Preliminary Design Review

Sponsor – Richard Emberley

Economical, Mechatronic, Burn-Extinguishing Robot

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0. Abstract

Despite the increased danger of wildfires in states such as California and Colorado, there is yet to exist a product that can autonomously circumvent the development of firebrands, or spot fires, that propagate the spread of wildfire far beyond the actual area of burn. If properly designed, such a product (or patent in public domain) could reduce countless civilian casualties and prevent millions of dollars in property damage. A product of the like would be analogous to "herd immunity" in vaccines, whereas neighbors that own the product will ultimately protect each other.

In terms of shareholder and public interest, the product would inadvertently have the pathos of being able to protect consumers from the devastation and death related to fires, as well as the ethos of aforementioned "herd immunity" and protecting one's community. Not to mention logos, customers can save money through self-insurance.

There are products on the market, generally in the commercial domain, that can protect a building from wildfire. However, these devices come at a high cost that eliminates even the upper-middle class household. The product we are designing and building is unlike anything in current existence because it utilizes thermal imaging technology to reduce the water consumption related to firefighting.

Our group drew many important conclusions throughout the process of researching and brainstorming. Results from expert interviews and consumer feedback afforded us a widened understanding of the direction of our work. Evaluation of existing products and patents further conceptualized the necessary physical parameters of such a project, ensuring we do not reinvent the wheel. During numerous ideation sessions, the team considered a range of design variations that could satisfy our problem and worked them down into one solid design.

1. Introduction

1.1. Fire Severity in California

The intensification of climate change has only served to exacerbate the severity of California's droughts. With the susceptibility of pockets of dry brush that stretch across the state, the potential for the spread of wildfires is a substantial issue at the forefront of political debate. Fires are no longer seasonal to the state of California, and the late *Camp Fire* (November 2018) remains the deadliest and most destructive wildfire in the history of California, causing at least 86 civilian casualties and $16.5 billion dollars in damage.

The dangers of a single ember are incredible, and the circumstances that gave rise to *Camp Fire's* path of destruction only further support this evidence: the main cause of the fire was a spark from downed power lines. Combining ideal burn conditions can cause significant destruction in general. Although such scenarios may seem statistically insignificant, the implications are far-reaching and devastating for a great number of US residents.

In nature, spot fires hold similar characteristics to *Camp Fire's* igniting spark. When wildland fires are brewing, organic debris such as pine needles, twigs, and bark are set ablaze. With the right conditions, in terms of wind and ambient air, these small embers can launch far beyond the heart of the fire, starting spot fires in neighboring areas. These firebrands destroy millions of acres and hold no preference in their consumption: wildfires can and will destroy both urban development and natural land without much warning.

With such problems plaguing the state of California, there exists need for a product that can autonomously extinguish spot fires arising near properties allowing the homeowners to evacuate with some peace of mind. Endeavors into developing such a product can serve in preventing countless civilian casualties, and also to inhibit the spread of wildfires as a whole.

1.2. Stakeholders and Economics

The cornerstone of any successful design involves exhaustive attention to the needs of the consumer. The consumers' and stakeholders' preferences define the product; desire is the backbone of any significant financial endeavor, and thus essential before any drafting is done.

One of the most substantial facets of this product is that it must be economical: consumers will only desire it if the price matches performance. Attention to this constraining factor will be considered in the design phase of our project in several different areas. In terms of economics, the manufacturing process is a large focal point. Any shape can be made in a computer-assisted drawing program, but the question stands: can it be manufactured? The design must follow the laws of available tooling and machinery in order to remain within a reasonable price point.

Beyond this, another important consideration is appeasing the customer. Features and cost share two sides of the same coin that never lands on its edge. In a first-to-file country like the United States where patents exceed the millions, it is the unique facets of a design that constitute its success in open market. For E.M.B.E.R. (where "mechatronic" and "robot" make up 40% of the whole idea), its autonomous nature is integral to customer attraction. Beyond the significance of fire protection, the existence of a self-controlled device holds its own inherent attractiveness.

2. Background

2.1. Customer Observations

In the first interview with our sponsor, Dr. Richard Emberley gave the team his input regarding the fire aspect of this project. With embers travelling up to five miles ahead of wildfires, he claims that the front of the fire is moving faster than can possibly be imagined. Emberley explained the two schools of thought on wildfire home defense. The first is leaving your home to do its own thing with whatever defenses already exist e.g. non-combustible roof, separation between urban and wildland. The second is to defend in place i.e. staying behind to spray embers around your home with a hose. This is proven to be an effective method, however, an obviously dangerous endeavor. Emberley wished us to find the best of both worlds by creating a device that can put out burning embers after the homeowner has evacuated to safety.

In the second interview with Kelly Fernandez, an operations manager for State Farm Fire and Casualty Company, the team narrowed down our customer base from general homeowners in high-risk wildfire zones. A device of this type is much more likely to sell to those homeowners who are educated on their insurance policy and staying updated with their estimated replacement cost. The more expensive the home, the greater the deductible that will have to be paid should the home be lost to a fire, and the potential discount offered for owning this device would be more significant as well. This leads us to believe that while no one wants to lose their home in a wildfire, wealthy homeowners are going to be more likely to self-insure by buying a product such as ours.

This idea was proven further by a survey we submitted to the Cal Poly parents page. The results of this survey are posted in Appendix I.

2.2. Existing Solutions

Several design solutions are already developed to address specific aspects of this issue. We will further discuss existing products, and a description of researched patents is provided in Table 2-1. Through this research, we found that while there are products and systems solving a part of the problem, there are no effective solutions that cover the entire issue as we intend to with E.M.B.E.R.

Product 1 | *Firebot*

The Firebot was a senior project with essentially the same goal as ours. They modified and programmed a Whitebox Robotics 914 PC-BOT to detect fire and extinguish it. As exciting as a roaming robot would be, our budget does not support this, and we do not believe that function is necessary to design a successful product.

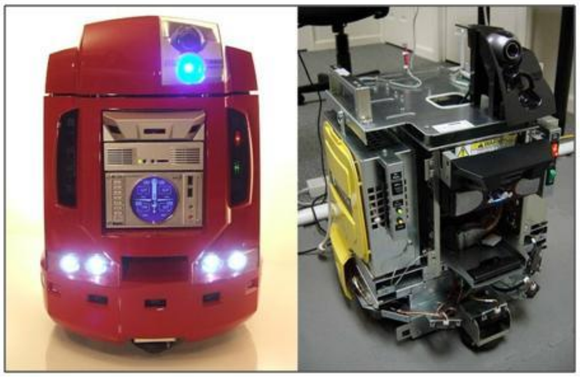

Figure 2-1. Firebot with and without a cover [1].

Figure 2-2. Multiple Firebot devices [1].

Product 2 | *Droplet*

Droplet is a robotic, lawn-watering sprinkler. The smart sprinkler system utilizes cloud computing in order to reduce water consumption up to 90%. This product relies on interconnectivity using Wi-Fi which is unattainable for us because power is often cut off during a wildfire evacuation.

Figure 2-3. Droplet marking its territory [2].

