Woodland Watchers

End of Project Documentation

Early Wildfire Detection

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Team: The Delightful Deer

Adam Reed
Lance Nevis
Rashamjot Kaur
Don Nguyen

Professor: Russ Tatro

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EXECUTIVE SUMMARY

Elevator Pitch: An interconnected grid of micro controllers equipped with smoke and temperature detectors with radio-communication used for early wildfire detection.

Wildfires are uncontrolled and unplanned brushland, grassland, or woodland fires. These fires have become increasingly more intense and frequent over the last few decades. The cost of wildfire prevention often exceeds several billions of dollars. These fires actively damage the environment by destroying large areas of forest, killing wildlife, and releasing toxic particulates into the atmosphere. These fires also pose a danger to the public's health.

Our proposed solution to this societal problem is to establish an effective 'grid' of microcontrollers equipped with smoke sensors, temperature sensors, radio transceivers, and local area power generation that we will refer to as "posts." These posts are split into two categories, primary posts, and secondary posts. Secondary posts have all of the previously mentioned modules, while Primary Posts have an additional module for cellular communication. This cellular communicator allows data to exit the 'grid.' Our design's purpose is to detect a fire as soon as possible and send an alert to fire fighters. This will hopefully give professionals the ability to stop a fire before it grows too large to contain.

Our team split this design into several features and compiled them into a feature set. This allowed us to detail the features our design support and helped us split the design's work between team members so we could initially work independently of one-another. We split the work into software and hardware categories. The software functions of this project were split into the interactive map, database, and microcontroller code/functionality. which had to obtain data from the sensors, and act accordingly to that data. The hardware portion of this project included the power supply system, and the connections between the ESP32 and it's sensors, communicators, and power supply.

These features were then split into several measurable metrics. The posts had to communicate with each other within a 200-500 meter radius. Signal transmission for triggers include the device ID, type of trigger, time of trigger, and time of trigger received. The database stores information about post locations and triggers. Smoke detector detects CO from 200-10,000ppm. The temperature detector detects a rate of change in temperature and the instantaneous temperature. Alternation between sleep and wake cycles. Mapped software showing love updates of post triggers.

To simply the breakdown of our design, and to establish deadlines for reports and feature sets, our team set up a project timeline using GANTT and PERT diagrams that detail the due date of each task. We further broke down each feature of the feature set into several tasks and split these tasks between each team member. We defined milestones that represent meaningful accomplishments within our project. These milestones represent important paths within our PERT diagram, with the most important path shown as the critical path. Everything within the critical path of the PERT diagram must be completed to successfully obtain a fully functional prototype.

We faced several risks while implementing our project. These risks are categorized as technical, systematic, and environmental. There were several technical, systematic, and environmental risks that had to be taken during the production and progression of our project. These risks were identified and mitigated to protect ourselves, and to ensure the progression of the project. Due to the Covid19 pandemic, we were faced with a unique set of risks and challenges. We had to maintain social distancing while implementing our own feature sets, and while integrating our design into a single working prototype.

The effects of Wildfires on the Environment and Health (May 2021)

Adam Reed[1], Lance Nevis[1], Rashamjot Kaur[1], and Don Nguyen[1], Member, IEEE

[1]California State University of Sacrament, Sacramento, Ca 95819 USA

Corresponding author: Adam Reed (e-mail: AReed@scsus.edu), Lance Nevis (e-mail: Lnevis@scsus.edu), Rashamjot Kaur (e-mail: RKaur@scsus.edu), Don Nguyen (e-mail: DNguyen@scsus.edu).

