Senior Design One: Divide and Conquer Version One

Group 4

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Project Narrative:

Over 100,000 forest fires have occurred worldwide . In the past, forest fires were considered a natural cycle and were ignored [1,3]. However, with increasing awareness emphasizing the preservation of natural resources, as well as recent forest fires, have put forest fires at the forefront of global environmental concerns especially due to the fires Australia in 2001 and 2002 and USA in 2002[2]. Forest fires not only increase the levels of carbon dioxide in the atmosphere, but also burn vegetation and plants that act as nature's CO2 sinks.

The increased carbon dioxide impacts air quality leading to smog and escalates the rate of global warming causing heatwaves [2,4]. In addition, humans and endangered animals' fatalities have been reported due to forest fires. As a result, forest fire detection and monitoring systems have sparked the interests of scientists and researchers worldwide.

The purpose of this project is to design and build a solar powered forest fire detection and monitoring system that will serve as a preventive measure for forest fires. This device would ideally be used in areas where human activity is present such as campsites especially parts of the forest that are highly susceptible to forest fires. This device can also be used to monitor and detect forest fires in general to help researchers and firefighters determine incoming fires or the severity of the existing fires. Thus, the device is aimed for prevention and facilitate extinction of forest fires.

The devices will be portable so that in can be mounted on trees nearby. The method of fire detection will include flame and smoke detection. The sensors used will be infrared sensors, ultraviolet sensor, thermographic camera, combustible gas sensors, metal-oxide-semiconductor sensors, electro-chemical sensors, and temperature and humidity sensors. A mesh network will be adopted for the monitoring system.

Current forest fire detection and monitoring systems use video cameras to recognize smoke spectrum, thermal cameras to detect heat glow, IR spectrometers, and LIDAR (detection of light and range) to detect smoke particles using reflected laser. The following forest fire detection and monitoring systems exist in the market:

1. AlarmEYE:
    a. video and infrared system using black and white color frequency.
2. EYEfi SPARC:
    a. Optical sensors that includes camera, light sensors, communication, weather, power system, option for tilt zoom camera.
    b. Does not include smoke detection
3. UraFire:
    a. Smoke detection system focused on “clustering motions and a time input”
4. Forest Fire Finder:
    a. Analyzes how atmosphere absorbs light and differentiates absorption behavior
    b. Can detect smoke in a range of 15km
5. ForestWatch:
    a. Sensor camera mounted on a tower using a using a 360° pan tilt camera that scans the forest in a range of 16-20km for smoke in the daytime and flame at night.
6. FireWatch:
    a. Optical sensor system that scans the forest using a 360° camera with a central office for monitoring and data processing.
7. FireHawk:
    a. Cameras stationed strategically in the forest, the system uses GIS mapping and ForestWatch software to calculate the shortest distance to the fire.

Example project research - Early forest fire detection using low-energy hydrogen sensors (Resource [5])

Fig 1: Forest fire detection hydrogen sensor implementation

“After establishing that hydrogen could be detected at 25m, the distance was increased to 85m and then finally to 110m. The smoldering organic matter representing the source of the fire had a constant area of approx. $2m^2$ and was located at the center of the test area. The stand structure in terms of tree species, age and spacing is not only very important with regard to forest fire hazard, but also for the positioning of the sensors in the stand. Where young pine stands are planted in rows, this creates regular wind channels, so that in this case positioning the sensors along transects seems appropriate. In older, more open stands, a grid-like array is recommended, because in this case the changing wind direction will have a greater influence. In stands with higher canopies, the gases released by smoldering matter have more scope for spatial distribution. Wind speed and direction determines to a considerable degree the appropriate distribution of the sensors.”

DOI: 10.5194/jsss-2-171-2013[5]

Table 1 – Requirements

Table 1 and Table 2 below show the preliminary expected requirements and constraints as determined by the project specification.