Product 3 | *Orbit Yard Enforcer*

The Yard Enforcer is a motion-activated sprinkler that protects gardens from animals and pests. It uses a combination of heat and motion detection to humanly repel wildlife. While Orbit has the same idea as our project, their heat detection is in a far lower range than we intend to work with.

Figure 2-4. Full view of the Yard Enforcer [3].

Figure 2-5. Yard Enforcer in action [3].

Product 4 | *Plumis Automist*

Automist is an indoor fire sprinkler that does not require a tank or commercial incoming water main. It uses less water than a traditional sprinkler system and is triggered by a ceiling mounted heat detector. In comparison, our system will be for outdoor use and function with a more precise fire detection system.

Figure 2-6. Automist Smartscan Hydra [4].

Figure 2-7. Automist Fixed Wall Head [4].

Product 5 | *FOAMSAFE Fire Protection Systems*

FOAMSAFE is an outdoor fire prevention system which, when activated, sprays a biodegradable foam around your property to make it fire resistant. This product helped us realize that it may be beneficial to not merely put out spot fires but to try and prevent them from happening in the first place. This could be done by presoaking the yard, while still trying to conserve as much water as possible.

Figure 2-8. FireMaster System in action [5].

Product 6 | *WASP*

WASP stands for Wildfire Automated Sprinkler Protection and is a gutter-mounted sprinkler system. The product is intended to be left on continuously after the homeowner has evacuated. There a significant amount of water waste associated with this product as it does not involve fire detection.

Figure 2-9. Gutter-mounted WASP system [6].

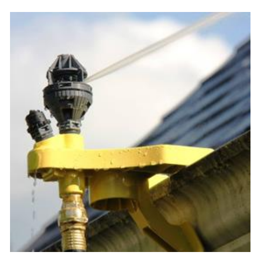

Figure 2-10. WASP system up close [6].

Table 2-1. Patents related to the project scope.

	Patent Name	Description	Patent No.
1	Automatic Spray Mechanism	The device is a motion-detecting sprinkler to deter animals. The system uses an electronic motion sensor to detect motion and an adjustable spray nozzle which automatically disperses water towards the area of motion.	8,904,968
2	Robotic Watering Unit	The system receives a map of the yard and determines which areas need water. A mobile utility vehicle provides that water accordingly.	8,322,072
3	Apparatus and methods for sensing of fire and directed fire suppression	The invention provides proactive and intelligent fire suppression and/or control using a microcontroller that is communicatively connected to at least one fire-energy detection sensor and at least one fire suppression device.	7,066,273
4	Motion Sensor Alarm and Sprinkler Device	Motion sensors installed around a home communicate with a sprinkler system to detect intruders and intend to scare them away by soaking them with water.	9,633,536
5	Retractable adjustable-trajectory rooftop fire sprinkler	Comprised of a sprinkler head, trajectory angle setting mechanism, and lockable flow-through hinge fitting. The function is to wet the roof and surrounding area to reduce the threat of ignition from embers.	9,084,907

2.3. Relevant Technical Literature

Table 2-2 displays literature that gave us insight into the project scope. Article 1 gave the team an idea of how fire spreads across a lawn with different environmental conditions. Article 2 discusses the appropriate amount of water to fight fires in the most effective and efficient way possible. The article focuses heavily on water conservation which is a main design constraint for us. Article 3 discusses the effect of various sprays and how well they extinguish fire. For this project, flow shape, size, and fire extinguishing capabilities are very important to consider if the device is to extinguish a spot fire before it spreads. Article 4 is related to Article 3 and discusses at what angles and heights a sprinkler should be set to achieve desired spray patterns. Article 5 describes how to build a water control system using microcontrollers which will become an integral part of the final product we design.

Table 2-2. Relevant technical literature.

Article Title	Description	References
Modeling Wind Adjustment Factor and Midflame Wind Speed for Rothermel's Surface Fire Spread Model	This article details the fire spread model adjusting for various environmental conditions.	Article 1
Water vs. Fire	A guide to effectively fighting forest fires.	Article 2
Fire suppression by water sprays	This article details the use of water as a suppressing agent, identifying the benefits and gaps of knowledge that exist.	Article 3

Influence of the trajectory angle and nozzle height from the ground on water distribution radial curve of a sprinkler	This article evaluates the effects of variation of height and angle of a sprinkler nozzle on water distribution.	Article 4
Design and Construction of Microcontroller-Based Water Flow Control System	This article describes how to design and build a water control system using microcontrollers.	Article 5

Table 2-3. Applicable industry codes and standards.

Code	Description	References
Model Water Efficient Landscape Ordinance (§490)	Describes how landscapes should help in fire prevention, and only the water reasonably required for beneficial use shall be used	Barclays Cal. Code of Regulations- Department of Water Resources
Water Waste Prevention (§493.2)	Outlines the requirements for preventing water waste	Barclays Cal. Code of Regulations- Department of Water Resources

3. Objectives

3.1. Problem Statement

Homeowners need a way to automatically suppress small scale fires that occur around their houses to prevent the fire from spreading to their homes and surrounding homes. Many homeowners in high risk areas currently have no way to defend against flare ups other than manually staying behind and using a hose themselves. The product solution must be reasonably priced, easy to set up, and relatively small.

Figure 3-1 shows the boundary diagram designed by the team. This is a visual depiction of the uncontrollable/controllable factors for the project. Inside the red boxes are the things that the team has control of when designing the project. This includes the side of the house with the electrical outlets and water spigot. Further from the house is the lawn, which is the main concern of the project, this is where the spot fires that the product will be extinguishing are present. Outside of the red box are the uncontrollable factors, such as, the wildfire creating the embers and the house. If the house were to ignite, the product would no longer be effective.

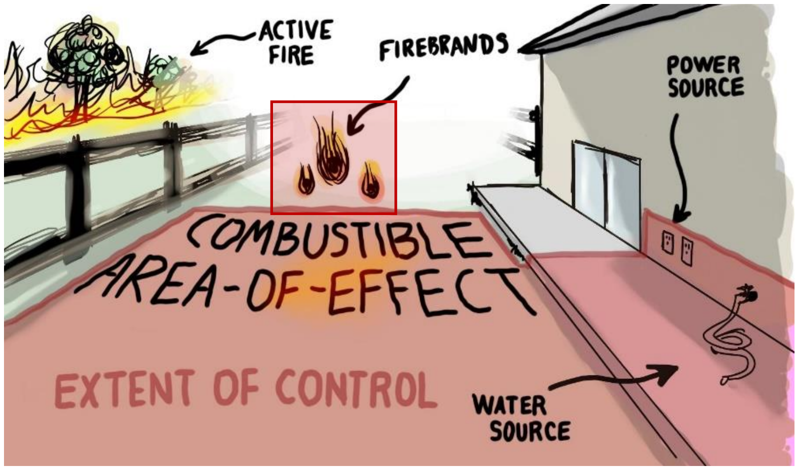

Figure 3-1. Boundary diagram.