ABSTRACT

The intensity, frequency and seasonal duration of wildfires is growing due to human impact on the environment. This is causing harm to people, and the environment as a whole. Our proposed solution to this societal problem is to establish an interconnected grid of microcontrollers equipped with sensors and modules for communication. We call these individual devices "posts." We broke our design down into several feature sets. These feature sets included defined measurements such as radio communication between posts within the range of 200 to 500 meters. After creating this feature set, our team broke the design down into a work breakdown structure with assignments for each team member and due dates defined within a GANTT chart. This was defined into a PERT chart with several milestones that indicate our progress towards completing the prototype of our design. After completing the design and building three posts (two secondary and one primary), as well as setting up the primary server/database, we were ready for testing. A test plan was established with defined due date within a GANTT chart. These tests were split between participating group members. Before testing was started, we evaluated several risks to ourselves and our project, and determined the severity and possibility of each risk. Our team also explored the current market for forest fire detection and looked closely at different technologies and solutions to this problem. We believe that our design addresses the issue of forest fires due to its rapidly deployable design and low cost.

KEYWORD INDEX

Air Quality Index, Camp Fire, Federal Budget, Fires, Fire Insurance, Hardware, Insurance, Lora, Microcontroller, Particulate Matter, Software, Solar Irradiation, Smoke, Temperature, Soil Organic Matter, Wildfires

I. INTRODUCTION

A. Introduction - Societal Problem

Wildfires are unplanned and uncontrolled brush land, grassland or woodland fires that can cause long lasting and sometimes irreparable damages. These fires have increased in both frequency and intensity over the last twenty years, primarily due to humans. Humans have more than doubled the yearly wildfires, and the number of acres burned. The seasonal duration of these wildfires has also increased, expanding to include the entire year as the 'wildfire season.' These fires are most often started by campfires, cigarettes and, unfortunately, malicious acts of arson.

These fires have dealt several billion dollars of damage to homes and businesses, destroying entire communities. Even with increased spending and attention to forest management and the clearing of flammable debris, the wildfires continue to increase in frequency and intensity. With the increasing frequency of these wildfires, monetary damages of a single fire are exceeding the yearly budget of forest management.

The smoke particulates from these fires can travel thousands of miles and affect the environment in entirely different continents if the fire is intense enough. They can also be trapped in the upper atmosphere and contribute to global warming. The smoke from these fires can also reach toxic levels from pollutants and particulate matter. A main component of this is particulate matter; a composition of liquids and solids burned that is part of the smoke. Particulate matter ranges from ultra-fine, fine, up to coarse based on the size of the particles (typically ranging from .1 - 10 micrometers).These solid and liquids are burned becoming part of the smoke lowering the Air Quality Index (AQI) and creating negative health-impacts in areas completely out of reach from the actual fires. Exposure to this smoke can cause many respiratory issues and can be particularly harmful to people with pre-existing conditions. During wildfires, there is a significant increase in the amount of emergency department visits and premature mortalities. These particulates are a concern in both short-term and long-term health. All of these components cause wildfires to be a very significant societal issue we deal with today.

B. Introduction - Design Idea

To combat the societal issue of wildfire destruction, we have created an early wildfire detection system in an attempt to locate potential wildfires before they have a chance to grow out of control. The primary functionality of our design is a low-cost rapidly deployable modules to create a "grid" of early wildfire detection units. To create an effective early wildfire detection module, the use of a microcontroller to control all communication between all components within the module. A rechargeable power source, low-power wide area network communication (LoRa), smoke and temperature detectors to ensure we can detect fires before they have time to grow out of control.

This module uses a reliable rechargeable power source to ensure the unit can function. We will be taking advantage of rechargeable lithium-ion batteries combined with solar panel units to keep the device active always. Through proper testing, we were able to determine the correct battery holder/charger and solar panel power output to ensure that it can provide enough power to keep the power output less than the power input. Using available solar irradiance tools available online, we are able to best place these devices to ensure that they receive the most available power to the solar panels to provide maximum output. The only challenge currently faced with our design in the power portion is full length testing due to the class format being a yearlong and our feature goal of reaching 2 years always-on power. This self-powered mechanism increases the overall worth of the design because it will require much less maintenance and will allow for rapid deployment.

