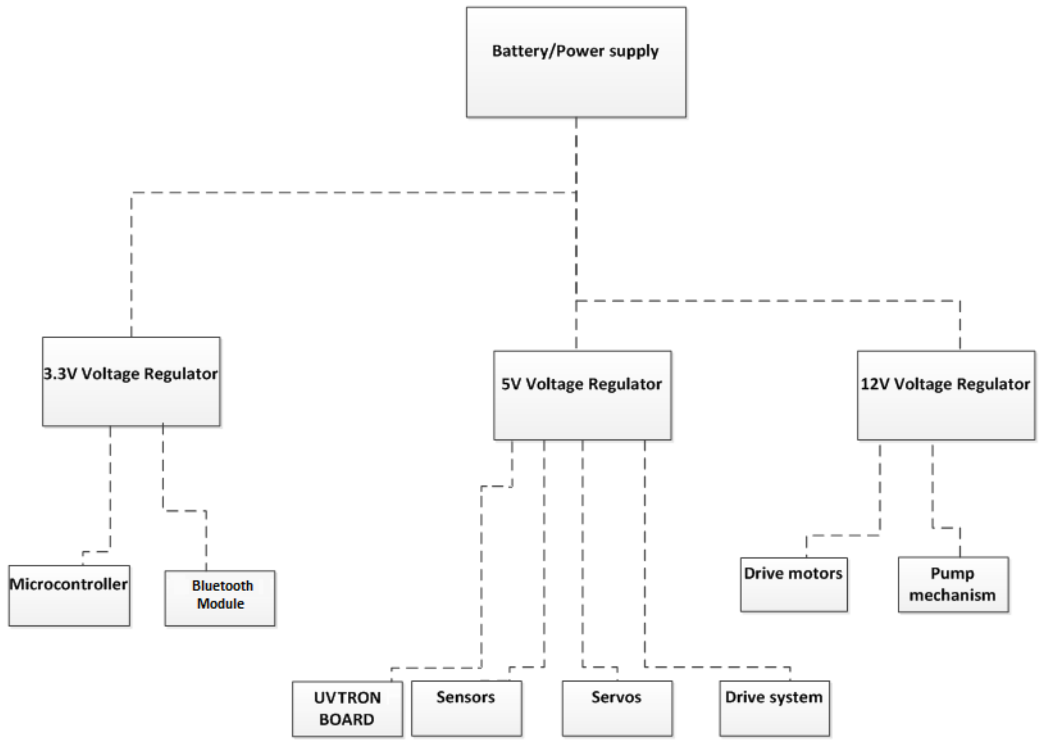


Figure 39: Power flow chart

5.7 Schematic Summary

HeatSeekr's completed microcontroller network will comprise three MSP430 microcontrollers in communication through an I^2C protocol. The master processor with appropriately take the role of the master and periodically request the status of the slave extinguishing system and the slave navigation system. The extinguishing system will constantly be monitoring for a change in frequency from the output of the Hamamatsu UVTRON particle detector, and in seeing a change will update the master processor upon request. The navigation system will monitor the current address being analyzed in the line follower, with the intent of finding the end of line code that signifies that the rover has reached the center of a room with a detected fire. When the navigation system has detected this code, it updates the master processor when it is queried for its status. The master processor constantly checks the status of the wireless module it is attached to; should a flag come from the remote sensor, the master processor will relay the information in the form of the room code to the navigation system, which will check each encountered address for the current code and then proceed to enter the room. The interconnectedness of the microcontroller network is illuminated by a comprehensive and all-encompassing view of the various schematic rendered systems, and this perspective is offered by the schematic summary in Figure 40.

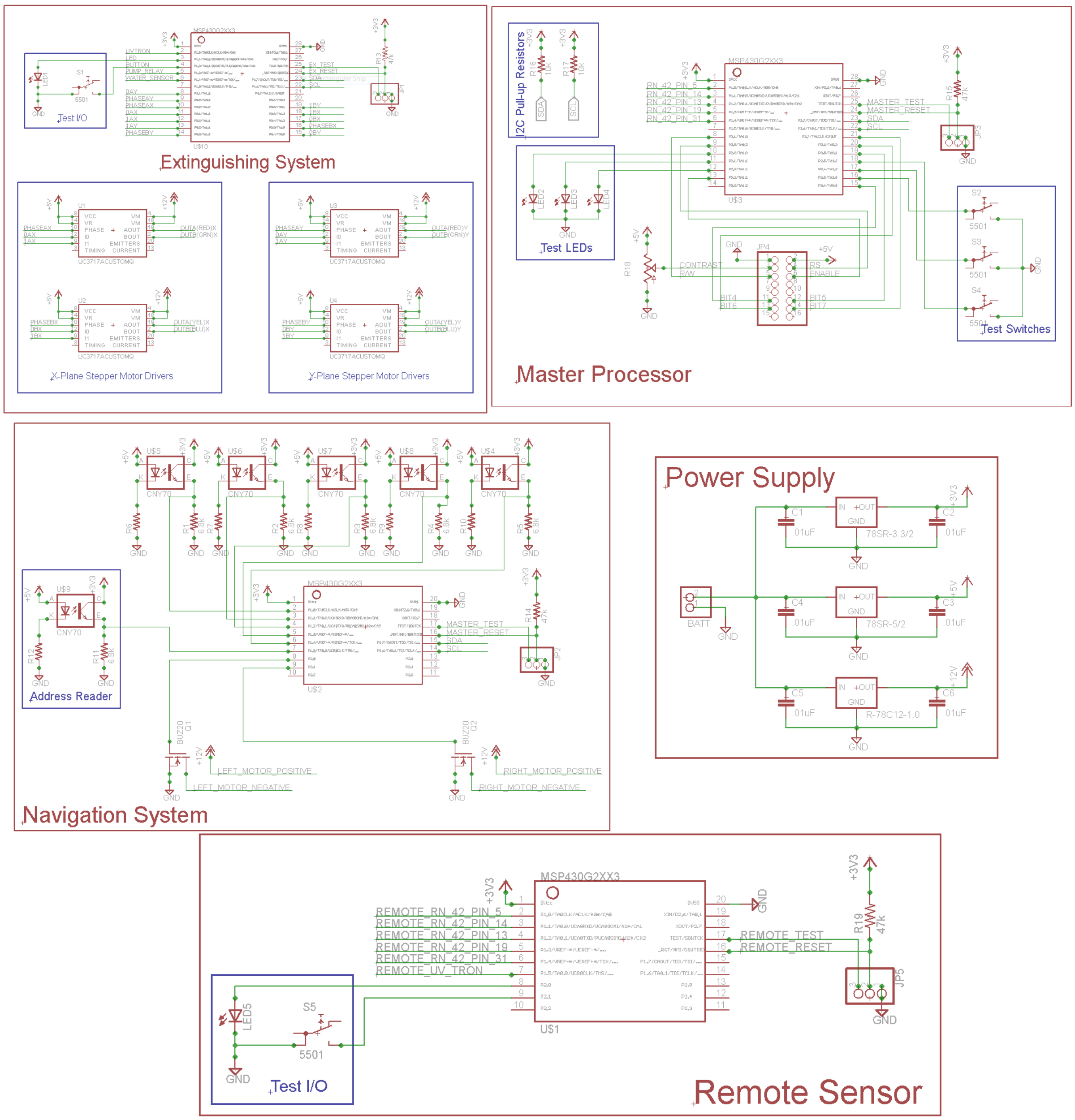


Figure 40: Complete schematic compilation for HeatSeekr, displaying the interconnection of all 3 subsystems, as well as representations of the remote sensor and the power supply for summary completion

6.0 Project Prototype Construction and Coding

6.1 Microcontroller

The microcontrollers and associated parts will be created on a 2-layer PCB design from Advanced Circuits' main website. Advanced Circuits promotes a special discount for college student orders which allows purchase of a $33.00 2-layer PCB board with a maximum size of $60in^2$. The board will be designed such that a portion is completely isolated and can be snapped off. Once finalized and constructed, the mainboard will be attached on top of the water tank for the extinguisher system. While the smaller board will be snapped off to form the board for the Remote Sensor.

6.2 Flame Detector

The concept behind the flame detector's construction is to prevent damage to the C10807 driving board and UVTRON particle detector, limit access to high voltage components, and limit the field of view of the UVTRON particle detector. The driving board and particle detector will be in close proximity to the fire extinguishing hose, necessitating a full enclosure be made between the two modules to prevent water exposure. The driving board acts as a power supply for the UVTRON particle detector, transforming 5V input to 350V output. To meet safety expectations, it is necessary to limit any accidental exposure to the powered UVTRON particle detector, as 350V poses a significant health hazard from the unshielded board. The functional role of the flame detector is that of the field of view limiter for the UVTRON particle detector. The particle detector has a 180° by 180° field of view, and without proper shielding, would be unable to pinpoint the location of a fire. By limiting the horizontal field of view to just a few°, the horizontal location of a fire can be ascertained, and the vertical field of view can be exploited to allow all heights of fires to be combated.

The flame detector comprises the second to highest layer of the rover, sitting above the PCB container and below the fire extinguisher exit nozzle. The UVTRON particle detector and C10807 driving board are contained within the flame detector, and the flame detector is attached to the PCB container by means of the stepper motor, with stepper motor base attached to the PCB container and the stepper motor shaft attached to the base of the flame detector. The flame detector is comprised of two 3.9 in diameter disks comprising the top and bottom of a short cylinder and a 12.2 in x 3.1 in rectangle comprising the shaft of the short cylinder. The UVTRON particle detector and C10807 driving board will be located inside the flame detector module, affixed to the apparatus by means of four screws. An example prototype is depicted in Figure 41.

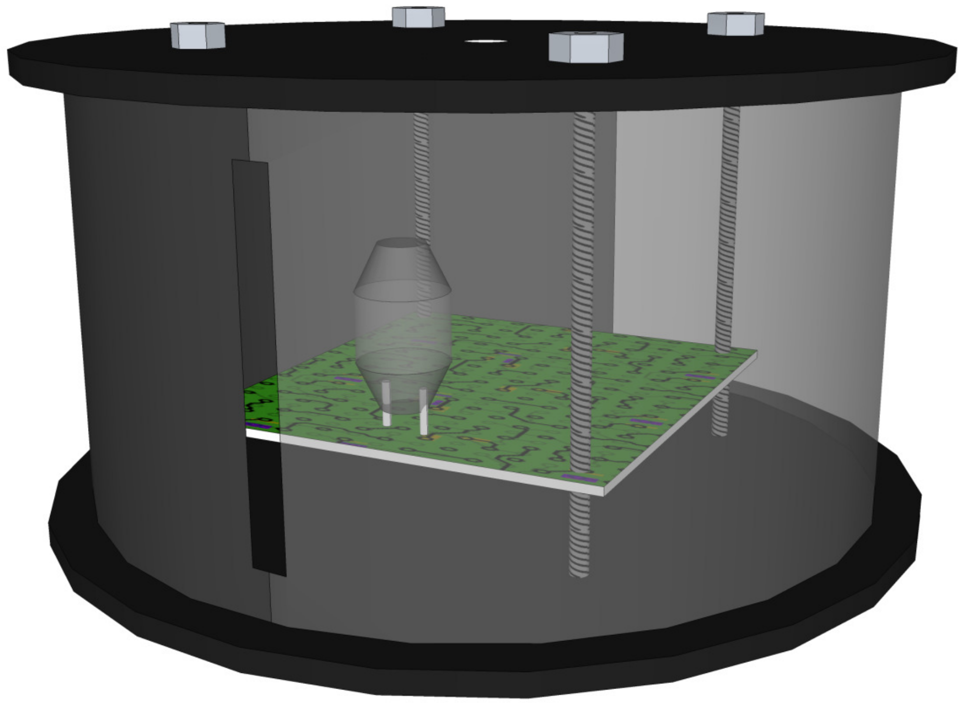


Figure 41: Flame detector rendering showcasing the UVTRON particle detector, C10807 driving board, structural disks, shroud with slit, and screw supports.