3.2. Customer Wants and Needs

Table 3-1 lists the wants and needs of the customer. This list was developed using personal knowledge and experience, a survey on the Cal Poly parents Facebook page, and expert interviews. Refer to Appendix I for a copy of the survey. The needs are critical requirements that the project must meet to be labeled a successful project. The wants are additional, non-critical design goals.

Table 3-1. Customer wants and needs.

Needs	Wants
Fully automated	Inexpensive
Extinguish spot fires	Small
Work without home power	Easy to set up
Cover entire yard area	Aesthetically pleasing
Connect to a hose	Interactive smart phone app
Be robust and sturdy	

3.3. QFD Process

Quality function deployment is a tool used to ensure that a product fulfills the customers' wants and needs and meets necessary engineering specifications. QFD makes the design process more efficient by ensuring that no time is wasted designing and building to unnecessary specifications.

Our team developed a QFD using Table 3-1 and the specifications listed in Table 3-2. The engineering specifications are measurable deliverables for the project. Next, a strength of correlation was determined between the wants/needs and specifications to decide if there were any redundant or missing specifications. Finally, some alternatives to our project were compared in order to figure out if it was worthwhile to continue designing this product or if an existent design is superior. When the House of Quality in Appendix II was finished, it became clear that there are no better alternatives to E.M.B.E.R., and the team has a very clear list of specifications to design around.

3.4. Engineering Specifications

Table 3-2. Table of engineering specifications.

Specification		Requirement or Target (units)	Tolerance	Risk**	Compliance*
1	Weight	Under 5 pounds	Max	M	T
2	Water Resistance	Up to IPX 5	Min	M	T
3	Manufacturing Cost	Less than $200	Max	H	A
4	Coverage Area	At least 2,500 square feet	Min	H	T, A
5	Heat Resistance	Remains operational in temperatures up to 150°F	Max	M	T, A
6	Battery Life	12 hours under full operation	Min	M	T, A
7	Accuracy	Target within half of a foot	Max	H	T, A
8	Set Up Time	Under 15 minutes	Max	L	T, S
9	Type of Fluid	Accepts water	Min	L	T
10	Power Source	Rechargeable batteries	Min	M	T
11	Mechatronic Complexity	Involves no technical setup by the user	Min	L	I

**L = Low, M = Medium, H = High

*T = Test, A = Analysis, I = Inspection, S = Compare to existing products

<u>Specification Measurement</u>

1. Weight will be measured with a standard scale.
2. Water resistance will be measured by visual inspection in order to make sure the device is functioning properly after being exposed to sustained, low-pressure water jet spray (IPX 5).
3. Manufacturing cost will be measured by compiling an analysis of the cost of all parts.
4. Coverage area will be tested on a piece of land, at least 2,500 square feet, and analyzed using a standard hose length to see whether the device can dispense water to the appropriate distance.
5. Heat resistance will be measured by exposing the device to a range of temperatures up to 150°F and ensuring that the device does not fail.
6. Battery life will be measured by running the device continuously until the batteries die.
7. Accuracy will be measured by the distance from a controlled hotspot location to the center of the area being sprayed with water.
8. Set up time will be measured by testing a group of individuals and how long it takes them to get the device up and running.
9. The type of fluid will be checked by guaranteeing the ability of the device to accept and disperse water.
10. The power source will be measured by running the device using battery power and testing for continuous operation.

11. Mechatronic complexity will be measured by inspecting whether the final product needs any technical input from the user.

<u>High Risk Specifications</u>

Spec #3 – Manufacturing Cost

Keeping the manufacturing cost under $200 will be difficult to achieve based on the complexity of this project. Acquiring the thermal imaging camera, batteries adequate for a 12-hour runtime, and motors will likely lead to a relatively high manufacturing cost.

Spec #4 – Coverage Area

Meeting the 2,500 square feet of coverage area specification could prove difficult given the other constraints on weight. Because we are aiming for the device to be relatively small and light, achieving a large coverage area may be a hard specification to meet.

Spec #7 – Accuracy

The accuracy specification is one of the most important for this device to meet as the product must be accurate in order to function effectively. High accuracy will be difficult due to the potentially broad range of system inputs. However, with a large enough spray of water, embers will be extinguished regardless of slight inaccuracy.

4. Concept Design

4.1. Ideation and Decision Matrices

Our initial process to develop a large quantity of crude ideas was participating in three separate ideations sessions. We broke down the brainstorming into various functions pertaining to our project including: 1) mounting and gimble, 2) nozzles and fluids, 3) camera and mechatronics, 4) packaging, and 5) miscellaneous. Appendix III contains an example of the ideation results. Progressing on the concepts developed during these sessions, we further developed each function by comparing and contrasting solutions available to the categories individually. These options were put into Pugh matrices that allowed us to narrow the scope of the project into four major functions and evaluate their best ideas. The four sections included fire detection, water dispersion, motion, and electronics. A copy of our Pugh matrices is in Appendix IV. The top-ranking alternatives were the Flir Lepton camera, oscillating sprinkler, servo motor, and Raspberry Pi, respectively. We created various combinations of the functions and compared these complete concepts with a Weighted Decision Matrix. This can be found in Appendix V and assisted greatly in the selection of our chosen design.

Table 4-1. Top conceptual ideas.

Concept Model Photo	Description

	The first concept idea was a two-camera design with integrated adjustable spray. By changing the nozzle area, water velocity can be increased or decreased to hit various targets. This concept focused only on the top portion of the overall design. The increased cost of using multiple cameras eliminated this option.
	The second concept design incorporated an oscillating sprinkler equivalent to the one we used in our concept prototype. This design only involved one camera because with the vertical array of nozzles and horizontal oscillation of the sprinkler, our system does not need to account for depth perception, negating the need for a second camera.
	The third concept design was cylindrical, using only a single spray nozzle which can adjust its angle vertically and rotate horizontally to target a fire. The tube exiting the bottom is the hose connection for the homeowner. All tubing within the device is fixed. We did not move forward with this concept because it requires additional motors, as well as two cameras.
	The fourth concept idea was a “shotgun” approach, wherein there are a large number of nozzles exiting the top of the device. This allowed for a fire in any direction to be suppressed, and the yard can presoak simultaneously to prevent future fires. There is a massive amount of water waste associated with this concept inclining us to move forward with more complex systems.

	The fifth concept design had four nozzles whose rotational motion was powered by fluid momentum rather than mechanical power. The cylindrical shape allowed for easy rotation of the device. While lowering power consumption, this idea does not solve the issue of increased water expenditure.

4.2. Selected Concept

Through research and evaluation of the decision matrices, our team came to a conclusion that blends the best solution for each project function. For fire detection, we decided that the Flir Lepton thermal imaging camera is superior due to its detection distance and accuracy. The only negative is the Lepton's high cost. However, relative to thermal imaging cameras on the market that meet our needs, it tends to match or even fall below their prices. For water dispersion, we chose an oscillating sprinkler because it is by far the best option as it scored high among all criteria. An oscillating sprinkler is cost effective and accurately dispenses a vertical sheet of water as far as 25 feet. For motion, a servo motor, much like the oscillating sprinkler, proved to be a clear unanimous winner in all fields. These included cost, speed, accuracy, and power efficiency. Lastly, for electronics, we plan to use an STM32 microcontroller, despite its ranking below Raspberry Pi in the Pugh matrix. This decision is based on the STM32's cost effectiveness and memory capacity relative to its low power consumption and easy interface.