ID	Category	Requirement
R1	System	The system shall detect the presence of a fire within 100m
R2	Electrical	The system shall be able to draw power from a battery or solar panel at any time
R3	Electrical	The system shall charge a battery with solar panel
R4	Electrical	The system battery shall last 36 hours without charging
R5	Electrical	The system shall communicate wirelessly to nearby nodes
R6	Software	The system shall differentiate other nodes and determine how to send data to hub
R7	Software	The system shall read all sensors periodically and store data internally
R8	Software	The system shall process all sensor data to determine if a fire has started
R9	Electrical	The system shall read voltages of the battery to determine health
R10	Software	The system shall report its own status/health to the hub.
R11	Software	The system shall store configuration and user defined data in non-volatile memory
R12	Mechanical	The system shall withstand fires up to 4 hours
R13	Mechanical	The system shall be able to withstand normal weather conditions
R14	Electrical	The system shall monitor environment with temperature and humidity sensors
R15	System	Average installation time should not exceed 30 minutes
R16	Mechanical	The system shall be able to withstand normal weather conditions
R17	Electrical	The system shall verify environment with temperature and humidity sensors

Table 2 – Constraints

ID	Category	Requirement
C1	Electrical	The system shall use solar power when available instead of the battery
C2	Mechanical	The system shall not be bigger than a bird’s nest. (15 x 15 x 15 cm)
C3	Mechanical	The system shall be mounted to a tree