The two disks are held together by three 3.1 in threaded screws with four nuts per bolt securing the location of the two disks. Four holes will be made in the top disk to accommodate the threaded screws, with additional holes required to secure the y-radial stepper motor of the fire extinguisher. Five holes will be made in the bottom disk to accommodate the threaded screws, with an additional hole to allow the shaft of the x-radial stepper motor that controls the horizontal sweep of the flame detector and its associated bracket, and additional holes made to accommodate the wires coming from the UVTRON driving board. The UVTRON driving board is secured to the flame detection module by passing the threaded screws through the holes on the board, ensuring that it is rigidly held in place. Four 0.4 in long plastic cylinders will be placed on each of the threaded screws to keep the UVTRON driving board aloft. Three L brackets will be placed on the interior of each disk in order to secure the rectangle shroud to the two disks.

The rectangle acts as the field of view limiting shroud, and thus fully encapsulates the UVTRON particle detector and C10807 driving board. The 12.2 in x 3.1 in rectangle will be made of flexible, infrared opaque plastic that will curve around the three L brackets on each disk to form the shaft of the short cylinder. The center of the rectangle will have a 0.2 in x 2.4 in slit cut out in order to allow UV radiation from potential fires to reach the UVTRON particle detector. The rectangle will be secured to the disks by the six L brackets, ensuring that it maintains its shape and that the slit stays in place.

6.3 Fire Extinguisher

The fire extinguisher occupies a large portion of the rover, comprising the first layer after the chassis as the fire retardant reservoir, an intermittent layer between the PCB board container and the flame detector as the MCP355 Swiftech PC liquid cooling pump, and the highest layer as the extinguisher exit hose and stepper motor. The fire retardant reservoir is secured to the chassis directly, with the PCB board container secured directly to the reservoir. The MCP355 water pump is attached to the back of PCB board container, above the reservoir and below the flame detector and extinguisher exit hose. The extinguisher exit hose goes from the MCP355 to the stepper motor located on top of the flame detector, where the fire retardant can be directed and expelled.

The fire retardant reservoir takes the form of a cubic rectangle composed of six acrylic panels held together with adhesive. The completed cubic rectangle takes on the dimensions 12 in x 7 in x 6 in, and is capable of holding 2.18 gallons of water. Affixed to the bottom of the reservoir is an exit nozzle to attach to the input hose for the MCP355. The nozzle is constructed by boring a hole in the bottom acrylic plate and securing a water tap into place with sealant. A similar procedure will be followed to allow an entry port on the top of the reservoir to accommodate refilling, though in place of a water tap a simple screw-on pipe shunt will be affixed, to prevent spillage.

The MCP355 water pump will comprise the mid-point of the fire extinguishing system, and is located above the reservoir. Screwed into a horizontal face of the PCB board housing, the water pump will be located on the back of the rover, with wiring to the extinguishing microcontroller routing through the main exit hole of the PCB board housing. The MCP355 water pump will have an exit hose leading up to the y-radial stepper motor: this hose will be roughly 8 inches longer than necessary to make a straight line to the stepper motor. This procedure will be followed in order to allow the fire detector to have full x-radial motion while scanning for fires.

The exit point of the fire extinguisher system begins with the exit hose leading from the MCP355 exit port. The hose is free to move and has roughly 8 inches of slack to accommodate the motion of the fire detection system. The hose is fitted to a bracket that secures the last inch of the hose with a metal friction tie. The bracket is connected directly to the y-radial stepper motor from the extinguishing microcontroller, which is screwed into the top disk of the fire detector housing. The system is designed to allow the fire detection system to specify the x-radial location of the fire through the fire detection algorithms; this specification places the exit hose of the fire extinguisher in the correct x-radial direction. Through a programmed algorithm, the y-radial stepper motor will alternate between a 90° arc of motion, liberally applying fire retardant to surfaces in an area encompassing a cubic rectangle roughly 0.4 inches in width, by 118 inches in height, and 177 inches in length, ensuring that the entire horizontal area specified by the x-radial motor is in the fire extinguishing range. Figure 42 depicts a prototype view of the exit portal of the fire extinguisher.

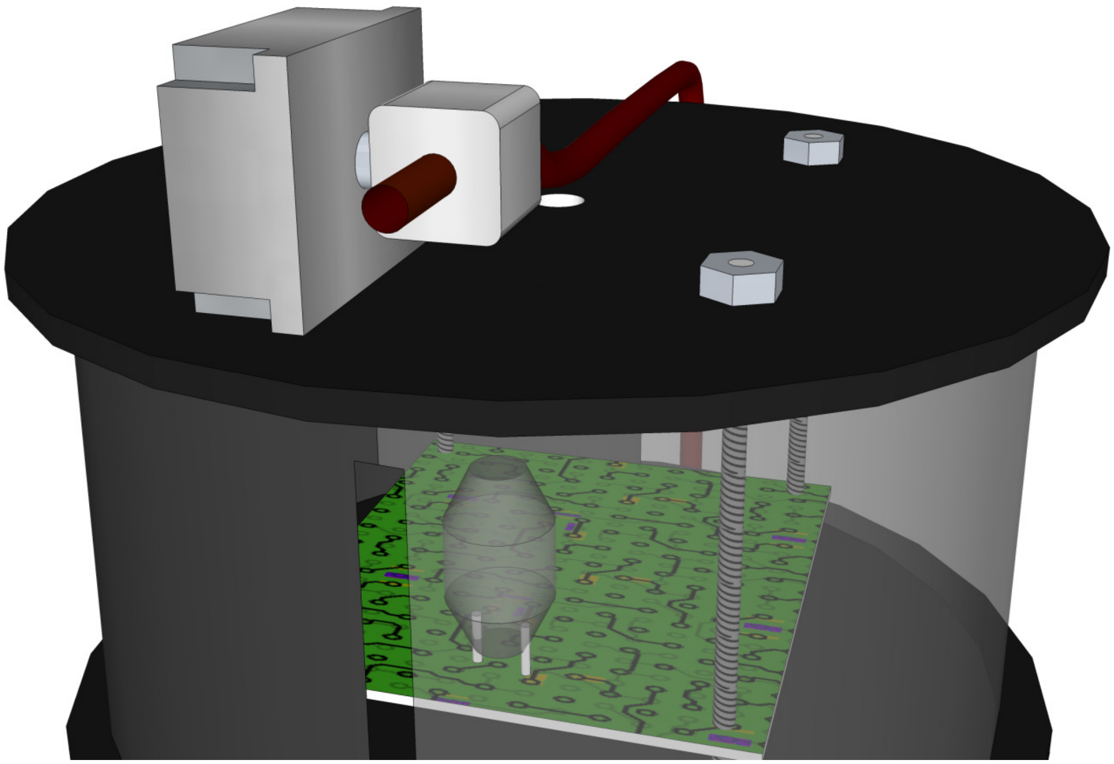


Figure 42: Exit portal rendering showcasing the stepper motor controlled exit hose

6.4 Water Tank

The water tank will be created from Plexiglas and mounted to the top of the chassis. Since the chassis dimensions will be 12.592in x 7.598in, the tank will be of size 12in x 7in x 6in for a total volume of 504in^3. Since one gallon of water fits in 231in^3, the tank will have capacity for 2.18 gallons of water weighing at 8.34lbs per gallon for a total maximum weight of 18.196lbs. For general operation, the tank is not to be completely full to prevent water spillage from sudden acceleration and deceleration from navigating to its different locations. It is estimated that the tank should have a standard load between 1.25gallons and two gallons for an average weight of 10.425lbs to 16.68lbs.

The Plexiglas for the tank's construction will require a total surface area of 396in^2 with the longest side being 84in^2 with dimensions 12in x 7in for the top and bottom of the tank. HomeDepot sells a 12in x 24in LEXAN sheet of Plexiglas with a thickness of .22in for $12.98 each. The impact strength of this Plexiglas is .4lbs/in which allows for the maximum weight of 18.196lbs to be distributed by the 84in^2 of the bottom base resulting in an impact of .217lbs/in. two sheets for $25.96 will have a total surface area of 579in^2 and can be reduced into one sheet providing both 12in x 7in sides and a 12in x 6in side with a section 12in x 4in leftover, and the 2nd sheet will provide the last 12in x 6in side and both 7in x 6in sides with a 6in x 18in and 6in x 7in section leftover. HomeDepot's lumber section will be able to provide the power tools necessary for accurately cutting the sheets to these specifications. Once each piece is cut, they will be joined together by solvent cement.

6.5 Water Level Sensor

The water level sensor probes will be screwed into the side of the water tank, close to the bottom. The exact placement will be determined after analyzing the real-world results of the duration of extinguishing and the amount of water consumed for extinguishing. These trials need to be run before placement so the maximum amount of water in the tank is utilized while at the same time, the rover will not attempt to put out a fire if it knows it won't have enough water to do so.

6.6 Line Follower

The line follower consists of a rectangle of perfboard containing five CNY70 reflective optical sensors, their respective resistors, microcontroller output wires, and power rail access wires. This module will be suspended underneath the chassis of the rover, separate from the main PCB located above the fire retardant reservoir. Thus, the line follower will represent the layer of design closest to the ground, in other words, the first layer of the robot, followed by the chassis, reservoir, etc. The method of suspension will consist of two threaded screws passed through symmetric holes located at opposite ends of a plastic project box containing the rectangular perfboard. The screws will be of slightly shorter length than the radii of the wheels used in the locomotion system, placing the line follower within a centimeter of the ground. This placement decreases the chance of the emitter portions of the CNY70 sensor packages interfering with transistor portions of adjacent CNY70 packages.

The plastic project box containing the perfboard will be large enough to contain a volume defined by 2 in width by 1.2 in depth and 0.79 in height. The purpose of the project box is to securely house the CNY70 array perfboard, preventing mechanical damage from obstructions on the track and any water spillage should a hose leak. The project box also relieves stress from the perfboard by moving the suspension support screws from the perfboard to the box. The bottom surface of the plastic project box will have a slit made in it to allow the CNY70s to project outwards in a line, giving them clearance from the box and allowing close proximity between the sensors and the ground. The rear horizontal surface of the plastic project box will contain a hole to allow for the output wires destined for the microcontroller and the input wires used for powering the array. The screws projecting thread-first from the plastic project box will be secured on the chassis using nuts and washers. Figure 43 depicts a prototype view of the plastic project box housing the CNY70 array.

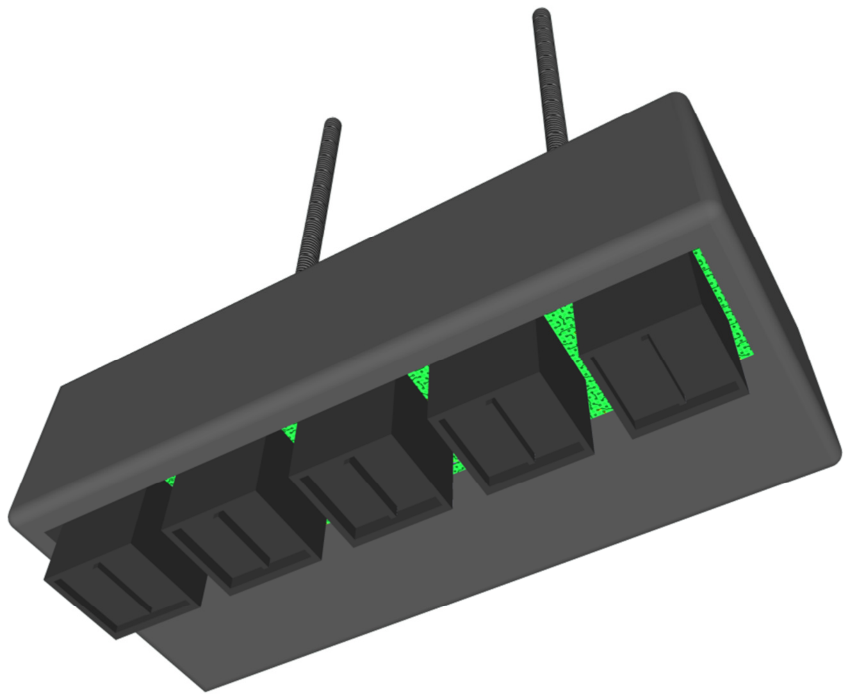


Figure 43: Prototype view of plastic project box housing the line follower CNY70 array

The five CNY70 optical sensors will be arrayed in a 1 x 5 formation, with the array being oriented as perpendicular to the travel direction of the rover. The optical sensors themselves will be oriented with the divider between the emitter and transistor pair being parallel to the travel direction of the rover. This is due to the nature of the predicted deviations from the line path being perpendicular to the direction of travel.