Once these choices were made, we began the process of constructing a concept prototype. The selected model will consist of two parts: 1) a non-rotating cylindrical base and 2) a rotating top housing. The base includes a hose connect protruding from the side for the homeowner to attach their garden hose to, as well as a turntable device that rotates the top housing. The turntable will be driven by a servo motor, which will be housed in the circular base. Located in the rotating top housing will be the oscillating sprinkler and thermal imaging camera positioned vertically above the sprinkler to get the highest vantage point possible. A preliminary CAD model of this concept is found below in Figure 4-2.

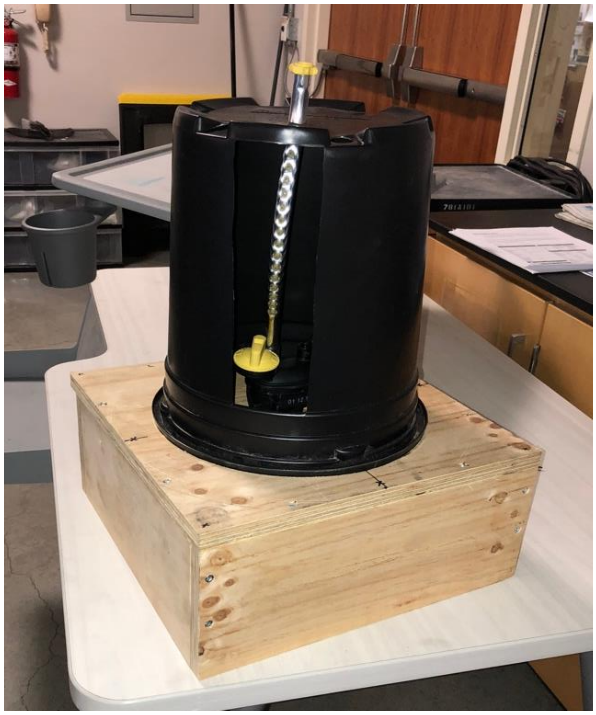

Figure 4-1. Concept prototype.

The base dimensions are not yet solidified; however, the rotating top housing will be 8 inches in diameter and 14 inches tall. Eventually, the base and housing of the final product will be constructed out of a thin, weather-resistant plastic. As for the concept prototype, we have chosen to build a square wooden base and use a plastic bucket for the top as this is simple to manufacture. The main component of our concept that is still under review is the connection between the base and rotating top housing. We are researching and developing the best way to integrate a motor and turntable assembly into our design, whether through gearing, pulleys, or other means.

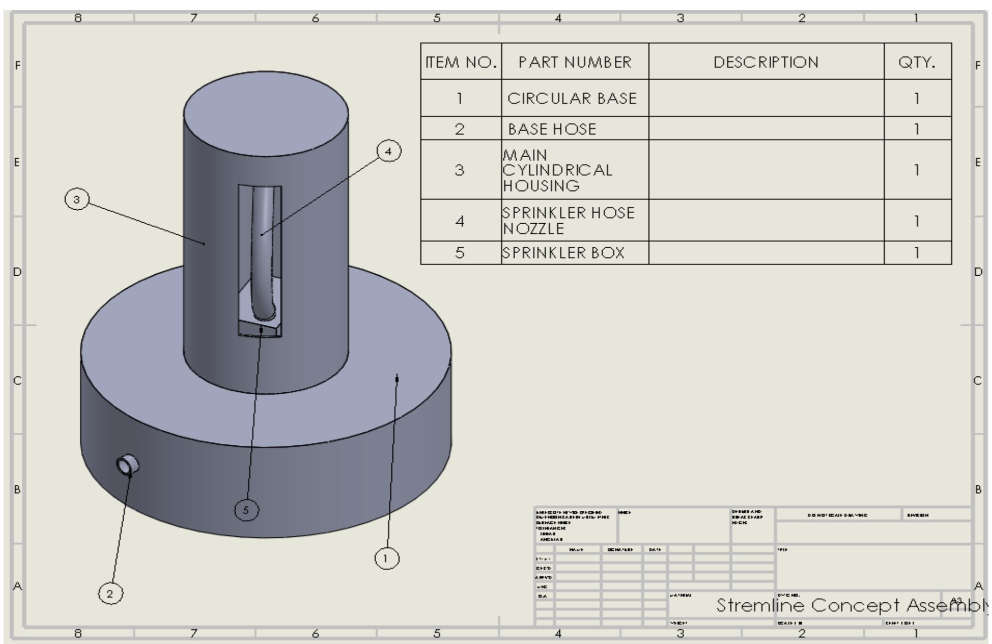

Figure 4-2. Initial concept CAD with BOM.

4.3. Preliminary Analysis and Tests

Our team performed a handful of preliminary tests, mainly focused on the water distribution of the oscillating sprinkler we plan to use. One of the primary specifications this device must meet is the ability to effectively dispense water in a circular area of about 2500 square feet (a radius of 28 feet). We ran the first test at maximum hose water pressure, which was 60 psig in this case, and measured the maximum spray distance of the oscillating sprinkler when positioned vertically. From this test, we concluded that the maximum distance was 30 feet, but the volume of water dropped sharply after 25 feet. Up until this cutoff distance, the water distribution was very even and accurate.

The second test we ran involved measuring flowrate to quantify the water consumption of our sprinkler. We attached a flowmeter to the hose and measured the flowrate, Q (gpm), at various water pressures to get a range of Q values based on spray distance. Figure 4-2 contains a plot detailing the flowrate data we gathered compared to Newtonian projectile motion. Even at maximum pressure, the flowmeter showed a relatively small flowrate of 4 gallons per minute. In addition, after running the sprinkler for a 5-minute interval, approximately 4 ounces of water collected in a 3-inch diameter cup. Extrapolated out, this corresponds to 16 ounces of water per 1 square foot in a minute. We obtained this data by setting up cups at 5-foot increments and measuring the volume of water that gathered in a set amount of time.