House of Quality

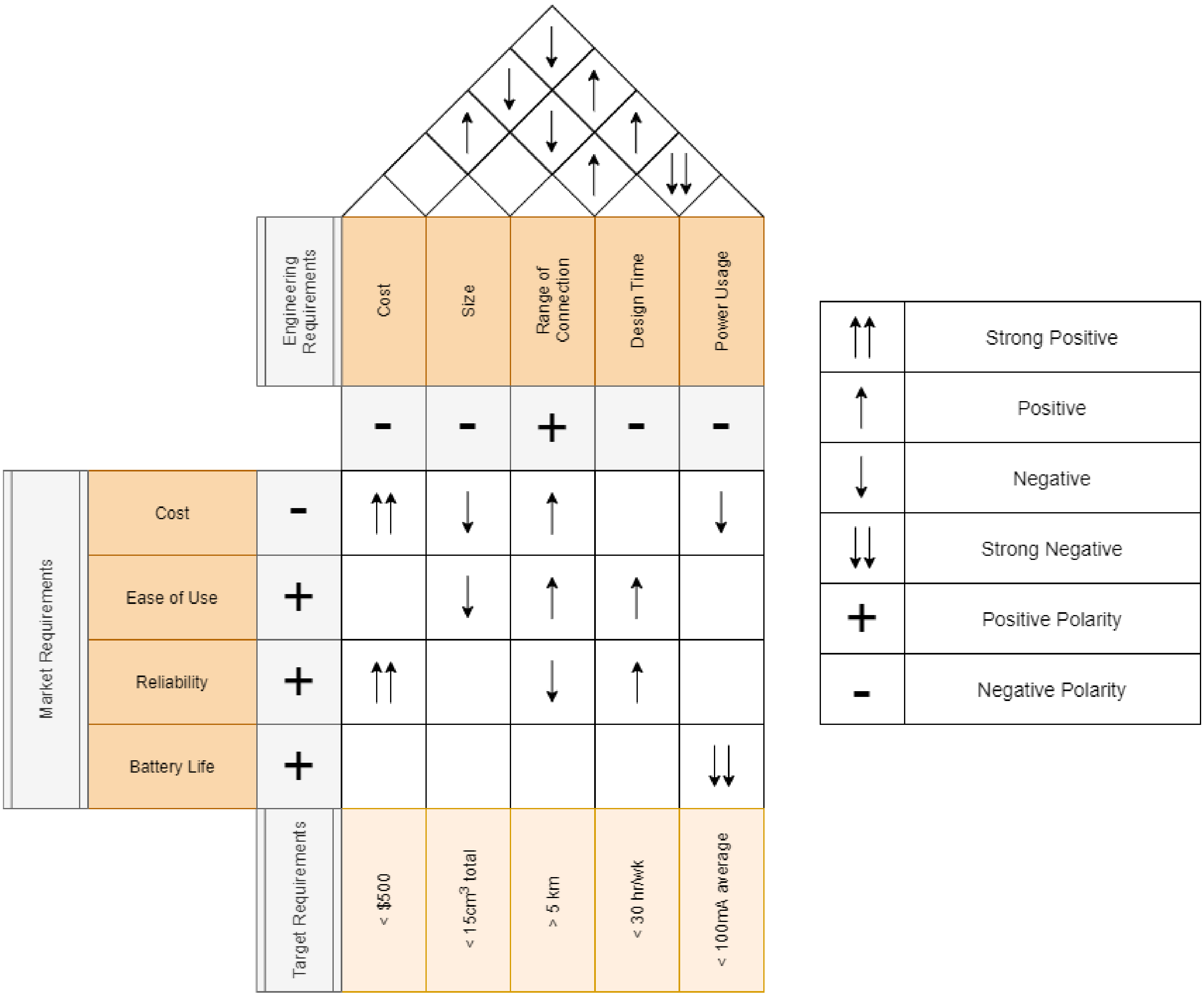

Fig 2: House of Quality

Table 3 - Approximate Cost

The cost of the system is important. The data included in Table 3 is a rough cost estimate on items that we believe could be implemented or critical to the system. This table does not guarantee that we find cheaper alternatives, nor is it fully representative of the final cost and the final design (i.e. a thermal camera may not necessarily be used in the final design, but it is included here). The table acts as a guide to see the general cost for the system and initial plan. Cost is determined by the distributor price when buying one of the items not in bulk.

Item	Minimum Unit Cost ($)	Maximum Unit Cost ($)
Solar Panel System	10	100
Sensors*		
Gas sensor	.10	15
Infrared sensors	1	30
Thermal Camera / Sensor Array	20	4,000
Temperature	.10	1
Humidity	.10	1
Electronics*^		
Controller	1	20
General components (resistor, capacitors, inductors, connectors)^	10	30
Specialized components (voltage regulation, MPPT, RF)^	10	30
PCB Manufacturing*^	20	20
Prototype (machine shop labor) (if applicable)	80	80
Development kit (for software)^	15	30
Miscellaneous (solder, jumper wires, coffee)	20	40
Total Cost**	$187.30	$417.00***

* Shipping not included in cost approximation

** Assuming one of each was purchased and each is used in the final design. Some items in this list may not be used.

*** Cost include the minimum price for Thermal Camera/Sensor Array, not maximum.

^ This item is not necessarily inclusive, i.e. it does not include administrative or other costs.

Block Diagrams

On the next few pages are our block diagrams. These diagrams help keep us on target with our requirements and allow us to follow a plan on how to implement our overall design. Each diagram contains arrows that point to a connected segment. Each connected segment is a functional block that must be connected, with power or signal or data, to another segment. In **Fig 1** the color-coded arrows represent the data path or average current direction of the system. **Fig 1** is our hardware design plan. **Fig 2** represents our software design plan, and the arrows represent logical connections between the segments. The "connection" can be made implicitly, by copying into a function, or by sharing a block of memory between two parts of the software.