The micro-controllers sole function is to execute a programmed set of instructions to get a device to perform a specific task, or small number of tasks (all depend on memory and processing capacity of the specific micro-controller). In the wild, where there is no established infrastructure to enable communication (such as cell-phone towers, or Ethernet lines), two impeded devices will be unable to communicate with each other over vast distances. By using communication within the radio spectrum with LoRa we avoid this issue. We have used transceiver modules in line with our ESP-32 to allow for our devices to communicate with each other inside the grid. Each of these modules is capable of storing the device ID, location of the device, and any sensor information received from the smoke/temperature sensors. Once the triggered signals reach our Primary Post, cellular communication is necessary to allow data to leave the 'grid' of detection and eventually arrive at a central database with the sensor trigger information, the time of the trigger, and the location of the module that was triggered.

The container of this project needs to be able to withstand the harsh effects of the environment. The device needs to be shielded from impact, light, rain, and other natural phenomena that would damage the unshielded device. The container for this part of the project was planned to be 3D printed, but the printer needed for use broke down during use. Unfortunately due to COVID-19 we were unable to procure another case to fit this design. For this presentation, plexiglass was cut for a preliminary case design, and moving forward we would move to a more secure case design.

To deal with the problem of wildfires, we have created a wildfire detection grid with the use of our modules where each device can transmit trigger information to other detectors and one of out of every 1000 detectors can communicate with cellphone towers to transmit the information to our database. This trigger data can be given to first responders as an early warning before the fire grows too large to control. The smoke and temperature detectors sample the temperature and particulates in the surrounding environment every wake state measuring the changes in the atmosphere to determine if there is a potential wildfire. If a possible wildfire is detected, this information is transmitted to the surrounding Post devices until it reaches a primary post to be sent out to the communication tower to warn of a fire. The entire post is a low cost device that is easy to replace if destroyed or becomes non-functional. This design allows a cost-effective and efficient way to prevent wildfires.

C. Introduction - Work Breakdown Structure

Each functionality of the project is broken down into a feature set of several activities to increase efficiency during design. These activities are simplifications of each function of the overall design. The completion of all of these individual tasks leads into our integrated design for the entire project.

The features include a database storing all relevant module information, an interactive map showing the location of our modules with triggers, a preliminary protective case, cellular communication with the Primary Post, temperature detectors, smoke detectors, transceivers for the devices to communicate to each other, micro-controller(s), and power modules for local area power generation. Each one of these features are broken down into several subtasks, and each subtask is broken down into several activities for an easy to follow set of our process layout.

These activities were distributed among team members based on the individual responsibilities for each feature set. The intention is to make as much of the project as modular as possible so everybody can work independently of one another during Covid-19. The total cost of each unit will be in the range of $60 for Secondary Posts and $100 for Primary Posts. There will also be an additional charge for cellular plan for texting trigger information. During this project, we used a pay per text plan, but if this design were implemented for use in the field, we would move to a monthly plan.

Don Nguyen completed work on the Micro-Controller and all its associated data calculations. This included when the device needed to be in a low-power state, and when it needs to enter wake state checking for any triggers to decide if the device should stay on or go back to sleep. Don was also in charge of the to the transceiver communication to other devices within the grid. The microcontroller stores its' most recent received and transmitted IDs to prevent ‘loops’ of transmissions from forming. This allows for communication between devices to pass all information collected.

Adam Reed completed the software side for the databasing, interactive maps, the cellular communication, and the preliminary protective case. The database holds all information on sensor triggers, the units unique ID, and location of the device. This is used to give the necessary information to first responders if sensors are triggered. This information along with the interactive maps allows for quick deployment to locations with potential wildfires.

Rashamjot Kaur completed the Temperature and smoke detector connections with the ESP-32 along with their associated code to pull the information from the required GPIO pins. These sensors report any triggers to the microcontroller with any data it receives after taking samples of the surrounding atmosphere.

Finally, Lance Nevis completed the power generation and management module. This portion of the module allows the device to stay charged year-round in both low power and full power settings on microcontroller. Using solar panels, rechargeable lithium-ion batteries, and a charge module to allow the device to stay charged. The completion of each individual component was integrated with the team to ensure that each Post works with only one Secondary Post and in a chain-like fashion with more than one Secondary Post passing information to the Primary Post to be transmitted to the cellular tower.