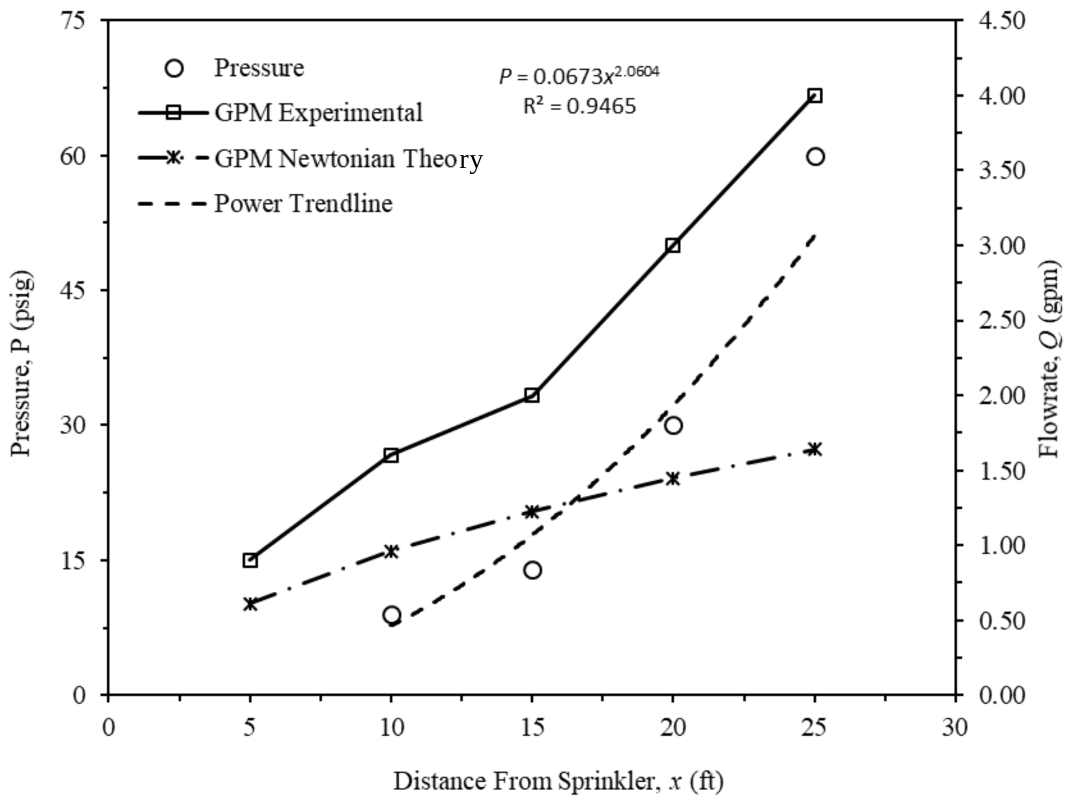

Figure 4-3. Pressure and flowrate versus distance from the sprinkler for experimental data and Newtonian theory.

4.4. Risks, Challenges, and Unknowns

The anticipated challenges with our chosen design direction are manufacturing an inexpensive final prototype, keeping power consumption low to maximize battery life, and realizing the full potential of our thermal camera. The housing, rotation, and camera components of our concept are specialized, which will increase expense significantly. Since our batteries will be running a servo motor, microcontroller, electric valve actuator, and thermal camera, we need to focus on low power expenditure. Our current experience with the Seek thermal camera, which plugs into an iPhone, leads us to believe that their depth of view does not match the datasheet specification on their website. Further signal analysis of Flir Lepton imaging will need to be performed in order to ensure it will fit our project requirements.

Risks and safety hazards have been preliminarily analyzed regarding our prototype design. The Design Hazard Checklist allowed us to run through potentially dangerous scenarios and determine if there are ways to minimize the risks associated with E.M.B.E.R. Descriptions of our related hazards along with plans to correct for them are located in Appendix VI.

One of the remaining unknowns that we have yet to solve is a successful way to make our electronics water resistant, while not insulating so much that they overheat. Additionally, the cool temperature of our water spray will likely wash out the thermal imaging camera. This requires us to develop an advantageous spray schedule that balances extinguishing embers with checking ember temperature.

5. Project Management

5.1. The Overall Design Process

The first few weeks of the design process were dedicated to developing an accurate scope of the project, determining the users, their wants and needs, and researching products and patents that already exist. All of the work completed in the beginning stages culminated in the Scope of Work, providing our sponsor with an idea of the direction we plan to take with this project.

The next few weeks were committed to concept models and prototype design selection ultimately leading to this Preliminary Design Review. Determining a final concept involved extensive brainstorming sessions and multiple meetings with our sponsor to ensure that the team is following in the path they envisioned. The team began design analysis and manufacturing a concept prototype. After the PDR, a manufacturing plan will be developed, and the Critical Design Review will be held with our sponsor to gain approval for the final design.

After the final design has been agreed upon, we will make a bill of materials and acquire the necessary parts to begin manufacturing. During manufacturing, the team will perform risk assessment, and then, perform testing procedures after manufacturing is complete. Finally, an operators' manual will be written, and a safety demo will be performed before the Final Design Review and presentation of the finished product. Table 5-1 is a succinct overview of all the major deliverables throughout the three quarters of this project. Refer to the Gantt chart in Appendix VII for complete project timeline breakdown.

Table 5-1. Overview of the major project deliverables.

Quarter	Week	Date	TASK
Q1	W4	2/1	Scope of Work
	W9	3/5	Preliminary Design Review Presentation
		3/8	Preliminary Design Review Report
Q2	W2	4/11	Interim Design Review
	W5	4/30	Critical Design Review Presentation
		5/3	Critical Design Review Report
	W7	5/16	All Parts Ordered
	W9	5/31	Manufacturing and Test Review Poster
Q3	W4	10/17	Senior Exam
	W5	10/22	Confirmation Prototype Review
	W9	11/29	Project Expo

5.2. What's next?

A few important upcoming milestones are the Interim Design Review and Critical Design Review, at which point we will have a detailed design with a refined CAD model and a manufacturing plan laying out exactly how we intend to manufacture our product with all the specific parts used in the design. We will be producing a structural prototype which is intended to function and look much closer to the final product. In addition, we will be performing fire extinguishing, flammability, and camera tests in the Cal Poly engines lab. A large majority of the preliminary analysis, research, and concept modeling is complete. Now, we are focused on developing and manufacturing our selected design.

6. Conclusion

In conclusion, the scope of this project is to create an automated sprinkler device which can detect and suppress small spot fires. Specific specifications of this sprinkler can be found in Section 3.4. Based on a large number of responses to the survey we sent out and an interview with an operations manager for State Farm Fire and Casualty Company, we have narrowed down the target customer and ideal price point that homeowners will be willing to pay. The target customer is determined to be upper-middle class homeowners living in medium to high risk fire areas. The ideal price point is approximately $500 because over 70% of survey respondents indicated that they would be willing to pay at least that much for a device such as ours.

We have narrowed our project down to a single design that we feel combines all of the functions listed in our Pugh and Weighted Decision Matrices (Appendix IV and V) into an efficient, effective, and low-cost product. A concept CAD model and prototype can be found in Section 4.2. We came to our design conclusion by conducting a thorough ideation and concept selection process (Section 4.1) and taking data retrieved in a preliminary sprinkler test (Section 4.3) to determine that the sprinkler selected has adequate range, accuracy, and efficiency to meet our specifications.

The Critical Design Review, our next project deliverable, is to be completed and presented by May 3, 2019. We will continue to develop and refine the concept for our selected design. Involved with the Critical Design Review is a more detailed structural prototype and manufacturing plan for our product.

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Figure References

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[3] “Orbit.” *Orbit Irrigation | The #1 Choice of Homeowners for Sprinklers, Drip, Mist, Hose End Irrigation*, www.orbitonline.com/products/hose-watering/sprinklers/specialty/pest-control/yard-enforcertm-on-spike-2688.