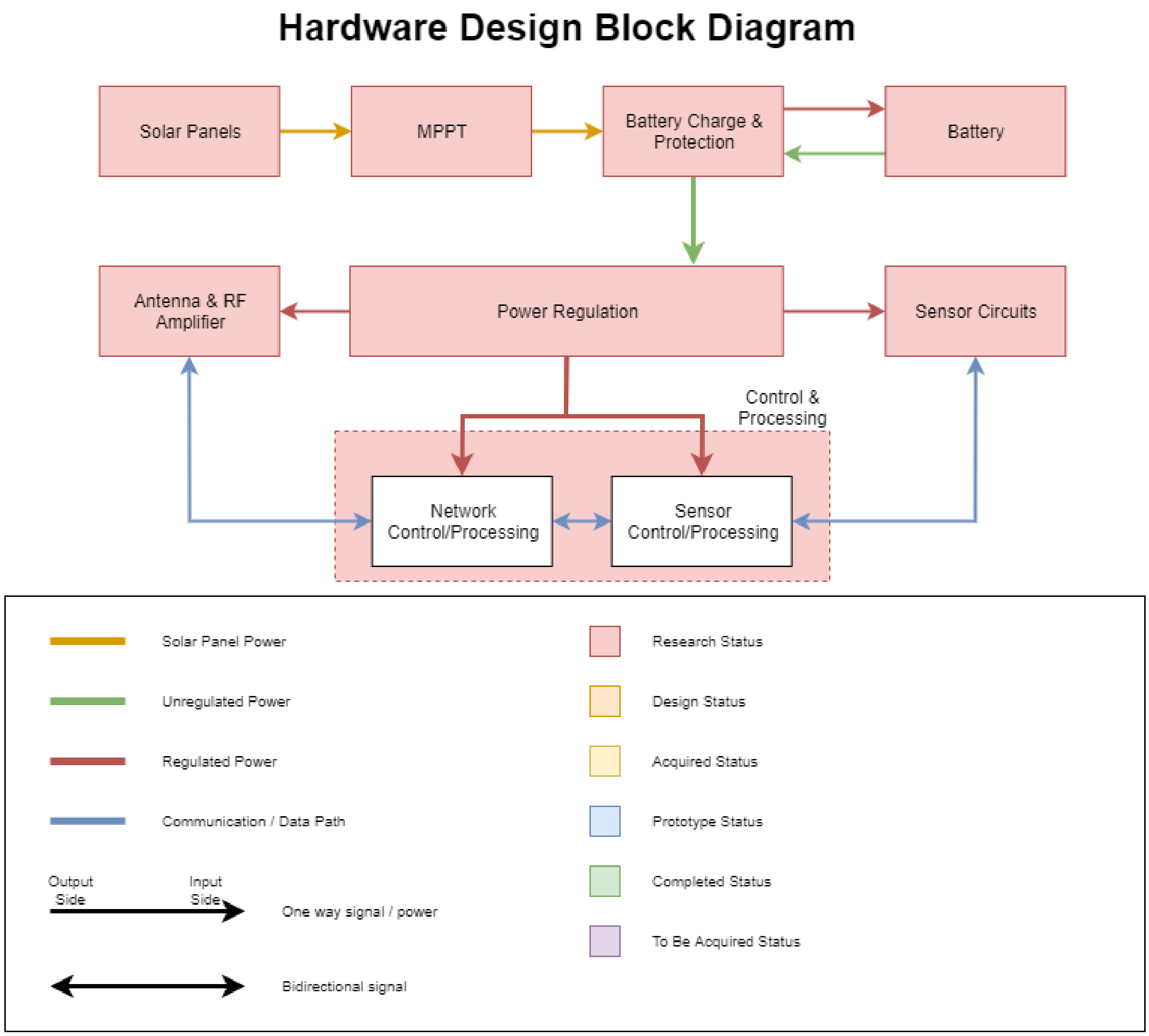

Fig 3: Hardware Design Block Diagram

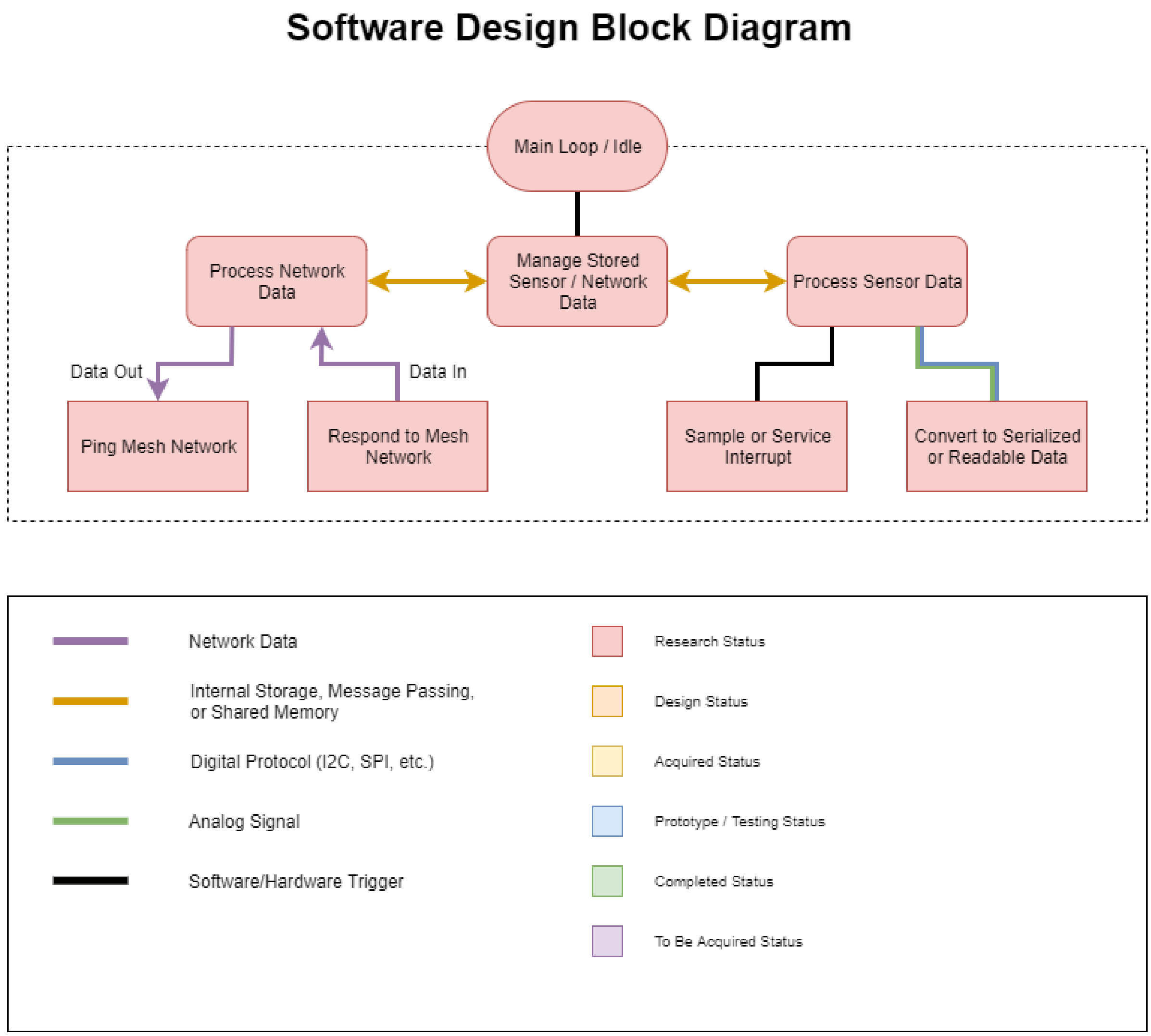

Fig 4: Software Design Block Diagram

Table 4 – Schedule for Spring 2020

Below is **Table 4** which shows our schedule we will follow over the next few month during the spring semester. Our goal, as shown below, is to be prepared to assemble the prototype by the end of the semester.