6.7 Address Reader

The address reader is essentially a re-oriented 1 x 1 CNY70 array version of the line follower. Similar to the line follower, the address reader is enclosed in a protective plastic project box to prevent exposure to environmental hazards. Contained within the project box is the perfboard containing the resistors, microcontroller output wire, and power rail access wire to serve the CNY70 sensor. Located several inches to the right of the line follower and rotated 90°, the address reader project box is suspended from the underside of the rover chassis by a single screw slightly shorter than the length of a wheel radius to ensure that the address reader is within an inch of the area reserved for the address markers. Figure 44 depicts a prototype view of the plastic project box housing the CNY70 sensor.

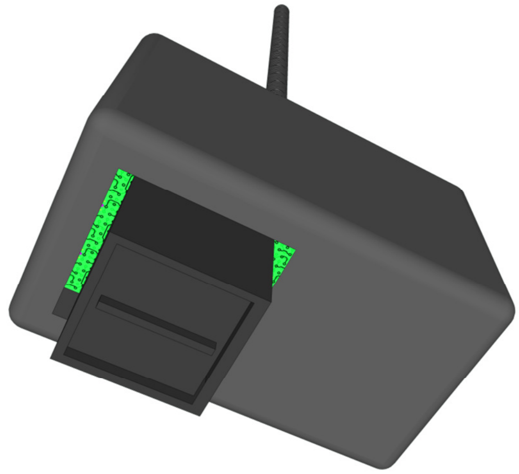


Figure 44: Prototype view of plastic project box housing the address reader CNY70 sensor

6.8 Navigation System Construction

The Vex robotics tank tread kit comes complete with instructions for installing all navigational motors and treads onto the chassis. It contains four tank tread drive/idler wheels, four bogey wheel assemblies, two single bogey wheel assemblies for tension, 12 bogey wheel support screws and nuts for attachment to the chassis, and two tank tread links with length adjustment of up to 32.75".

For each chain, the support structure for the chassis will be set up with axles separated by 11 open holes for other pieces. Of the two axles, the rear axle will be connected to one of the planetary gear motors. Two bogey wheel assemblies will then be attached with four screws and nuts to the chassis leaving two open holes between each axis and the bogey wheel assembly. In between the two bogey wheel assemblies, single bogey wheel assembly for tension will be inserted flush with the right bogey wheel assembly and secured with two screws and nuts. This tensioner will allow adjustment of the tracks once the entire system has been assembled. After the tensioner has been secured, the mount drive wheels can be installed on each axle and the tread links can easily wrap around the rest of the wheel system with the teeth of the drive wheels running mesh with the rollers on the links. Once the links are fully connected in a closed loop, the tensioner can be loosened and repositioned upwards so that the links are tightened into place to prevent them from sliding off during motion. A prototype rendering the completed chassis and tank read assembly is provided in Figure 45.

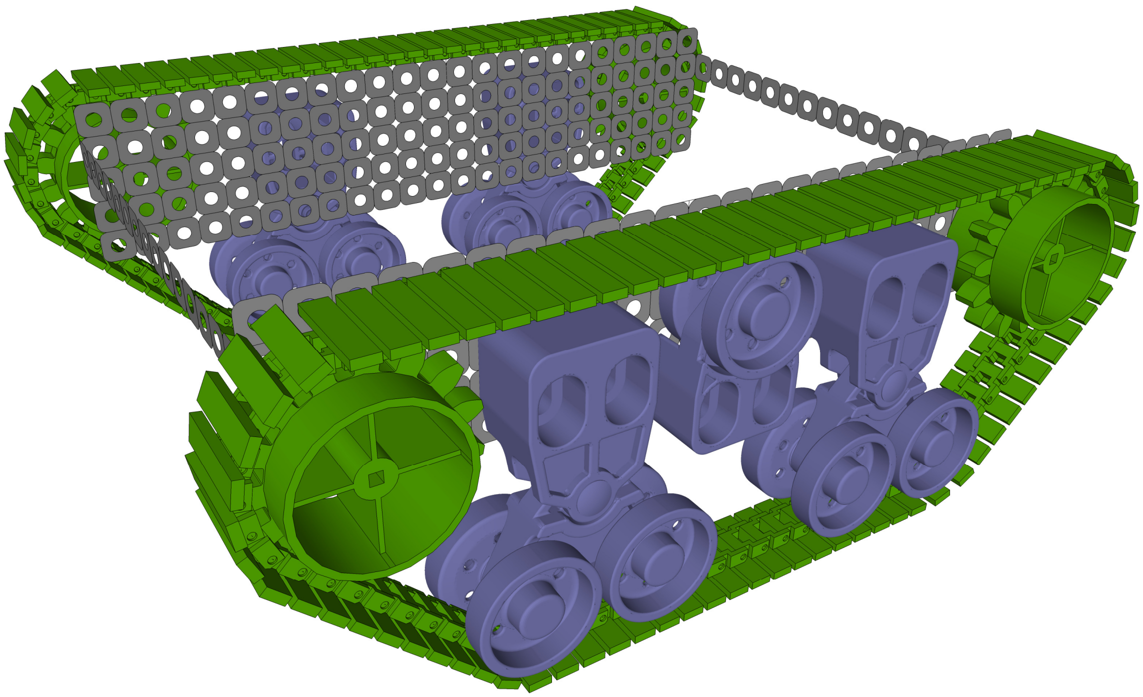


Figure 45: Prototype view of the completed VEX tank tread system and chassis

6.9 Wireless System

The wireless system is a self-contained surface mount module. Therefore the module will have its own pad on every PCB that requires wireless. Caution will need to be advised during PCB layout to prevent or limit the number of traces that route next to the PCB trace antenna on the wireless module.

6.10 Prototype Summary

The completed HeatSeekr prototype is projected to weigh roughly 30 pounds when the fire retardant reservoir is full, with the 2.18 pounds of water constituting 18 pounds to the total weight of the system. The rover will stand at roughly 20 inches, including the pillar on which the flame detector is situated. HeatSeekr is project to be 10 inches wide and 14 inches long, with the bulk of the dimensions coming from the water tank situated in the center of the rover. A prototype summary is presented Figure 46, showcasing a mockup of the completed HeatSeekr prototype.

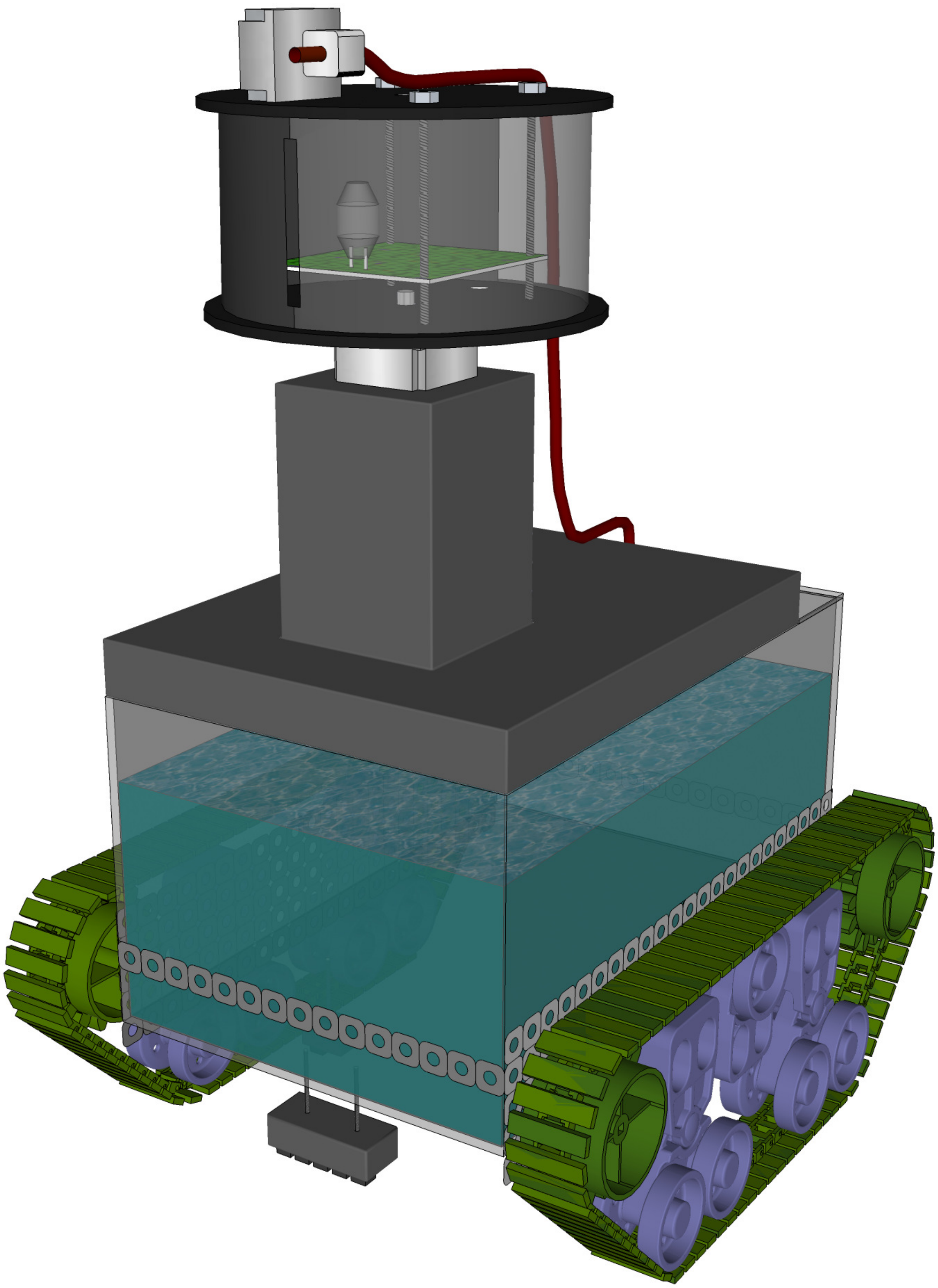


Figure 46: Summary prototype representation of HeatSeekr

7.0 Project Prototype Testing

7.1 Microcontrollers

Each subsystem will be initially tested independently, as described in the next sections, of the master and slave specifications before proper implementation. To do this, a microcontroller will be programmed with its basic functions and commands and hooked to a breadboard to implement the PCB circuit. At this point, each system will undergo a series of testing to verify that all systems are working correctly independently of the other systems. Once a system has completed its testing and all project specifications have been met, the system will be added to the master and slave system with the master processor. At this point, testing of the master processor can begin by sending input data from the master processor breadboard to each other system. Once each system has shown individual successful testing with the master processor, all of the systems will be combined together to successfully demonstrate the fully working master and slave system. At this point, each system will be tested once again to verify that no other system is interrupting another system during operation. Once all specifications have been met for the project, then a finalized schematic and PCB layout can be created and mounted to the HeatSeekr's chassis.

7.2 Flame Detection

7.2.1 Detection Range

The fully assembled Hamamatsu UVTRON particle detector and C10807 driving board connected to the MSP430 will constitute the hardware union required to test the detection range. Fully enclosed in its shroud, the flame detector should ideally detect flames directly within its narrow horizontal field of view and wide vertical field of view. The testing environment for this particular test will be in the standard classroom setting. The testing procedure will involve setting the fire flag override as toggled by one of the push buttons connected to the overlord microcontroller, which mimics the flag set by the stationary hanging detector when it detects a fire from its personal UVTRON particle detector and C10807 board and sends the room code and fire flag to the rover. Next, the positioned reached flag will be set by pressing the corresponding push button on the overload microcontroller, mimicking the flag set by the navigational microcontroller indicating that the rover has proceeded to the center of a room and is ready to start scanning. The rover is now in testing posture and variables can now be defined and varied.