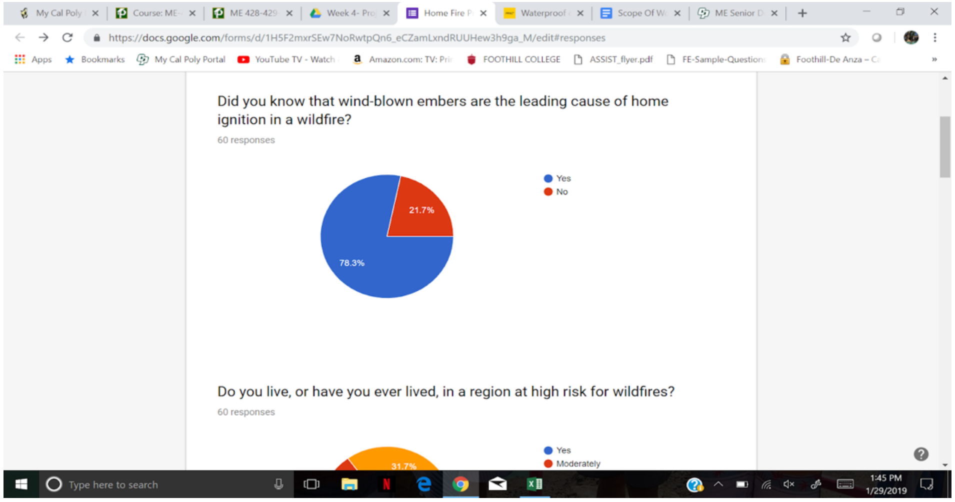
[4] Yusufm.com, Okler.net And. “Plumis.” *Traditional Sprinklers Impractical? Approvers Trust Automist*, plumis.co.uk/automist.html.

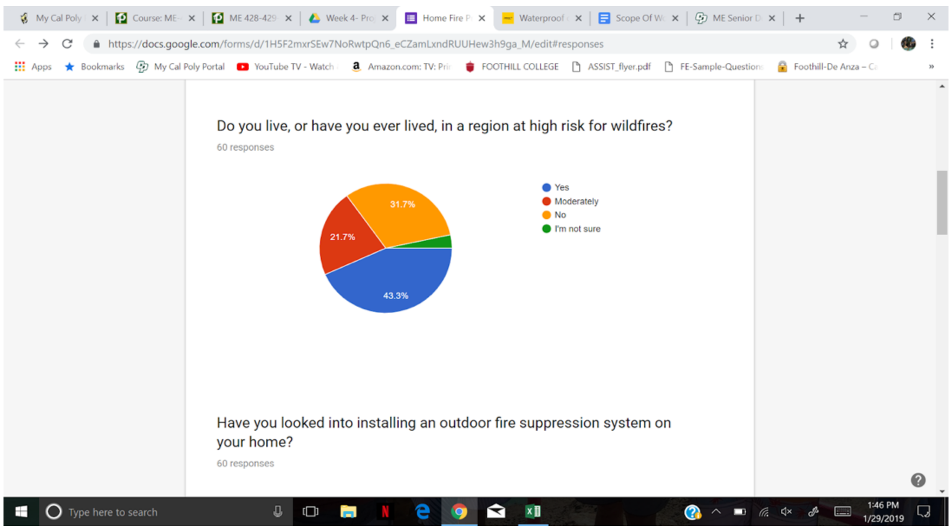
[5] “Wildfire Protection Systems.” *Consumer Fire Products, Inc.*, www.consumerfireproducts.com/wildfire-protection-systems.html.

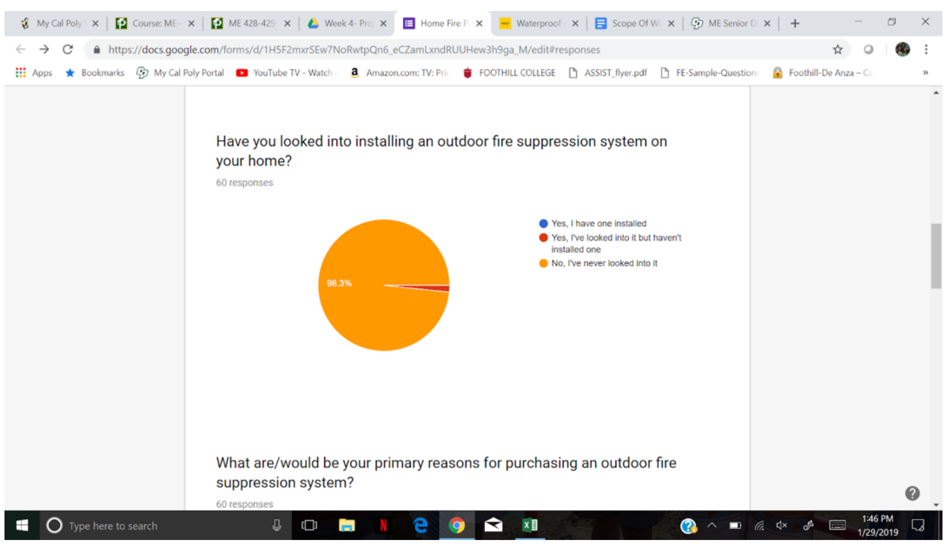
[6] “WASP Patented Gutter Mount Sprinkler System.” *WASP | Wildfire Automated Sprinkler Protection | Remote Sprinkler Protection*, www.waspwildfire.com/the-wasp/wasp-gutter-mount-sprinkler-system/.