D. Introduction - Project Timeline

Our project timeline is broken into two different designs to achieve optimal structure. Using a GANTT chart, we are able to clearly define project begin/end dates, who is assigned to each task, and who is the leader during this time. Within this chart we can see a clearly defined visual reference of completed tasks along with the dates they were completed. Within our GANTT design, we can also see project milestones that lay out markers for the overall project design.

The second project structure tool used for project management was the PERT diagram. This design places focus on the path of our overall project highlighting the critical path and milestones. The critical path is used to show what progress was made during each step of the design in our overall project showing the major components needed to have a functioning design. Using determined dates and a Work breakdown structure, our project is clearly defined to show what has been accomplished, by which team member, and the date it was completed. While the GANTT places a focus on the dates and progress percentage completion, the PERT is much more useful as a visual representation of the progress that will be made and allow for a clear description of our planned outline.

One of the most important milestones achieved was approval of our design idea contract. This approval was a foundation to our entire project as it showed that our advisor believed this project was feasible and our goals could be reached in the time allotted. Our next milestone was finding the appropriate microcontroller that would allow everything to communicate properly with the sensors, other devices, and maintain a low-power state so that it may stay powered year-round. After finding our microcontroller, we had to find sensors that had the capability to detect wildfires in the most meaningful way and within an efficient time period. One of the final components to our early milestones was finding a means of communication and power to our device so that signals could be sent out to the proper authorities to report any potential wildfires. While these are early stepping-stones to more key milestones, this early progress allowed us to set the path to a successful project and bring all of these components together.

Future milestones include completion of our individual component functionality. Communication allowed the Post devices to communicate with neighboring posts and for Primary Posts to communicate with the database. Data Collection from the temperature detector and smoke detector and successfully translating that data to the micro controller allows our Posts to detect potential fires. An Interactive map gives our project the capability for the database to be accessible by the map to display recent triggers on the map. Creating a power system that successfully achieve local power area generation and keeping the device active at all times. The combination of all these will created a complete prototype feature set that has total functionality between Secondary and Primary Posts.

The timeline did not result in any cost increase of our project. The creation of the total timeline was over a one-week duration. The total level of effort for this portion of the project was primarily in work hours to create an effective and efficient way to outline the key components of our project design. The GANTT chart outlines individual tasks assignments, start/end dates and the tasks that will be completed. While the PERT places focus on highlighting the milestones and critical path. This design was essential to the total level of effort for our entire project.

E. Introduction - Risk Assessment

This project has associated risks that could potentially impact its completion. These risks are split between three categories: Technical Risks, Environmental Risks, and Systematic Risks. Technical risks and Systematic risks are foreseeable risks that we have planned to avoid pitfalls. Environmental risks are risks that would impact our project without warning. Systematic risks involve risks we take though processes that we use to work on our project. Technical risks involve risks that we take when we work on specific technical parts of the project.

Covid-19 has introduced a dramatic change in our overall lifestyles and procedures introducing new environmental and systematic risks outside of what we would normally follow. For this project, the biggest complication that comes with the pandemic was creating a project that allowed all of us to work in a socially distant fashion with a modular based product. Our detection system highlights this modular fashion for a project because each individual Post is built to be cheap and all components are accessible to be purchased by everyone. The code, schematics, and other designs can be passed without ever having to be in physical contact through source control programs, pictures, and videos for design. With the use of modern technology not only were we able communicate with each other very easily, but also maintained all update without ever having to meet in a physical setting. Our overall project was completed and tested without having to be in contact in any other setting that may cause exposure to the virus. This type of design significantly reduces the chance of exposure to Covid-19 for the whole group. This did not completely prevent us from avoiding all stresses, but our team kept an open line of communication to ensure any potential stress was supplemented with teamwork.