The detected signal for this prototype testing will take the form of an un-shrouded, naked sample flame. The ultraviolet phenomena detectable by the UVTRON include flames and high voltage ionizations, but flames were chosen to be tested due to the applications of the rover. The sample fire will take the form of a medium sized tea candle with sloping sides so as to not block a view of the flame from various vertical positions. The specifications for the Hamamatsu UVTRON particle detector make mention of the ability of the UVTRON to detect fires as small as cigarette flames from a distance of 16.4 feet: for the purposes of this test, the flame from a medium sized tea candle is assumed to qualify and exceed this minimum flame.

The variables for the detection range prototype testing are the radial, distance, and vertical locations of the sample fire, with the latter being the first to be varied. The typical height of a classroom is roughly 8.2 feet, and as stated in the research section, the type of fires expected to be combated safely by the rover would mostly occur in the lower half of a room's height. Thus testing will involve placing a candle on the ground floor level and at half the room's height. The purpose of this range test is to determine whether the vertical sensitivity of the UVTRON particle detector meets the specifications while in the field of view limiting shroud.

The radial testing will involve placing the sample fire at the same distance and vertical location, but at different radial locations with reference to the entrance track of the rover. Radial locations to be tested include a fire near the entrance track, defined as 0°, a fire opposite the entrance track, defined as 180°, and a fire perpendicular to the entrance track, defined as 90°. The designed scanning mechanic should ensure that each location is covered in the standard room sweep.

The final range testing variable will be distance, and will be the most telling of the rover's capabilities. The sample fire will be placed on the same radial and vertical position in the room, but at different distances from the rover. The testing room will have this maximum vertical distance measured and divided into 3 equal distances, with the fire tested at the end of each of these distances.

Success for the prototype testing will be indicated by the testing LED located on the extinguishing microcontroller. This LED is set to turn on when a fire is detected, and so will be monitored during the testing procedure to determine whether the various ranges, distances, and radial locations were in the rover's field of view.

7.2.2 Detection Environment

The fully assembled Hamamatsu UVTRON particle detector and C10807 driving board connected to the MSP430 will constitute the hardware union required to test the detection environment. The detection environment is defined as the lighting conditions of the room where fire detection is expected to take place. The user manual for the Hamamatsu UVTRON particle detector states that fire detection should be possible even under direct sunlight. The testing environment for this particular test will be in the standard classroom setting, and an outdoor setting to mimic the maximum expected sunlight from window factor. The testing procedure will involve setting the fire flag override as toggled by one of the push buttons connected to the overlord microcontroller, which mimics the flag set by the stationary hanging detector when it detects a fire from its personal UVTRON particle detector and C10807 board and sends the room code and fire flag to the rover. Next, the positioned reached flag will be set by pressing the corresponding push button on the overload microcontroller, mimicking the flag set by the navigational microcontroller indicating that the rover has proceeded to the center of a room and is ready to start scanning. The rover is now in testing posture and variables can now be defined and varied.

The sample lighting in the classroom will include full fluorescent lighting, mimicking daytime indoor fire detection, and as close to complete darkness as possible, mimicking the worst case nighttime indoor fire detection scenario. The sample lighting outdoors will only test noontime sunlight levels, preferably on a relatively clear day. This level of lighting is assumed to test whether the rover can detect fires in a room with windows banking several walls, each allowing sunlight to enter the room.

The detected signal for this prototype testing will take the form of an un-shrouded, naked sample flame. The sample fire will take the form of a medium sized tea candle with sloping sides, similar to the sample flame from the distance range test. Because the benchmark for the UVTRON particle detector is a cigarette flame, and because the device is claimed to only allow wavelengths typical of flame and high voltage ionization frequencies, this sample flame is assumed to be a valid testing variable.

Testing will involve placing the flame at the same distance, radial location, and height from the rover for each test, varying only the light levels between tests. For this particular test, the sample flame will be placed at the height of the sensor, directly in front of the rover at a distance of 4.9 feet. The testing LED on the extinguishing microcontroller will be observed to determine the results of the test. When the set-up procedure has been followed, the rover will initiate scanning protocol and, should the test be successful, stop on the flame and trigger the LED. Unsuccessful tests will be observed as a forever repeat of the scanning mechanic.

7.2.3 Pinpoint Speed

The fully assembled Hamamatsu UVTRON particle detector, C10807 driving board connected to the MSP430, and the stepper motors will constitute the hardware union required to test the detection environment. When the fire detected flag and the position reached flag have been set by the overlord microcontroller and the navigational microcontroller respectfully, the extinguishing microcontroller will initiate the scanning algorithm, which combines a step by step varying of the direction in which the field of view of the scanner is pointing while simultaneously checking the status of the flame detector for detected fires. In order to meet specifications, this scanning algorithm must find the flame in the room within 20 seconds, representing requirements of both the algorithm and the hardware.

For the purpose of this test, three distinct locations will be chosen for sample fire placement in order to test the scanning algorithm. These locations correspond to the starting, ending, and midpoint scanning locations. These radial locations will have constant height and distance, as these two variables should not factor into the pinpoint speed. The constant height will be the height of the sensor and the distance will be 4.9 feet. The sample fire will take the form of a medium sized tea candle with sloping sides, similar to the sample flame from the previous detection range and environment tests. As this is a test of the algorithm and hardware, it is not necessary to test the limits of flame detection by the UVTRON particle detector as in the other two tests. As a result, the lighting environment will be a sample room with normal fluorescent lighting.

Testing procedure will involve setting the flags externally through the use of the pushbuttons on the navigational and overlord microcontroller, and then monitoring the testing LED on the extinguisher microcontroller to determine when the scanning algorithm has detected the fire. A timer will be used to determine the moment when the scanning algorithm starts and the moment the fire is detected in order to determine the time it takes for the algorithm to pinpoint the fire. As mentioned earlier, the specification is 20 seconds.

7.3 Fire Extinguisher

7.3.1 Extinguishing Range

The fully assembled MCP355 Swiftech PC liquid cooling pump, fire retardant reservoir, fire retardant delivery hose system, and the MSP430 will constitute the hardware union required to test the extinguishing range. Nestled behind the PCB container, the MCP355 should ideally propel a column of water through the exit hose and reach a maximum distance of 14.7 feet in concert with the firing algorithms in the MCP355. The testing environment for this particular test will be any level outdoor environment. The testing procedure will involve setting the fire flag override as toggled by one of the push buttons connected to the overlord microcontroller, which mimics the flag set by the stationary hanging detector when it detects a fire and sends the room code and fire flag to the rover. Next, the positioned reached flag will be set by pressing the corresponding push button on the overload microcontroller, mimicking the flag set by the navigational microcontroller indicating that the rover has proceeded to the center of a room and is ready to start scanning. The rover is now in testing posture and variables can now be defined and varied.

The pass/fail criterion for this testing procedure will be the extinguishing of a sample flame. The fire extinguishing system should be capable of handling larger fires, but for distance testing purposes, the sample fire will be defined as follows. The sample fire will take the form of a medium sized tea candle with sloping sides so as to not block a view of the flame from various vertical positions. The medium tea candle will require adequate water in order to be extinguished: for the purposes of this test, the flame from a medium sized tea candle is assumed to qualify.

The variables for the extinguishing range prototype testing are the radial, distance, and vertical locations of the sample fire, with the latter being the first to be varied. The typical height of a classroom is roughly 8.2 feet, and as stated in the research section, the type of fires expected to be combated safely by the rover would mostly occur in the lower half of a room's height. Thus testing will involve placing a candle on the ground floor level and at half the room's height, simulated in the field with an elevated platform set at roughly 4.9 feet. The purpose of this range test is to determine whether the firing pattern from the MSP430 can adequately cover the specified fire extinguishing area.

The radial testing will involve placing the sample fire at the same distance and vertical location, but at different radial locations with reference to the entrance track of the rover. Radial locations to be tested include a fire near the entrance track, defined as 0°, a fire opposite the entrance track, defined as 180°, and a fire perpendicular to the entrance track, defined as 90°. The designed scanning mechanic should ensure that each location is covered in the standard room sweep.

The final range testing variable will be distance, and will be the most telling of the rover's capabilities. The sample fire will be placed on the same radial and vertical position in the room, but at different distances from the rover. The testing area will have 14.7 feet measured and divided into 3 equal distances, with the fire tested at the end of each of these distances. Success for the prototype testing will be indicated by the total extinguishing of the sample fire.

7.3.2 Efficiency

The fully assembled MCP355 Swiftech PC liquid cooling pump, fire retardant reservoir, fire retardant delivery hose system, and the MSP430 will constitute the hardware union required to test the efficiency of the fire extinguisher system. Together with pre-programmed firing algorithms, the MCP355 based fire extinguishing system should be able to extinguish detected fires under the specified 15 seconds and with using less than 1/4th of the total water capacity. When the fire detected flag and the position reached flag have been set by the overlord microcontroller and the navigational microcontroller respectfully, the extinguishing microcontroller will initiate the scanning algorithm, detect the fire, and then begin the process of extinguishing, which combines a step by step varying of the direction the fire nozzle is being pointed in while sending a voltage to the relay controlling the MCP355 pump's power. Meeting the required specifications imparts a necessary level of proficiency on the level of hardware and algorithm combined.

For the purpose of this test, three distinct locations will be chosen for sample fire placement in order to test the scanning algorithm. These locations correspond to the minimum range, medium range, and maximum range of the pump, corresponding to a sample flame 5 feet distant from the rover and located on the ground, a sample flame 10 feet distant and located at 2 feet height, and a sample flame 15 feet distant at a height of 3 feet. These locations will have constant radial location, as these variables should not factor into the extinguishing efficiency. The constant radius will be the direction directly between the starting and ending radial location of the scanner. The sample fire will take the form of a medium sized tea candle with sloping sides, similar to the sample flame from the previous extinguishing range tests.

Testing procedure will involve setting the flags externally through the use of the pushbuttons of the navigational and overlord microcontroller, and then monitoring the status of the rover to determine when it has detected that the flame has been extinguished and the fire extinguisher should be turned off. A timer will be used to determine the moment when the fire extinguisher starts and the moment it stops to determine the time efficiency of the extinguisher. After each test, the amount of water remaining in the rover will also be taken note of, to determine whether the rover meets the water use specifications. As mentioned earlier, the specification is 15 seconds and less than 1/4th total water capacity usage.

7.3.3 X and Y axis Rotation Specifications

The two Nema 16 step motors for the X and Y axis rotations are to be connected to the navigational microcontroller through the use of two H-bridges each. For testing purposes, the motors will not be mounted onto the water tank's surface until they have been shown to successfully meet all specifications. The X axis motor is expected to push a heavier load through the system as it will move the UVTRON's shield and Y axis motor mounted above it, so it will be have a heaver load attached to its axle than the Y axis motor. Once the motors are connected to the microcontroller through a breadboard and H-bridges, the microcontroller will send commands to show that the motors are moving forward and backwards as expected.

Each stepper motor will be making incremental movements at 1.8° per step; however, since the Y axis motor is located above the UVTRON shield and controls the angular flow of water from the nozzle, it will be limited to a certain range of step movement to prevent water pouring directly into the UVTRON and ruining equipment. For this reason, the Y axis will be initialized with the nozzle pointing at 90° of the UVTRON's shield. With a step turn of 1.8°, 50 steps will have it pointing directly down at the UVTRON. To prevent this, the Y axis will be permitted to move only 60° away from its initialized location. This will allow a 30° leeway preventing the water from splashing directly into the UVTRON, and allow for theoretical maximum angle of 45° from a horizontal plane and up to 60°. The amount of steps each motor will require to move 60° is 33.33 steps, so a limiting constant of 33 will be used in the Y axis coding to prevent movement beyond this 120° range.