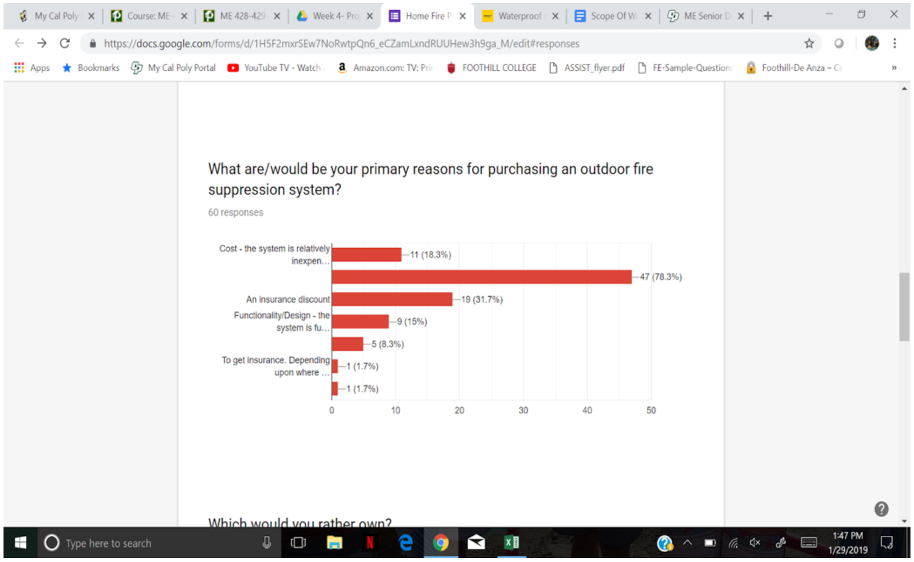
Table of Appendices

I. Customer Survey

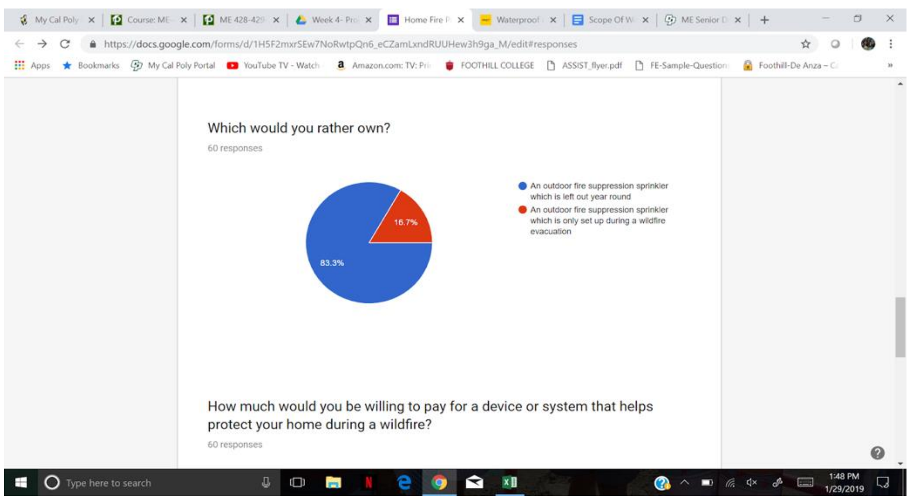




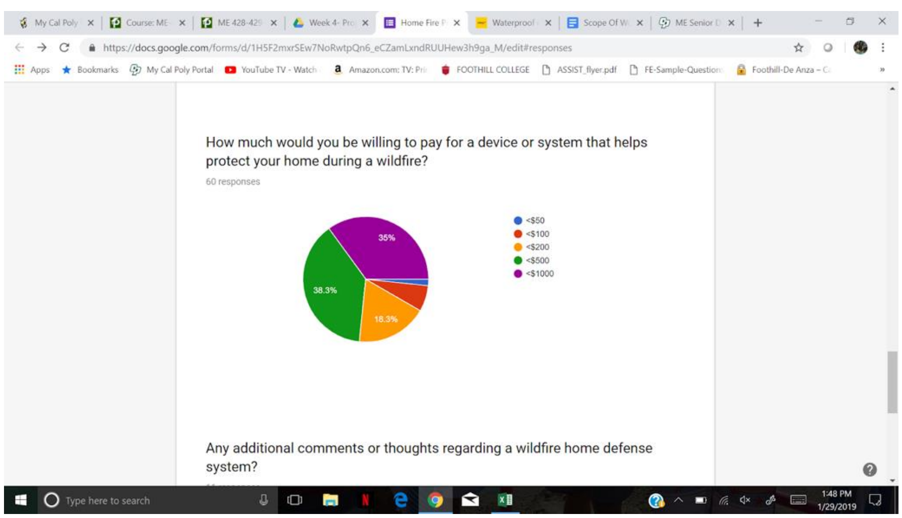




What are/would be your primary reasons for purchasing an outdoor fire suppression system?
60 responses
Cost - the system is relatively inexpen...
An insurance discount
Functionality/Design - the system is fu...
To get insurance. Depending upon where ...
11 (18.3%)
47 (78.3%)
19 (31.7%)
9 (15%)
5 (8.3%)
1 (1.7%)
1 (1.7%)
0
10
20
30
40
50



Which would you rather own?
60 responses
An outdoor fire suppression sprinkler which is left out year round
An outdoor fire suppression sprinkler which is only set up during a wildfire evacuation
16.7%
83.3%



How much would you be willing to pay for a device or system that helps protect your home during a wildfire?
60 responses
<$50
<$100
<$200
<$500
<$1000
35%
38.3%
18.3%
Any additional comments or thoughts regarding a wildfire home defense system?

II. QFD House of Quality

Correlations	
Positive	+
Negative	–
No Correlation	

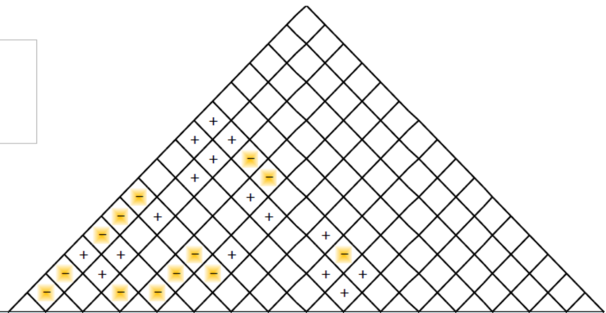
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: Team E.M.B.E.R.

Revision Date: 1-29-19



								Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16						
	WHO: Customers							Direction of Improvement	▼	▲	◇	▼	▲	▲	▲	▲	▼	◇	▼						NOW: Curr. Products					
Row #	Weight Chart	Relative Weight	Wealthier homeowners	Average homeowners	Commercial	Government	Maximum Relationship	HOW: Engineering Specifications (Tests) / WHAT: Customer Requirements (Needs/Wants)	Weight	Power Source	Waterproof	Manufactured Cost	Coverage Area	Heat Resistance	Battery Life	Accuracy	Set up time	Type of fluid	Mechatronic Complexity						Our Current Product	Firefighter	Hoser On A Roof	Leave Sprinkler On	Wasp	Row #
1		5%	2	8	2	1	9	Affordable	○	●	▽	●	○	○	●	●	▽	●	●						4	5	5	4	2	1
2		4%	5	5	1	1	9	Small	●	●	▽	○	●	▽	●	○	○	●	●						4	1	2	4	5	2
3		6%	7	7	1	1	9	Easy/quick installation	○	●	▽	▽	▽	▽	▽	▽	●	●	▽						5	4	5	5	5	3
4		15%	10	10	8	8	9	Fully automated	○	○	▽	○	○	▽	●	○	●	▽	○						5	5	5	5	3	4
5		2%	1	3	1	1	9	Operate as regular sprinkler	▽	○	▽	○	○	▽	●	▽	▽	●	○						2	3	1	5	1	5
6		12%	7	7	7	7	9	Work continuously	▽	●	▽	●	▽	▽	●	▽	▽	●	▽						3	4	3	2	5	6
7		5%	3	1	1	7	9	App connectivity	▽	●	▽	○	▽	▽	○	▽	○	▽	●						4	4	3	1	5	7
8		6%	7	5	2	2	3	Desirable	▽	▽	▽	○	▽	▽	▽	▽	▽	▽	▽						4	4	1	1	3	8
9		9%	4	5	6	6	9	Robust	●	○	●	○	▽	●	○	▽	▽	▽	○						4	4	3	2	4	9
10		7%	3	8	3	3	9	Power efficiency	○	●	▽	○	○	○	●	○	▽	○	○						3	5	3	1	5	10
11		10%	6	8	5	5	9	Large area of coverage	○	○	▽	○	●	▽	▽	○	▽	●	○						4	5	2	5	5	11
12		6%	7	7	1	2	9	Low water consumption	▽	▽	▽	▽	○	▽	▽	●	▽	●	▽						3	1	1	1	3	12
13		14%	9	9	8	8	9	Safety	▽	●	●	○	▽	○	▽	▽	▽	○	▽						5	4	1	2	4	13
14		0%	0	0	0	0																									14
15		0%	0	0	0	0																									15
16		0%	0	0	0	0																									16