Powering our microcontroller and attached sensors has a very important role in our project design and with power comes potential technical risks that must be avoided. If the solar panels in succession with the batteries and charger module are unable to produce enough power to ensure our device will stay powered year-round, then this will lead to failures in the design. By examining how much power, the solar panels can pass to the charger module, how large the batteries are, and how long the device can stay charged we are able to avoid this risk. Since a portion of this testing is incomplete due to time constraints of a feature set reaching to 2 years and the project going for a year introduces a risk. If a module in this feature set of the design loses functionality, then the device will turn off completely losing communication with the other Posts. Our solution to avoid this complication was to adjust the size of the solar panels and batteries to ensure we do not lose power.

One of the largest hazards that we will meet is a single break in this chain of communication. If communication breaks down between any of these modules, it will potentially cease the function of the entire project. To avoid this risk, we implemented more devices nearby so that surrounding Secondary Posts can also receive trigger information for potential wildfires.

The sensors are another hazard. If the sensors malfunction, or stop working all together, the post will cease its primary purpose, to observe its local area. To avoid this, the best solution provided was to run routine testing every few months to ensure that all sensors are working properly. The physical connections between different hardware modules must be tested. The potential damage that can be done is high for improperly connected devices. This is avoided by testing all modules before they go out into production.

As the primary and secondary posts are distributed, the potential for human error increases. For each post, the location must be stored in the database with its associated ID. If the individual responsible for distributing these posts mistypes this information into the database, it could result in false positives in wrong locations and the failure to report positives in others. The potential for this is moderately high, but the impact it would have on the project is small because these would be easily fixable errors. Our solution to this is to use a two man team during installation of devices to confirm all devices are installed and checked for all proper locations.

Theft and destruction of the posts is an unfortunate possibility. The potential for this is low, but if in the case where an animal destroys the post, or a human steals/destroys the post, the entire post would need to be rebuilt. This would have a large impact on the project. While avoiding possible destruction is challenging, we are able to implement a call and response between devices to see if any Posts do not report back so we can determine where potential devices may be destroyed.

The total effort is directly correlated to reporting hours within the team discussing the overall design, potential pitfalls, and how to address and resolve all complications. The risk assessment will allow us to save a significant amount of time on effort to possible upcoming complications.

F. Introduction - Problem Statement Revision

For centuries wildfires have followed a periodic niche, igniting primarily from lightning during summer. Wildfires are unplanned and uncontrolled brush, grassland or woodland fires. These fires have increased in both frequency and intensity over the last twenty years, primarily due to humans. Humans have more than doubled the yearly wildfires, and the number of acres burned in the last twenty years. The seasonal duration of these wildfires has also increased, expanding to include the entire year as the ‘wildfire season.’ These fires are most often started by campfires, cigarettes and, unfortunately, malicious acts of arson.

These fires have dealt several billion dollars of damage to homes and businesses, destroying entire communities. Even with increased spending and attention to forest management and the clearing of flammable debris, the wildfires continue to increase in frequency and intensity, with the monetary damages of a single fire exceeding the yearly budget. While the responsible parties of these fires have been making efforts to help the victims, tens of thousands of victims will never see the value of their homes returned to them.

The smoke particulates from these fires can travel thousands of miles and affect the environment in entirely different continents. They can also be trapped in the upper atmosphere and contribute to global warming. The smoke from these fires can also reach toxic levels from pollutants and particulate matter. This smoke can then settle in areas such as valleys for days at a time before dispersing. A main component of this is particulate matter, which ranges from ultra-fine, fine, up to coarse based on the size of the particles (typically ranging from .1 - 10 micrometers). Particulate matter is a composition of liquids and solids burned that is part of the smoke. As these solids and liquids are burned, they become part of the smoke, and create negative health-impacts. Exposure to this smoke can cause many respiratory issues and can be particularly harmful to people with pre-existing conditions. During wildfires, there is a significant increase in the amount of emergency department visits and premature mortalities. Firefighters are the heroes that stop these fires, but they are also one of the primary victims of them. The number one killer of firefighters is heart disease/sudden heart attacks, but the carcinogens, and particulates from these fires also impact the lungs of firefighters. Prolonged exposure to high temperatures also destroys the muscle-tissue of firefighters, and the loud noises they're exposed to damages hearing. All of these components cause wildfires to be a very concerning societal issue.