Once the motors are moving as expected, the water pump will be installed to the Y axis, and the Y axis will be added onto the X axis to verify that the water pump is not pushing the X or Y axis out of position. Since the water pump will be spraying a steady stream of water up to two gallons, the system must be verified that creating an explosive force at the Y axis does not send either axis off course and cause the extinguisher system to lose accuracy. Verification that the X and Y axis maintain position will be required before allowing the system to progress further. If either axis not be able to maintain a steady position during water spray, then recalculation of the X and Y axis positions will be required.

7.4 Wireless System

It is anticipated that the wireless system is going to be one of the most quarrelsome sub-systems of HeatSeekr. To mitigate any issues that pop up, the wireless system will be tested as thoroughly as possible while the project is still in the breadboard stage of assembly. The first challenge will be to ensure the RN-42 and the microcontroller are able to communicate over UART. This will be tested by leaving the RN-42 in its default factory state, connecting the module to a host computer via Bluetooth, connecting the module to the UART interface of the microcontroller and executing the pseudo-code in Figure 47. With this code running on the microcontroller, a terminal window can be opened on the host computer to send data to the RN-42 over Bluetooth. Once the connection has been established, the user will simply type the capital letter 'A' in the terminal. The expected result will be a capital 'B' displayed in the terminal and LED 1 should illuminate. Additionally, the LED connected to GPIO8 on the RN-42 should blink as Bluetooth traffic is exchanged.

```
Initialize UART
Initialize RN-42
Setup LED 1

main_function(
While (UART RX buffer == empty)(
Do nothing
)
If (UART RX buffer == 'A')(
Turn on LED 1
Set UART TX buffer = 'B'
)
)
```

Figure 47: Pseudo-code for testing the ability to transparently send data wirelessly

The next test will be to ensure two RN-42's can establish a connection and communicate with each other. This test will require two RN-42's and two microcontrollers. One of the RN-42's will need to be configured to operate as a master. Each Bluetooth module will need to be connected to the UART of a microcontroller. The master microcontroller will receive the pseudo-code in Figure 48 while the slave microcontroller will receive the pseudo-code in Figure 49. The expected result is that both LEDs will remain off until the switch on the master is pressed. Once that is pressed, the master will transmit data to the slave. If the slave receives the data it will turn on its LED. The slave will then transmit data back to the master. If the master receives the data it will turn on its LED. This test will be repeated several times with the devices further and further apart, as well as with a differing amount of walls between them. Finally, this test will be repeated with the program starting while the devices are in range of each other, the devices will go out of range, and then brought back into range before pressing the button. This final test will ensure the Bluetooth modules are able to autonomously reconnect as soon as their signals are close enough.

```
Initialize UART
Initialize master RN-42
Setup LED 1 and switch 1

main_function(
While (switch 1 != pressed)(
```

```
Do nothing
)
Set UART TX buffer = 'A'
While (UART RX buffer == empty)(
Do nothing
)
Turn on LED 1
)
```

Figure 48: Pseudo-code for testing the communication between two RN-42 modules, Master

```
Initialize UART
Initialize master RN-42
Setup LED 1

main_function(
While (UART RX buffer == empty)(
Do nothing
)
Turn on LED 1
Set UART TX buffer = 'B'
)
```

Figure 49: Pseudo-code for testing the communication between two RN-42 modules, Slave

7.5 Water Level Sensor

Due to its simplicity, this sub-system is not anticipated to cause any issues, therefore it only requires a simple test. Figure 50 contains the pseudo-code for this test. With the code executing on the microprocessor, a wire from pin 2 and a grounded wire will be dipped into water. When the wires are in the water, LED 1 should turn on. When the wires are removed from the water, LED 1 should turn off.

```
Setup LED 1
Turn on pull up resistor 2

main_function(
While (Pin 2 == 1)(
Turn off LED 1
)
While (Pin 2 == 0)(
Turn on LED 1
)
```

Figure 50: Pseudo-code for testing the water sensor

7.6 Remote Sensor

Most of the component testing for the remote sensor will have been performed from the individual component tests. For example, when the remote sensor is assembled, the wireless system will have already been tested. Therefore there are only two operational tests the remote sensor will require. The first test is to ensure the production wireless code executes successfully. This test will be performed by pressing the push button on the remote sensor. This button will be coded to act as if a fire was detected. The expected result, therefore, is for the LED to turn on and for the main processor to change states from roaming to trying to locate the room at the address the remote sensor gave it. Once that operation has been fully debugged, the second test required is to ensure the entire device operates successfully. This is accomplished by placing a fire in front of the remote sensor's UVTRON sensor. The expected result is the same as before, the LED should illuminate and the rover should attempt to navigate to the fire.

7.7 Navigation System

7.7.1 Navigational Hardware

The two planetary gear motors for the right and left movement control for the navigational tread system are to be connected to the navigational microcontroller through the use of two MOSFETs. Each motor will be mounted onto an axis on one of the tank tread chains, and allow for movement to be applied when invoked by the navigational microcontroller. Since each motor is expected to move independently and together at the same time, function testing of driving straight and turning methods must both be accounted for. Once the system has shown that the microcontroller calls and motor coding complete all specifications, the system will be applied to the main chassis and tire treads for weight load testing. Before creating and implementation of the water tank is installed, the system will be required to move weights to simulate a fully load water tank. The testing will begin with a five pound weight and involve a series of testing to ensure that the navigational system is capable of driving forward, turning, and transferring from a tile floor to carpet or driving over a doorway's floor base. Once testing for five lbs has proven successful, the weight load will be increased in increments of five until a maximum weight that causes stalling will occur. This value will be stored as design specifications for a maximum load for further development if needed. Once the maximum load is found, the water tank system will be implemented and tested to determine how much water spillage will occur while in motion. Since water will be actively moving with the system, it is essential that no water be spilled from the water tank while in motion or coming to a complete stop. If water does spill out, the acceleration and deceleration of the navigational motors will have to be reduced or increased respectively. If changes in the acceleration still cause water spillage to occur, then a finite amount of water that does not cause spillage will have to be observed and recorded for a maximum water capacity for further development.

7.7.2 Line Follower

The line follower uses five ADC channels to read the value of the five sensors, therefore the first test is to simply ensure all five sensors and channels operate as expected as well as determine a threshold value for the production code. The pseudo-code in Figure 51 shows how these sensors will be tested. An initial approximate threshold will be determined by executing this code while the processor is connected to the debugger. The debugger allows one to see the value of all variables in the processor. With this code executing, the threshold value can be narrowed down by moving the sensor around the line on the floor. When the processor has detected the sensor is on top of the line, the LED will turn on. If the sensor is on top of the line and the LED is not on, the threshold value needs to be decreased. Once the actual threshold value is determined, all sensors can be cycled through by pressing the pushbutton. For all five sensors, when the selected one is on the line, the LED should turn on, and when the selected sensor is not on the line, the LED should turn off.

```
Initialize ADC
Setup LED
Setup pushbutton
Set threshold variable

main_function(
while (1)(
while(pushbutton is not pressed)(
select ADC channel 0
adc_function()
)
while(pushbutton is not pressed)(
select ADC channel 1
adc_function()
)
while(pushbutton is not pressed)(
select ADC channel 2
adc_function()
)
while(pushbutton is not pressed)(
select ADC channel 3
adc_function()
)
while(pushbutton is not pressed)(
select ADC channel 4
adc_function()
)
)
)
```

```
adc_function(
turn on ADC
put CPU to sleep
wake up CPU when ADC is done
if (ADC result > threshold)(
turn on LED
)
else(
turn off LED
)
)
```

Figure 51: Pseudo-code for testing the line following sensors

7.7.3 Address Reader

For simplicity, the addressing line will not have a clock line. This means the addressing sensor will approximate a clock by using time delays. These delays will need to be determined through testing as they are variable upon the rovers speed. The pseudo-code in Figure 52 depicts how these delays will be determined. The first test will require a strip of alternating tape four squares large. The processor will need to be connected to the debugger during this test. The threshold variable should be the same value as determined during the line follower testing. When the pushbutton is pressed, the rover starts moving and address reader will read the pattern it passes over. When the delay has been configured properly, the 'address' variable will display '1010' in the debugger.

```
Initialize ADC
Setup pushbutton
Setup LED
Set threshold
Set delay variable

main_function(
while (pushbutton is not pressed)(
do nothing
)
Turn on both drive motors
adc_function()
address [0] = line
wait 'delay' milliseconds
adc_function()
address [1] = line
wait 'delay' milliseconds
adc_function()
address [2] = line
wait 'delay' milliseconds
adc_function()
```

```
address [3] = line
wait 'delay' milliseconds
)

adc_function(
turn on ADC
put CPU to sleep
wake up CPU when ADC is done
if (ADC result > threshold)(
set global variable 'line' = 1
)
else(
set global variable 'line' = 0
)
```

Figure 52: Pseudo-code for testing the address reading sensor

7.8 LCD

The majority of the testing for the LCD will occur through the testing of the other systems. For example, when the remote sensor push button is pressed, one of the systems to check is to ensure the LCD displays the appropriate message ('Fire at [address]!').

7.9 Power Supply

The battery should be tested according to the charging stage and the discharge stages.
Charging stage:

- Connect the battery to the system with no load
- Connect multi-meter to battery to check for voltage
- Connect multi-meter to battery to check for current
- Monitor the time it takes for the battery to reach charging state

Discharging stage

- Connect the battery to with a predetermined load
- Connect Multi-meter to battery to check for voltage
- Connect Multi-meter to battery to check for current
- Monitor the time it takes for the battery to reach charging state

7.10 Battery Charging

The fully assembled HeatSeekr rover will constitute the hardware required for testing. Located on the rear PCB container, above the fire retardant reservoir, the battery will be the main focus of charge time testing. The testing environment for this particular test will be a room temperature indoor space in which the battery can be expected to function normally. The testing procedure will involve running HeatSeekr for a sufficient time so as to completely drain the battery. The rover is now in testing posture and variables can now be defined and varied.

The pass/fail criterion for this testing procedure will be the time required for the rover to reach full battery charge in its fully assembled state. The battery should be capable of fully charging within 12 hours, but active monitoring will be required in order to determine the exact charge time. The sample battery level in this case will be what is required to cease the functioning the entire HeatSeekr platform, assumed to be a valid point at which the battery can be considered empty.

The only variable to be considered is the amount of time required by the battery to be fully charged. Testing procedure will involve monitoring the status LED on the battery to determine when the battery receives full charge. By checking at intervals of 15 minutes, a relatively painless test can be conducted that will reasonably determine the charge time of the battery. Care will be taken to ensure that the testing environment remains constant over the course of the test, as temperature, motion, and light incidence can greatly affect the charge time of the battery. These constants will be maintained by controlling the room in which the battery testing is taking place, ensuring that entrances and exits of personnel into the room remain at a minimum, all sources of light are kept to a minimum, and that the rover remains untouched over the course of the test.

7.11 Battery Life

It is important that the lifespan of the battery that will power HeatSeekr's motors and the HeatSeekr's electronics is tested. To test the battery, the rover will be drained three separate times at varying speeds, one being full speed, the next being minimum speed and the last being somewhere in between. The results determined from this test will be the basis for how long the rover will run and at what speed. The battery will also have to be tested for the electronics. This will be done by draining the battery completely as well. When the battery is no longer supplying the necessary power that the sensors need, then it will be known that it has failed to gather and/or deliver results that were previously predicted. Since there will be only one battery, there will be no need to do any kind of hybrid testing. Table 33 shows the test procedure will be used to rate the battery life.

Test	Description	Expected Results
Battery Life: Full Speed	Constant motion until battery is drained	30-45 minutes
Battery Life: Low Speed	Constant motion until battery is drained	1-1.5 hrs.
Battery Life: Moderate Speed	Constant motion until battery is drained	45 minutes to 1 hr.

Table 33: Procedure Summary for Battery Life Testing

7.12 Battery Safety

There are a few things to know and consider in order to properly handle batteries in a safe manner. The first item to look at is the physical appearance of the battery, identify if the container has any cracks, or signs of fluids on or around the battery. If this were found around the battery, then it could be that the electrolyte is spilling, leaching or leaking out. If any of these signs are present, gloves or any kind of protection should be used since the electrolyte is a solution of acid and water, thus skin contact should be avoided. Consequently, the battery would need to be replaced immediately.