Week	Milestone (Tasks)	Start Date	Deadline
1 to 2	Brainstorm ideas	January 06, 2020	January 17, 2020
3 to 4	Choose a project and discuss basic design and roles	January 20, 2020	January 31, 2020
4	Finish Divide and Conquer V1		January 31, 2020
5	Discuss the details of the project (components, functions, design)	February 03, 2020	February 07,2020
5 to 6	Update Divide and Conquer V2 Finish proposal for sponsor	February 03, 2020	February 14, 2020
6 to 9	Research and fine-tune design	February 17, 2020	March 06,2020
9	SPRING BREAK		
10	60-page Draft		March 20, 2020
10 to 12	Finalize design Finish technical documentation	March 16, 2020	April 03, 2020
12	100-page Report		April 03, 2020
12 to 15	Organize all documentations Acquire materials and components for prototype	April 06, 2020	April 17, 2020
15	Submit Final Documentation		April 21, 2020

Table 5 – Schedule for Summer 2020

Table 5, shown below, is our Summer 2020 schedule. This table has an accelerated build/test cycle which starts in May and we expect to enter final testing on or before July 6th.

Week	Milestone (Tasks)	Start Date	Deadline
1 to 2	Assemble/ Build prototype Test components	May 11, 2020	May 22, 2020
3	Acquire components for final product Adjust documentation	May 25, 2020	May 29, 2020
4	Build final product	June 01, 2020	June 05, 2020
5 to 6	Integration Testing (hardware and software)	June 08, 2020	June 19, 2020
6 to 7	Make necessary adjustments	June 22, 2020	July 3, 2020
8	Final testing	July 6, 2020	July 10, 2020
9	Finalize product	July 13, 2020	July 17, 2020
10 to 11	Finalize documentation	July 20, 2020	July 31, 2020
11	Final Product		July 31, 2020

Mechanical Design Ideas:

The following mechanical designs are some ideas on how the system will be mounted. All the designs are meant to be mounted to a tree or other tall/natural structure. The first design, **Fig 3,** simply gets mounted to the side of the structure. This works great for a small system and large trees. The second design, as represented in **Fig 4**, would have a large loop that gets wrapped around an older tree that would fasten the system to a tree branch/trunk. The design shown in **Fig 5** would get hung on a tree branch up high. Finally, the fourth design idea in **Fig 6** would get clamped around a tree branch high in the tree. The estimated size of the system is only 15cm. Each design is to be constructed with an outer covering that is fire resistant for a certain timeframe and protects the internal components for a small amount of time.