As wildfires expand and burn, they release harmful gasses and other particulates into the air, lowering the Air Quality Index (AQI). The particulates of these fires often harm the respiratory organs in humans, with children and elderly being the most vulnerable to this damage. The AQI has been associated with increased hospitalizations and early mortalities. These particulates are a concern in both short-term and long-term health.

After reviewing our design and making some slight modifications, we feel that our design idea addresses the previously stated problems. Homes can be saved if an early warning system inside the home warns the homeowner before the fire gets too large to control. This same early warning system idea can be applied to a much larger area of forest. If a fire is detected long before it grows exponentially out of control, it could possibly save tens of thousands of homes. If a fire is stopped long before it grows out of control, firefighters are exposed to less carcinogens, high temperatures, and possibly other toxic substances.

G. Introduction - Device Test Plan

A successful deployment of a project needs an inclusive testing plan that meets our design requirements. Tests are created based on the punch list and its measurable metrics. These measurable metrics are broken down into tests based on each of the features in the punch-list. These are combined into an all-inclusive test that tests all the previous tests at once.

Each test starts from the ground and moves up to a more complicated and functional behavior of the device. We will be testing the power system by measuring the voltage levels of the solar panel, the voltage regulators to ensure the battery charged receives 3.7V, voltage booster to increase the voltage to 5V to power the ESP-32. The battery providing power to the post will be tested for how long it can keep the device powered in all states and how long it takes to charge the device. This will be accomplished primary by time recordings and a multimeter to take voltage measurements. By measuring the voltages of sensors, we can translate those voltages into useful information about temperature and parts per million of carbon monoxide and other hazardous gasses in the air. Using some coding within our ESP-32 we can trigger the sensors in a controlled environment to show that the sensors will transmit data based on a fire or smoke nearby. Testing these sensors will allow us to test the range of the sensors to determine an effective range of detection for fires.

A field test will be used to determine the effective range of communication between our devices. The Posts must be able to communicate with all of its closest neighbors to be able to transmit the data through the grid to the Primary Post. Any time a sensor is triggered, the Post must be able to transmit the ID, time of trigger, and type of trigger to its surrounding neighbors until the information reaches a Primary post. By putting Posts close together and moving them further apart we can continuously send signals and record how effectively the data is transmitted. We can continue this process until we reach its limits and determine the most effective range between posts.

Behavioral tests are also important. The microcontroller needs to "behave" in predictable ways that meet our design idea requirements. For example, these behaviors start off as low as "triggering" the post to indicate the detection of a fire, then ending with that trigger cascading though the entire network and arriving at the server that runs the database and map. Behavioral tests are also performed on the database and map itself. We'll be testing the behavior of the map in *Test 12* by checking if the map can access the database, display the location of the trigger, and determine the approximate direction a fire is traveling by showing vectors on the map.

All of these components used for our design will be enclosed in a protective case designed by us. This case will need to be tested for durability and through various weather conditions to ensure that it will not malfunction if introduced to any extreme weathers. These drop tests will move toward a permanent solution for our device being protected and continue to be useful year-round.

H. Introduction - Market Review

Determining the marketability of our deployable prototype and forecasting its demand is essential to the survival of a project and it’s resulting product. By finding products that solve our societal problem on the market, we roughly estimated how much better or worse our design is, and if it addresses the problem with cost and profit in mind.

The purpose of our design is to have a rapidly deployable device that can monitor areas that do not have communication infrastructure in a cost-effective manner. Our design addresses this by reducing the cost of each post and making them disposable. Due to the increasing intensity and frequency of these fires, we believe that our design can provide a sustainable market by initially setting up the sensors, then providing maintenance to the grid by replacing older posts.