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	HOW MUCH: Target Values	Weigh Less than 5lbs	Remains on after power goes out	Must be water resistant up to IPX 5	Less than $200	Minimum 2500 sqft	Max Surface Temp of 150⁰F	12 hrs under full operation	Within 1ft radius of spot fire	Within 15 min	Must accept water	Involve no mechatronic setup/input from user					
	Max Relationship	9	9	9	9	9	9	9	9	9	9	9					
	Technical Importance Rating	289.2	589	285.1	375.2	280.1	223.1	482.7	256.5	281.7	495.7	298.4	0	0	0	0	0
	Relative Weight	7%	15%	7%	10%	7%	6%	13%	7%	7%	13%	8%	0%	0%	0%	0%	0%
Curr. Products	Our Current Product																
	Firefighter	0	0	0	5	5	5	5	5	3	5	5					
	Hoser On A Roof	0	0	0	5	5	5	5	5	5	5	5					
	Leave Sprinkler On	0	0	0	5	2	5	5	0	5	5	5					
	Wasp	5	0	5	4	4	3	5	4	2	5	5					
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

III. Ideation

Mounting & Gimbal	Nozzles & Fluids	Camera & Mechatronics	Packaging	Miscellaneous
Staked in-ground	Nozzle angle	Number of cameras?	Flame-resistant	Multiple systems
Stakes & plate	Flowrate adjustment	One camera	Heat-resistant	Quadrant of smoke detectors
Leveling bubble	Nozzle angle default at 45 degrees; adjust to needed	Two cameras	All fits into pelican case	Remote-controller capacity
Auto-leveling	Full range; "rain down"	Imaging camera type	Plastic v. metal?	Warranty
Moving	Triggers homeowner's sprinkler system	Range of camera specified	Run off of Arduino	Water yard before?
Roof of house	Tubing system	Negate "wrong target" problems	Fan and hole in the bottom/mouth allowing heat to escape	After first ember, the danger is already there.
Maximize range	Waterproof from itself	Research further into blackbody radiation	Layering system	Init state that waters the yard initially.
Sprinkler on a Plate	Nozzle height above ground	Cameras all around		Should it aim or spray whole yard? If it sprays the whole yard it could prevent future flare-ups.
	Top & bottom nozzle idea	Cameras fixed		
	What Reynolds number is most effective?	Rotating nozzle		
	Minimize minor/major losses	Cameras set up around the yard		
	Find flowrate and average losses of common hose; set as standard for model	Camera resolution?		
	Attach hose when needed	Motor driver		
	Hose directly to base, or adapter?	Motors?		
	Own line for hose.	Stepper motors		
	Width/shape of stream	Servos		
	Mist is effective	Arduino/Microcontroller?		
	Water stops fire from re-lighting.	Backup Battery		
	Component of motion powered by hydraulic forces	How many batteries?		
	Soak, then go out	Roving mode		
	Don't waste water, though	Battery life balancing: performance vs. mechatronic complexity		
		Solar panel		
		Net-zero/net-positive in roving mode		
		Current and voltage?		
		On switch? Or always in roving mode?		
		Phone app?		

IV. Pugh Matrices

Function: Fire Detection		Alternatives					
Criteria	Weight	Flir Lepton	Total	Seek Thermal	Total	Temperature Gun	Total
Cost	3	1	3	2	6	4	12
Distance	1	4	4	4	4	3	3
Accuracy	4	4	16	3	12	1	4
Power Efficiency	2	4	8	4	8	4	8
	Final Total		31		30		27
	Rank	1		2		3	

Function: Water Dispersion		Alternatives					
Criteria	Weight	Oscillating Sprinkler	Total	Angled Nozzle	Total	360° Spray	Total
Cost	3	5	15	3	9	5	15
Distance	1	4	4	3	3	4	4
Accuracy	4	4	16	4	16	3	12
Low Consumption	2	4	8	5	10	1	2
	Final Total		43		38		33
	Rank	1		2		3	

Function: Motion		Alternatives					
Criteria	Weight	Servo Motor	Total	AC Motor	Total	Stepper Motor	Total
Cost	3	5	15	3	9	4	12
Speed	1	4	4	3	3	3	3
Accuracy	2	4	16	3	12	4	16
Power Efficiency	4	4	8	3	6	2	4
	Final Total		43		30		35
	Rank	1		3		2	

Function: Electronics		Alternatives					
Criteria	Weight	Raspberry Pi	Total	Arduino	Total	STM32	Total
Cost	3	4	12	4	12	4	12
Ease of Use	1	4	4	4	4	4	4
Memory	4	5	20	3	12	4	16
Power Efficiency	2	3	6	4	8	4	8
	Final Total		42		36		40
	Rank	1		3		2	

V. Weighted Decision Matrix

Morphological Matrix			
Fire Detection	Flir Lepton	Seek Thermal	PIR Sensor
Water Dispersion	Oscillating Sprinkler	Angling Nozzle	Single 360° Sprinkler
Motion	Servo Motor	AC Motor	Stepper Motor
Electronics	Raspbery Pi	Arduino	STM32

Criteria	Weight	Flir Lepton, Oscillating Sprinkler, Servo Motor, STM32		Seek Thermal, Oscillating Sprinkler, Servo Motor,		Flir Lepton, Angling Nozzle, Stepper Motor, Raspberry Pi		Seek Thermal, Angling Nozzle, Stepper Motor, STM32		Flir Lepton, Oscillating Sprinkler, Stepper Motor,	
		Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Cost	3	3	9	4	12	1	3	2	6	3	9
Coverage Area	2	5	10	5	10	2	4	2	4	5	10
Accuracy	4	4	16	4	16	5	20	5	20	4	16
Efficiency	5	5	25	4	20	2	10	3	15	3	15
Capacity	1	4	4	3	3	5	5	4	4	3	3
	Total	64		61		42		49		53	

VI. Design Hazard Checklist

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
The system will have revolving components and gears.	Enclose the gears to not allow human fingers to fit inside.	5/20/2019	
The system will have a revolving top component that may accelerate and decelerate quickly.	Run the closed loop servo motor with a gain saturation to ensure that the angular acceleration does not exceed an unsafe amount.	5/20/2019	
The system will have potential pinch points. The device is going to rotate using gears meaning there are potential pinch point hazards in the gears.	Enclose the gears to not allow human fingers to fit inside and keep the nozzle window small enough to avoid pinching fingers.	5/20/2019	
The system will be exposed to potentially extreme environmental conditions because it is intended to be left outdoors year-round and in range of wildfires.	Create a housing the insulates the device from the environmental conditions and heat.	5/20/2019	

VII. Gantt Chart