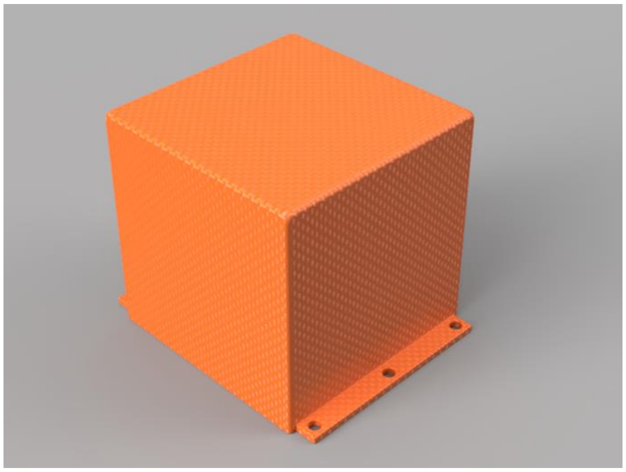

Fig 5: Nick's mechanical design idea

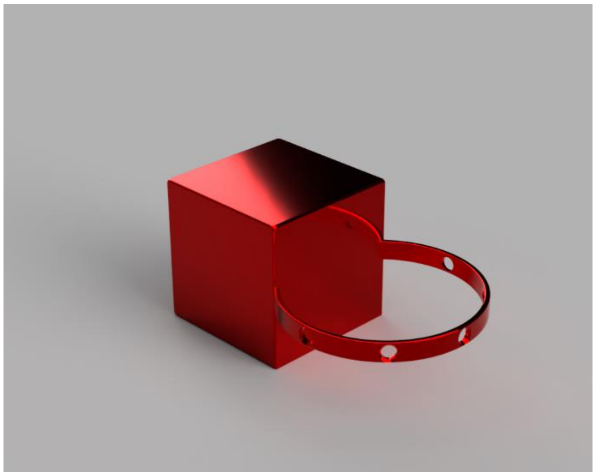

Fig 6: Noora's mechanical design idea

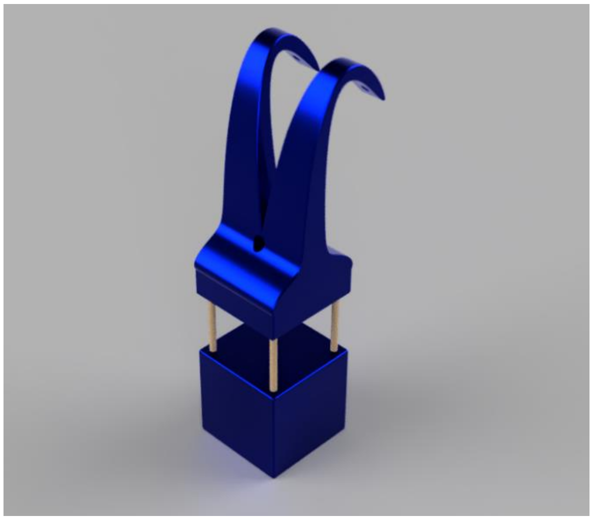

Fig 7: Arisa's mechanical design idea

Fig 8: Jonathan's mechanical design idea

Research

Gas sensors:

Gas sensors are a way to verify the likelihood that our sensor has detected a fire. The system must detect a fire with great confidence.

"Gas emissions are also particularly relevant during smoldering fires. This is a form of combustion that mostly occurs in porous or grained but densely packed materials. Air diffuses through the pores and produces combustion in the inner side of the material. The combustion products in smoldering fires are typically different from the ones generated in open flame fires." [6]

By using a gas detector to read the chemical composition of the air around the system, finding a fire with our methodology can have an increased confidence that a fire is, in fact, present in the detection area. As shown in Table 6, the different concentrations of chemicals could allow us to pinpoint the difference between normal conditions to a fire condition.

Table 6 – Concentration measurement ranges for fire emissions provided by different vendors [6]

Gas	IST	Alphasense	GfG
NH_3	√ 10 ppm	√ 100 ppm	√ 200 ppm
CO	√ 300 ppm	√ 500 ppm	√ 300 ppm
H_2	√ 2000 ppm	√ 2000 ppm	√ 2000 ppm
HCl	√ 30 ppm	√ 100 ppm	√ 30 ppm
HCN	√ 30 ppm	√ 100 ppm	√ 50 ppm
HF	√ 10 ppm		√ 10 ppm
HBr			√ 30 ppm
H_2S	√ 30 ppm	√ 100 ppm	√ 100 ppm
NO	√ 100 ppm	√ 100 ppm	√ 100 ppm
NO_2	√ 50 ppm	√ 20 ppm	√ 30 ppm
SO_2	√ 100 ppm	√ 20 ppm	√ 10 ppm
O_2			25%

Smoke detection:

"The most popular and widespread fire alarm systems are based on the detection of smoke"[6]

Another method researched was using a smoke detector, similar to inside a home. This is a tried and true method of finding a fire. If there are particles, then there is a good chance of fire.

"Smoldering fires produced larger particles, which were captured faster by photoelectric detectors. On the other hand, smaller particles, which are found in flaming fires, were detected faster by ionization detectors. Moreover, the results indicated that, given the same consumed mass, smoldering fires resulted in more smoke particles than flame fires. They also found that ionization alarms could not detect some smoldering fires that photoelectric alarms detected. This became more relevant for smaller burning quantities that generated less smoke than the 10% obscuration/ft specified in the UL 217 standard." [6]

By using smoke sensors, we might be able to simplify the design by looking for, not only the fire itself, but it's smoke.