It is also important to keep the connection terminals free of dirt in order to have a flawless connection. The cables that are used to connect to the battery should not be very tight since it could lead to post breakage or meltdown. It is very important to be aware of the weather condition the battery will be exposed to. It is also important to keep the battery above freezing temperature and limit exposure to heat. Temperatures above 80°F will accelerate the discharging process of the battery. Finally, it is important that during the usage of the battery that the terminals should not be shorted, since this will cause a very high current flow from one terminal to the other, therefore draining the battery and could potentially cause an overheat in the shortage object and cause a fire which would be very dangerous.

7.13 Finalized Project Testing Experiment and Expectations

Once the HeatSeekr has finished all of its initial subsystem testing and has been properly constructed together, testing of all specifications at once can begin. To do this, a series of long testing will occur to ensure that all systems work as intended and that the HeatSeekr can fully operate with minimal human interaction. The HeatSeekr will be placed in a standby state on a perceived line for line follower navigation. A lit candle or Sterno heating urn will be placed in a room near the remote sensor. Once the remote sensor picks up on the heat signature emitting from the fire, a wireless signal will be transferred to the HeatSeekr's array and communicate with the master microcontroller to begin line navigation to the remote sensor's room address. By accessing the navigational system's motors, the tank treads should begin movement and carry a fully loaded HeatSeekr prototype onto the setup path created for the line follower. Weighing up to 30 lbs, the HeatSeekr should be able to correctly identify the line path laid out to it for the hallway and enter the correct room to scan for the fire. Once the HeatSeekr has entered the room, it should begin scanning with the UVTRON by rotating the fire extinguisher system's X axis motor. Once the UVTRON has located the fire, with accuracy improvements from its shielding, the HeatSeekr should begin to rotate the fire extinguisher system's Y axis and turn the water pump on for spraying. Should the HeatSeekr's position need changing due to a range issue or obstacle preventing a straight shot at the fire source, the robot should navigate to avoid it as needed and continue spraying. Once the fire is fully extinguished, the system can await further commands from the remote sensor, await human confirmation that the room is safe by simulating a fire fighter's examination and reset the machine, or simply resetting itself and returning into the hallway by use of line navigation to continue searching for further fires in the building. After testing has concluded that all tasks are being completed correctly, the water level system should either be low or manually drained to indicate that a water refill is required for further fire extinguishing.

8.0 Administrative Content

8.1 Milestone Discussion

In a project as heavily integrated as HeatSeekr, it was important to divide the workload and set a series of breakthroughs and accomplishments in a timetable to ensure that pipelining of necessary part choices, research, and design could be made as early as possible. Figure 53 displays the initial block diagram for dividing up the various subsystems. This division didn't mean the owner was completely responsible for that system; instead the owner was responsible for ensuring the group discussed and planned each section.

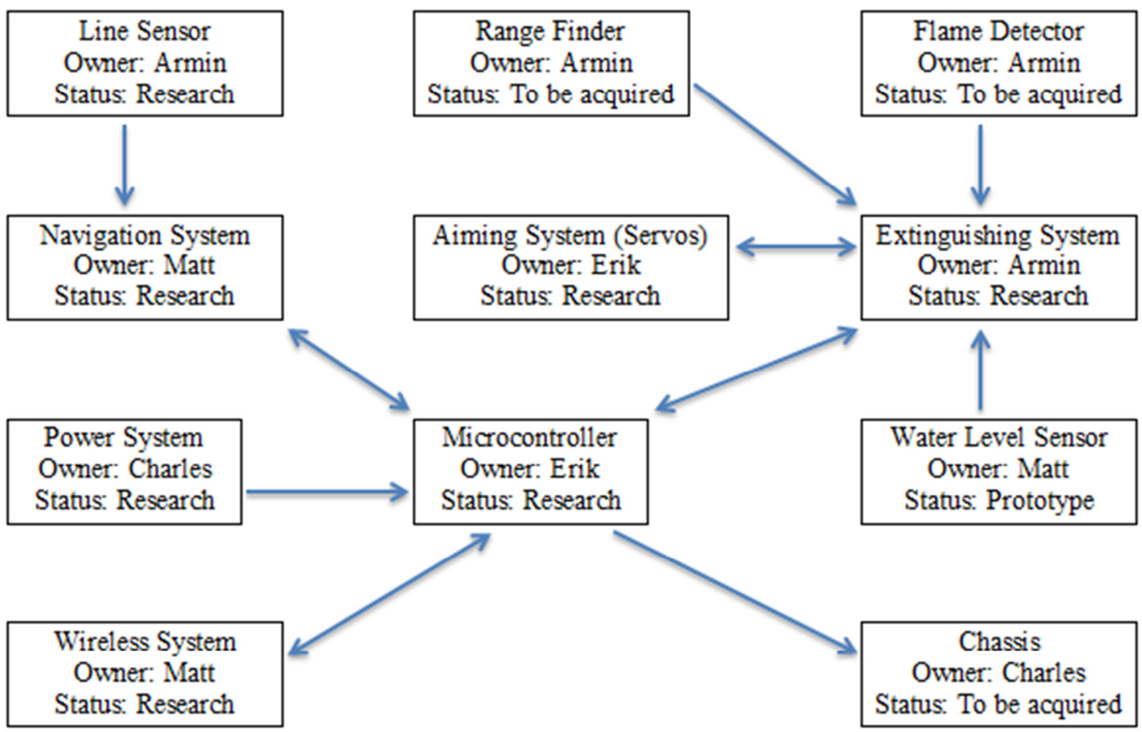


Figure 53: Block diagram illustrating the data flow and owners of each subsystem for HeatSeekr

Milestones were especially helpful due to the incredible work being undertaken by the various researchers taking so much of their invaluable time. These great works forced the researches to often work alone, without the aid of their compatriots. Thus having a codified set of milestones provided a guiding beacon through which the researchers could efficiently research topics to tackle to most important aspects of design as fast as possible. The milestones corresponded mostly to part choices, as these considerations had the biggest impact on the design methods and prototype construction. Another driving consideration were the deadlines given to the group. In these situations, the group deadlines were often set a few days prior to the assigned deadline to allow ample time for review.

- Initial Project Design .... January 28th
- Selection of fire detection components .... February 14th
- Selection of extinguishing system .... February 14th
- Power consideration .... February 14th
- Mobile or Stationary .... February 14th
- Table of Contents .... February 19th
- Processor selection .... March 5th
- Drive System selection .... March 5th
- Chassis selection .... March 5th
- Line-following system design .... March 5th
- Battery chemistry selection .... March 19th
- Servo motor selection .... March 19th
- Power rail design .... March 19th
- Remote sensor design .... March 19th
- Pump selection .... April 9th
- Tank specifications .... April 9th
- Complete 30 pages for paper .... April 22nd
- Assemble paper .... April 22nd
- Purchase all components .... September 9th
- Preliminary testing of components .... September 13th
- Testing of nozzle servos .... September 19th
- Complete interfacing of microcontrollers .... September 19th
- Fully breadboard all HeatSeekr components .... October 7th
- Layout PCB .... October 14th
- Test and debug all coding .... October 14th
- Order PCB .... October 21st
- Assemble PCB .... November 4th
- Assemble HeatSeekr .... November 8th
- Testing of all systems .... November 18th

8.2 Budget and Finance Discussion

HeatSeekr's budget will be supported by the entire team with an even split for all costs. Before the research for design and part selection was completed, the estimated total for all parts was around $550. After careful consideration for each system, a total cost of $524.71 has reached. Since this realistic value is under the estimated budget, additional funding can be provided for any taxes and shipping on parts. In order to prevent further spending on purchasing excess parts due to design flaws and testing malfunctions, micro-management is crucial in preventing any issues. Although price is important, an emphasis on quality items has been placed in order to receive high end products at low costs.

Since the majority of parts cost over $20 dollars each, so testing will have to done very carefully to prevent any short circuits or damage to other devices. For the fire extinguisher system, two Hamamatsu UVTRON flame sensor and corresponding Hamamatsu drive boards will be required for the remote sensor and for the mobile HeatSeekr. The UVTRON costs $35.95, and the drive board costs an additional $49.94 for a grand total of $171.80 for the flame sensor. Thankfully, the Hamamatsu Corporation allows for free samples of their product for to students working on projects that require a heat sensor. Thanks to their generosity, a free sample of the UVTRON and accompanying drive board has been donated to the HeatSeekr's budget and reduced total costs by $85.89. To power the extinguisher system, a MCP355 Swifttech PC liquid cooling pump will be purchased for $83.95 from Sidewinder computer systems Inc. This pump will be placed inside of the water tank and shoot water through its tubing toward the detected region of a fire. The water tank will be composed of a strong Plexiglas of 0.25" thickness to support the estimated 16lbs of weight from the maximum capacity of two gallons. The water tank dimensions will be 12in x 7in x 6in, and two sheets of Plexiglas can be bought from HomeDepot with dimensions 12in x 24in with a thickness of .22in. These sheets have been designed to be cut to provide the maximum amount of leftover Plexiglas, which will allow the HeatSeekr additional lengths of 12in x 4in, 6in x 18in, and 6in x 7in leftover as needed. The pump's tube will travel through the surface of the HeatSeekr toward the front of the body, and connect to the X and Y axis motors of the fire extinguisher system to provide for proper aiming. The X axis motor will be installed below the UVTRON to control both the flame sensor and the water direction, and the Y axis motor will be installed on top of the Y axis motor to allow for variance in range. These motors will be 2 Nema 16 step motors model 39BYG302, and cost $12.95 each for a total cost of $25.90 to be acquired from Circuit Specialists. These motors will be equipped with 2 H-bridge stepper motor drivers that cost $2.34 dollars each, for a total cost of $9.36. This entire system will then be connected onto the fire extinguisher system's MSP430G2553. In total, there will be 4 MSP430G2553s hooked up in a master and slave setting. These microcontrollers have numerous vendors on the Texas Instrument's main website, and average around $2.50 each for a total investment of $10.00. The entire system will be mounted onto a $25.00 chassis, and a VEX robotics tank tread kit for $29.99 will be installed to the sides of the chassis. Both pieces will be bought from Robot Marketplace. One of the axles on each of the tank treads will be replaced with the planetary gear motors model PGHM-02, which will be purchased from Robot Shop for $37.95 each resulting in a grand total of $75.90 for the navigational motors. These navigational motors will be connected to a MOSFET that translates the navigation system's microcontroller to the motors. The Reflective Optical Phototransistors will be used for line navigation, and installed on the front end of HeatSeekr's chassis pointing down toward the floor. Six of these phototransistors will be required for proper line navigation, and each can be acquired for $0.76 from Vishay for a total investment of $4.56. Finally, all circuitry components will be attached to a designed PCB board from Advanced Circuits using their student discount for a $33.00 circuit board. The board will be designed so it can snap off, and a small corner of it will be used to design the remote sensor which will have its own microcontroller and UVTRON flame sensor. A simplified rendition of the HeatSeekr's budget is shown in Table 34 below.

Part	Estimated Cost	Number to Acquire	Total Cost
Hamamatsu UVTRON Flame Sensor R2868	$35.95	2	$71.90
C3704 Hamamatsu UVTRON Board	$49.94	2	$99.88
MCP355 Swifttech PC Liquid Cooling Pump	$83.95	1	$83.95
1.0 kg/cm Nema 16 Step Motor- 39BYG302	$12.95	2	$25.90
H-bridge Stepper Motor Driver	$2.34	4	$9.36
Vex Robotics Tank Tread Kit	$29.99	1	$29.99
Planetary Gear Motor PGHM-02	$37.95	2	$75.90
MOSFETs	$2.95	1 pack of 5	$2.95
Reflective Optical Phototransistor	$0.76	6	$4.56
3.3V / 5V Switching Regulator	$13.18	2	$26.36
2-layer PCB board	$33	1	$33
Plexiglas	$12.98	2	$25.96
MSP430G2553	$2.50	4	$10.00
Chassis	$25.00	1	$25.00
		Total:	$524.71

Table 34: Total Budget for HeatSeekr

8.3 Conclusion and Summary

The completed HeatSeekr system represents the union of many diverse and intercommunicating systems representing many disciplines within electrical engineering. Unified under "The Overlord" master processor, the fire extinguishing and navigational have been engineered to meet the specifications set out initially in section 2.1 with the designs and programming outlined in section 4. Through careful research and a distillation of the core principles and goals behind HeatSeekr, an extensive catalog of for-purpose components have been fit into the prototypes of section 5.

Analysis of the capabilities and attributes of the chosen hardware has shown that the required specifications regarding maximum detection range, detection response time, navigational response time, extinguishing range, weight and size can be fully realized through a practical prototype. Through a careful crafting of the required algorithms and a thorough optimization of available processing power, the few weaknesses of the specific hardware choices have been overcome and even positively utilized in the resulting design.

By meeting the specifications set initially, HeatSeekr has demonstrated its ability to reach its aspired-to goals. Through the successful derivation of the navigational algorithm and hardware, HeatSeekr can be deployed in a variety of residential, commercial, and industrial environments, enabling a possible future integration into the greater fire protection infrastructure. By solving the problems inherent to the relatively slow moving rover algorithms by applying wireless technology and nodal sensors, HeatSeekr has laid the foundation for a comprehensive, facility wide fire protection strategy, enabling the possibility for pinpoint fire responses that will potentially save sensitive property that would otherwise be lost by less discriminating fire protection systems.

To conclude, HeatSeekr represents a robust union of many engineering disciplines, and through methodical adherence to the design and prototype plans, will easily transition to a high performance, working model. Through the challenge of integrating several complex systems, a greater knowledge of the engineering process has become available to every researcher involved in the creation of HeatSeekr.

9.0 Appendices
9.1 Copyright permissions

dks738@gmail.com on behalf of Daniel Stough [Dani Actions

Tuesday, March 26, 2013 11:18 AM

To: ferik [ferik@knights.ucf.edu]

- Flag for follow up. Start by Wednesday, March 27, 2013. Due by Wednesday, March 27, 2013.
- You replied on 3/29/2013 10:20 PM.

Hi Erik,

As long as you cite any diagrams or pictures, you can use whatever will help with your project. I'm always interested in the cool ideas other people are working on; what's your project about?

Regards,
Dan S.

ferik

Tuesday, March 26, 2013 12:07 AM

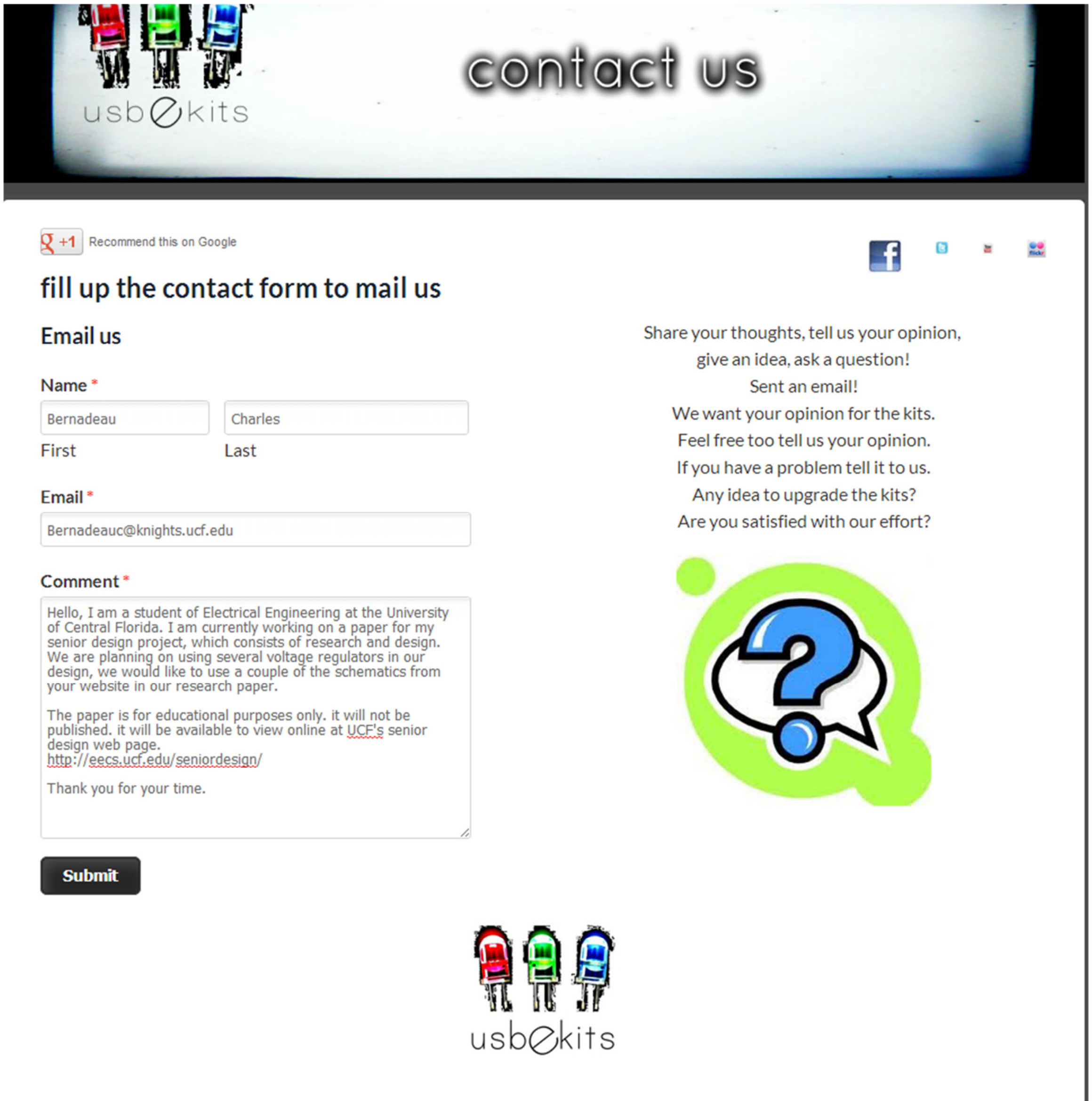
Sent Items

Mr. Stough,

I am student at the University of Central Florida currently working on a senior design project similar to your Xfire project. Part of our research paper is that we have to document any projects that have given us inspiration, and your Xfire was a very interesting read. Can we have your permission to use your UML class diagram, state diagram, and block diagram in our report? They would only be used to explain how your project works in our section about other researched projects. Please let me know if we can use your images, or if you have any further questions about our project.

Thanks for your time,

Erik Ferreira



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The paper is for educational purposes only. it will not be published. it will be available to view online at UCF's senior design web page.
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09819133129

Contact Form

First Name:
Bernadeau Charles

E-Mail Address:
Bernadeauc@knights.ucf.edu

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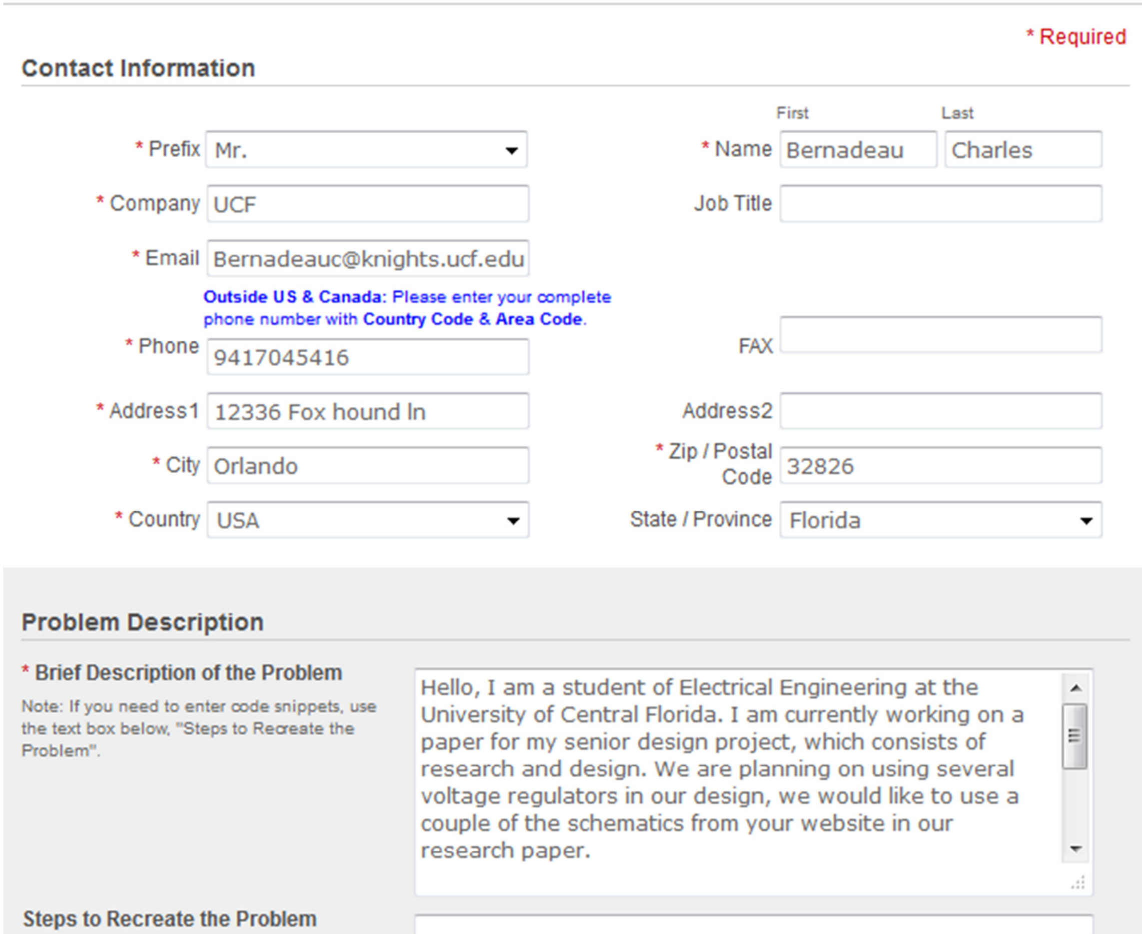

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Contact Information

* Prefix	Mr.	* Name (First / Last)	Bernadeau / Charles
* Company	UCF	Job Title	
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* Phone	9417045416	FAX	
* Address1	12336 Fox hound ln	Address2	
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*** Brief Description of the Problem**

Note: If you need to enter code snippets, use the text box below, "Steps to Recreate the Problem".

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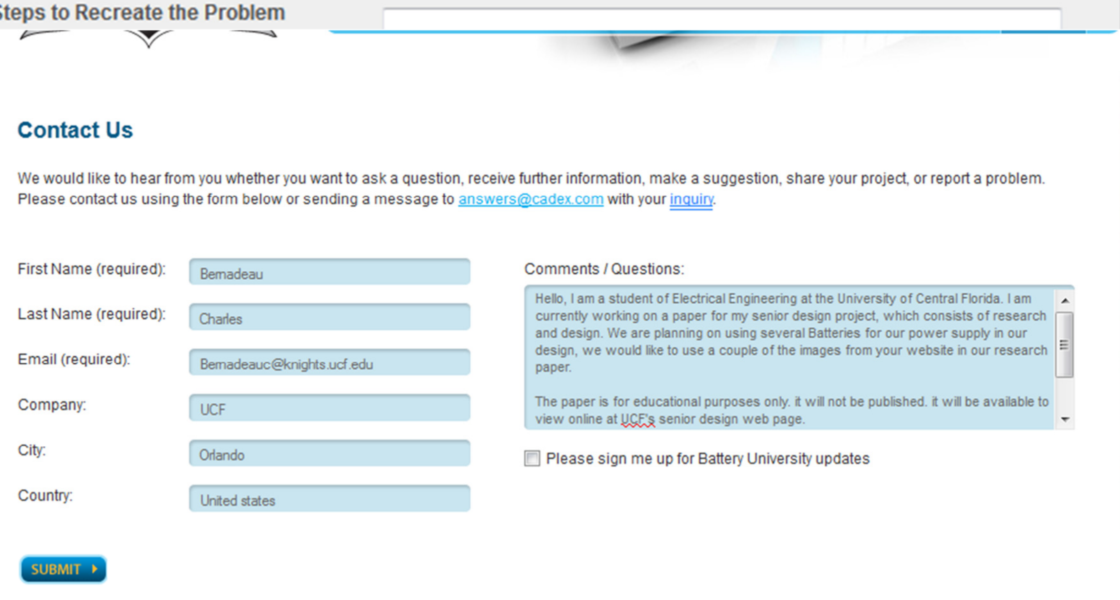
Steps to Recreate the Problem



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We would like to hear from you whether you want to ask a question, receive further information, make a suggestion, share your project, or report a problem. Please contact us using the form below or sending a message to answers@cadex.com with your inquiry.