Computer Vision:

Using typical object detection frameworks such as YOLO:

There are many known frameworks for detecting objects such as YOLO (You Only Look Once). However, they tend to lack accuracy when it comes to small objects such as fire that can easily blend in with the background in a daylight. To verify this, we would have to train and test a model specific to a dataset containing fire.

Using other methods:

Frameworks such as YOLO only looks at one image and determines the objects within it. To have better accuracy than iterating a single image, we can incorporate motion and color detection. Motion can be easily detected by applying frame differencing which does not require the need of high-quality resolution or high frame rate. The color classification is also very feasible with low-resolution cameras as well. Both frame differencing and color classification are more suitable with low-resolution cameras to identify fire than frameworks such as YOLO. This method has already been made by Nicholas True [7].

Another method that seems more appropriate for forest fires is applying smoke detection to the framework by adding optical flow along with frame differencing. This method by the Ministry of Public Security of Shenyang Fire Research Institute [8] shows how it can detect fires and smoke at a distance with a video dataset. This method may be better than the other frameworks mentioned as it can detect smaller fires (dataset used contains smaller fires compared to the others). To verify this, we would need to train and test the other frameworks to properly assess how the accuracies differ.

The drawbacks of using computer vision for this project are cost, finding an appropriate one that fits into our kit, and time as we must train and test different frameworks with several datasets.

Control Scheme:

We are planning to use state machine to read data from our sensors and identify patterns from it to determine if the fire exists. This would require us to perform many tests and adjustments, but the code itself should be simple.

We can also apply machine learning to analyze the sensor data to have better predictions and accuracy, but this may require us to create our own algorithm as it needs to be compatible with the sensors we will be utilizing. Not much documentation is available for this type of machine learning.

MPPT & Power Research:

Assuming a 12v system that draws an average of 100mA, we determined the needs of the system to be almost 29Wh per day. For 5 hours of maximum power output with an MPPT we need 5.76W so a 500mA MPPT would be needed.

For batteries, there are many chemistries to use. The main battery chemistries are Li-ion, NiCd, Lead Acid, Gel, and Nickel metal hydride. There are advantages and disadvantages to each type of battery. The Depth of Discharge (DOD)[9,10] on lead acid is 50% while you can discharge li-ion 100% of course this causes the number of charge cycles to drop but if a li-ion is only discharged 50%[10] then the number of charge cycles until the batteries die increases.

For regulating the power of a given system you will need a charge controller for the batteries and dc-dc converters for regulating the voltage for sensors and other components. Buck converters are good for stepping down voltage of our system. They are the most efficient of power regulation often higher than 90%[11]. As for monitoring a power system you need to measure the input current and output current to know if your system can handle what you are asking it to do. This will also tell you if the solar array can handle charging the batteries and maintain power in the system.

Mesh Networks

There are a few “tried and true” methods to implementing a mesh network. Some companies, like Espressif, have mesh network libraries that work with their ESP32 components which is intended to help users develop a framework with mesh networks[14]. These work at the 2.4GHz frequencies and only allow for 200-600m range per hop[15]. Due to this limitation on the 2.4GHz and 5GHz bands, some other options like 433MHz and 900MHz need to be explored. With these frequencies, one can get 10s of Kilometers distance. Calculating the link loss for the two frequency ranges, there is some benefit on link loss by 6.5dB when using a 434MHz signal over a 915MHz signal at 500m. This benefit though comes at the cost of complying with federal regulations on the power output of devices on the 400MHz bands as well as cost. Generally, 900MHz components/modules are cheaper than 400MHz modules. Lastly, the new IEEE 802.11ah standard encompasses wifi at 900MHz which may allow for these devices to simply connect as a wifi network instead of some custom implementation. For a custom implementation, using a brand like Digimesh[16] or Zigbee[17] might be a good option[18]. The difference between the two, for our case might push us to using the Digimesh approach even though Zigbee can be IEEE 802.15.4 compliant[17]. The most generic approach is to use an LoRa module which will allow us to send data at 900MHz or 400MHz generically and our software will handle the transactions on the Application layer.

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