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Last Name (required):	Charles
Email (required):	Bernadeauc@knights.ucf.edu
Company:	UCF
City:	Orlando
Country:	United states

Comments / Questions:

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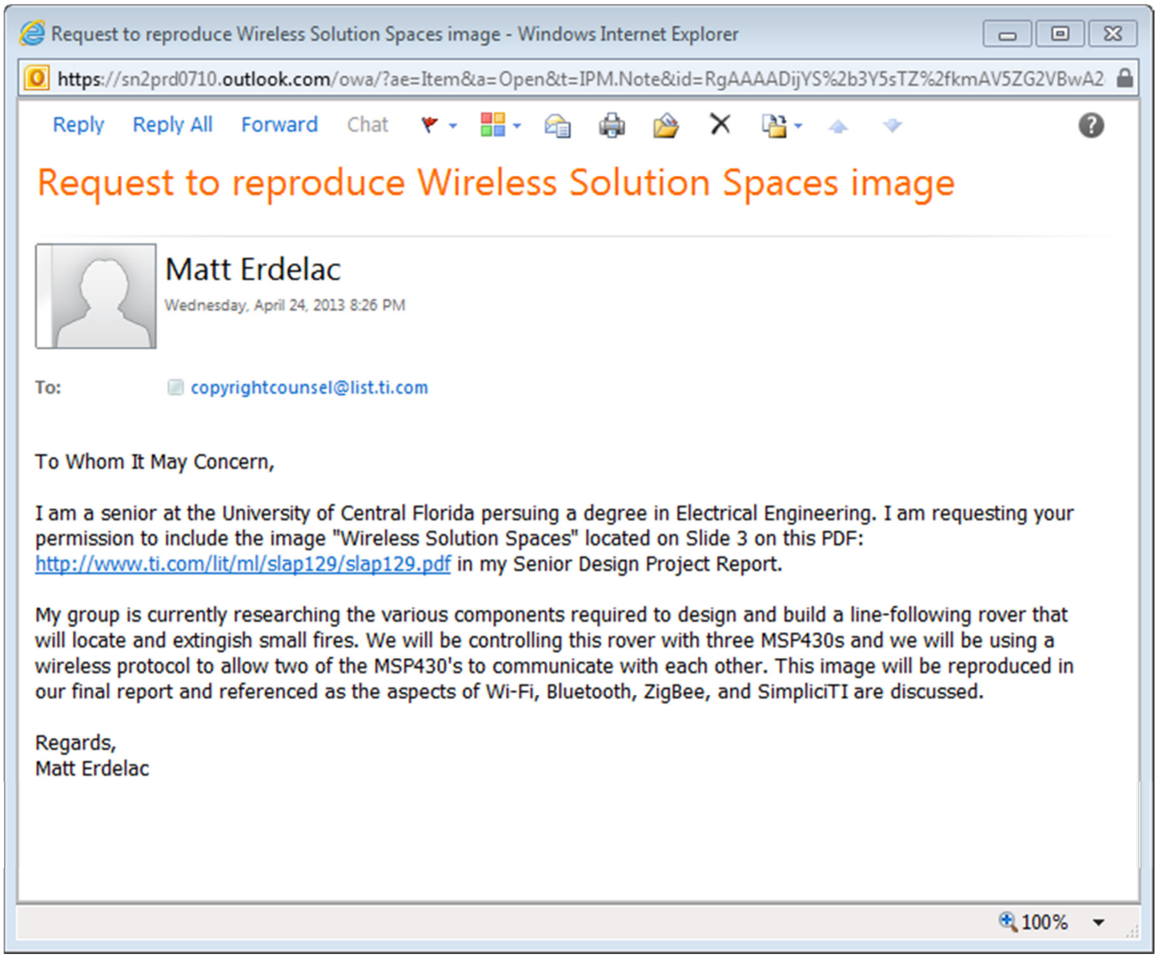
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Matt Erdelac

Wednesday, April 24, 2013 8:26 PM

To: copyrightcounsel@list.ti.com

To Whom It May Concern,

I am a senior at the University of Central Florida persuing a degree in Electrical Engineering. I am requesting your permission to include the image "Wireless Solution Spaces" located on Slide 3 on this PDF: http://www.ti.com/lit/ml/slap129/slap129.pdf in my Senior Design Project Report.

My group is currently researching the various components required to design and build a line-following rover that will locate and extingish small fires. We will be controlling this rover with three MSP430s and we will be using a wireless protocol to allow two of the MSP430's to communicate with each other. This image will be reproduced in our final report and referenced as the aspects of Wi-Fi, Bluetooth, ZigBee, and SimpliciTI are discussed.

Regards,
Matt Erdelac

100%

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9.2 Bibliography

"14.8V 5500mAh LIPO Battery Pack." *Tenergy*. N.p.. Web. 24 Apr 2013. <http://www.all-battery.com/148volt-5500mahli-polypack.aspx>.

"78SR-X/2." *Murata Powe Solutions*. N.p.. Web. 24 Apr 2013. <http://www.murata-ps.com/data/meters/mpm_78sr-2a_a00.pdf>.

"AcryliteFF." *Tapplastics*. N.p.. Web. 24 Apr 2013. <http://www.tapplastics.com/uploads/pdf/FF Physical Properties.pdf>.

Afandi, Shoaib. "Firefighting Robot." *Firefighting Robot*. N.p.. Web. 24 Apr 2013. <http://www.ece.okstate.edu/abetdata/assessment/programlevel/CapstoneReports/2004Spring/FireFightingRobot.pdf>.

"BUZ20." *Infineon Technologies*. N.p.. Web. 24 Apr 2013. <http://www.datasheetcatalog.org/datasheet/infineon/1-buz20.pdf>.

"CC2520." *Texas Instruments*. N.p.. Web. 24 Apr 2013. <http://www.ti.com/lit/ds/symlink/cc2520.pdf>.

"CMOS IR Camera Module SEN-08773." *Sparkfun*. N.p.. Web. 24 Apr 2013. <https://www.sparkfun.com/products/8773>.

"CNY70." *Vishay*. N.p.. Web. 24 Apr 2013. <http://www.vishay.com/optical-sensors/list/product-83751/>.

"Controllng Motors with an MP430." *Roland*. N.p.. Web. 24 Apr 2013. <http://lars.roland.bz/controlling-motors-with-an-msp430/>.

"Delrin (Acetal Homopolymer)." *Plastics International*. N.p.. Web. 24 Apr 2013. <http://www.plasticsintl.com/datasheets/Delrin_150.pdf>.

" DE-SW050 5V 1A Switching Voltage Regulator." *Dimension Engineering*. N.p.. Web. 24 Apr 2013. <http://www.dimensionengineering.com/products/de-sw050>.

"FlamesorRON R2868." *Hamamatsu*. N.p.. Web. 24 Apr 2013. <http://www.superdroidrobots.com/product_info/R2868.pdf>.

"Futurlec." *PM42M Stepper Motor*. N.p.. Web. 24 Apr 2013. <http://www.futurlec.com/PM42M.shtml>.

"GHM-13 Spur Gear Head Motor." *Robot Shop*. N.p.. Web. 24 Apr 2013. <http://www.robotshop.com/12vdc-152rpm-ghm-13-spur-gear-head-motor.html>.

"HIPP40IBZ." *Intersil*. N.p.. Web. 24 Apr 2013. <http://www.digikey.com/product-detail/en/HIP4020IBZ/HIP4020IBZ-ND/1976759>.

"HT23-180-8 High Torque Stepper Motor." *Probotix*. N.p.. Web. 24 Apr 2013. <http://probotix.com/specs/HT23-180-8.pdf>.

Korua, Roger. "H-Bridge Fundamentals." *Roko.ca*. N.p., n.d. Web. 24 Apr 2013. <http://roko.ca/articles/hbridge.php?page=1>.

"LM7812." *National Semiconductor*. N.p.. Web. 24 Apr 2013. <http://www.datasheetcatalog.org/datasheets/150/44435_DS.pdf>.

"Model 276-1657 CdS Photoresistor ." *Radioshack*. N.p.. Web. 24 Apr 2013. <http://support.radioshack.com/support_supplies/doc38/38703.htm>.

Montoya, Anthony. "El Patron." *El Patron*. N.p., 07 May 2001. Web. 24 Apr 2013. <http://www.ee.nmt.edu/~wedeward/EE382/SP01/group1.pdf>.

"MSP430G2553." *Texas Instruments*. N.p.. Web. 24 Apr 2013. <http://www.ti.com/product/msp430g2553>.

"Nema 16 Step Motor 39BYG302." *Circuit Specialists*. N.p.. Web. 24 Apr 2013. <http://www.circuitspecialists.com/nema_16_step_motor_39byg302.html>.

Newton, Brad. "Building and Acrylic Aquarium." *Cichlid-forum.com*. N.p., n.d. Web. 24 Apr 2013. <http://www.cichlid-forum.com/articles/diy_acrylic_aquarium.php>.

Nikosapi, . "MSP430 HD44780 Controller Software." *nikosapi.org*. N.p.. Web. 24 Apr 2013. <http://nikosapi.org/wiki/index.php/MSP430_HD44780_Controller_Software>.

"Planetary Gear Motor PGHM-02." *Robot Shop*. N.p.. Web. 24 Apr 2013. <http://www.robotshop.com/12vdc-planetary-gear-motor-pghm-02-3.html>.

"Planetary Gear Motor PGHM-03." *Lynxmotion*. N.p.. Web. 24 Apr 2013. <http://www.lynxmotion.com/p-516-planetary-gear-motor-12vdc-4101-14rpm-6mm-shaft.asp&xgt;.

"PTH04070W." *Texas Instruments*. N.p.. Web. 24 Apr 2013. <http://www.ti.com/lit/ds/symlink/pth04070w.pdf>.

"R-78C12-1.0." *Innoline*. N.p.. Web. 24 Apr 2013. <http://www.recom-power.com/pdf/Innoline/R-78Cxx-1.0.pdf>.

"RN-171." *Digi-Key*. N.p.. Web. 24 Apr 2013. <http://www.digikey.com/us/en/ph/Roving-Networks/rn171-network-module.html>.

"RN-42." *Roving Networks*. N.p.. Web. 24 Apr 2013. <https://www.sparkfun.com/datasheets/Wireless/Bluetooth/rn-42-ds.pdf>.

Sembel, Frisco. "Heat Seeking Fire Extinguisher." *Heat Seeking Fire Extinguisher*. N.p.. Web. 24 Apr 2013. <http://courses.engr.illinois.edu/ece445/projects/fall2011/project14_design_review.pdf>.

Stough, Daniel. "Xfire." *Xfire*. N.p.. Web. 24 Apr 2013. <http://www.danielstough.com/projects/xfire/>.

"Vex Robotics Tank Tread Kit." *The Robot MarketPlace*. N.p.. Web. 24 Apr 2013. <http://www.robotmarketplace.com/products/VEX-276-2168.html>.

9.3 Software

Adobe Illustrator. Adobe Systems. Proprietary software.

Eagle Layout Editor. CadSoft Computer GmbH. Proprietary EULA.

Google SketchUp. Google. Proprietary EULA.

Microsoft Visio. Microsoft. Proprietary EULA.

Microsoft Word 2010. Microsoft. Proprietary commercial software.

SolidWorks. Dassault Systemes. Proprietary EULA.