We possibly have a large list of clients, but the primary client for this device would be CalFire, and, by extension, the US taxpayer. Firefighting institutions and government organizations could benefit from our design by having constant observation in areas that would otherwise be unobserved for long periods, giving these institutions more time to fight fires before they grow out of control.

We explored other competitors’ methods for addressing this societal problem and compared their solution to ours. We have found that our competitors use high-quality cameras instead of basic smoke and temperature sensors. Our competitors are also dependent on communication infrastructure, limiting the location of their design. This severely limits their market due to the high cost of their products.

We believe that due to our modular design, and use of cheap general-purpose sensors, that we address the issue of cost and profitability. Given that our design is cheap and easy to produce, we can create a large volume of the posts. Given the size of forests, we believe our design addresses the societal issue while providing long-term and sustainable growth. During the production of our early wildfire detection modules, we also realized that our low-cost rapidly deployable design could be transformed to meet other needs such as irrigation or tracking systems. Since we offer a cheap method to cover a wide area with communication available, by changing out the sensor library modules on our devices along with the sensors, we can meet more needs than just the original societal issue we approached. By making these adjustments, our marketability increases greatly.

I. Introduction - Testing Results

The implementation and integration of our early wildfire detection system required extensive testing of each individual component and integrated module to meet the expectations of our feature set. Our feature set offers 9 features and our device test plan was broken up into 15 different tests to ensure confidence in the design of our product. In this report, we will cover the different components tested and how these tests allowed us to fulfill the demands of our feature set.

The first components featured is the MQ2 smoke sensor and the DHT22 temperature sensor Composing of Test 1 and 2. The MQ2 sensor was tested for voltage levels, sensitivity, and that our sensors would trigger when introduced to a potential smoke in the area within the range of 200-10,000 ppm. This was tested in a safe environment by taking using a bee smoker holding the smoking end near the sensor to allow the device to trigger. By monitoring the ESP-32 serial communication port, we were able to track if smoke was detected. In a similar fashion, the temperature sensor was tested for voltage levels while attached to the microcontroller. The temperature sensor was exposed to the heat from the smoker and examined for signals received over the communication port. These triggers were predefined measurements so that the device only after reaching a specific threshold such as a temperature rise of 12 degrees per minute or a high enough temperature to signal a potential fire or a certain smoke threshold. These first two tests define the first two features within our feature set directly related to early detection of these fires.

The third set of testing was focused on the power module of our design. This consists of the solar panels, the batteries, the charge module, and the voltage step-up. The charge module was responsible for connecting the solar panels that allowed up to a 5V output and drop this voltage down to 3.7V alongside the batteries to allow the device to charge the batteries. Leaving the charge module, a voltage of 3.3V was passed into a voltage step-up and leaving the step-up, we received a voltage of 5V. The testing required for this feature was completed with the use of our Analog Discovery 2 for oscilloscope use and a multimeter. By testing the voltage points at every input and output, we were able to track our voltage along the entire device. The analog discovery allowed us to track our power and compare the results to our predicted values/requirements. The final portion of this was to test that the module could power the microcontroller, sensors, and communication devices. Another component of this testing allowed us to recognize that we needed an upgrade to our charge module due to the power drain caused by the smoke sensor. We also purchased larger batteries, but this was expected and neither of these elements caused a change in the process or functionality of the power module.

The next set of testing covered the primary components of communication with our design. The first set of communication is within our grid from Post to Post ensuring we could pass any trigger information, times, and the device ID consistently. The second set of communication involved sending this received information from the Primary Post to the closest local cellular towers. The final component of this testing was to ensure we could chain this communication across multiple Posts and still be able to define from which Post and where this information was being sent from. Another component of this information is to ensure that ID's are not retransmitted and can be reset upon the triggers being received and successfully stored. Upon finalized testing on this, we can confidently cover features that consist of range of devices, information sent, and communication to the cellular towers.

The Post devices store their ID, location and can transmit the triggers received along with the time. This information is stored in the database so when a trigger is received, the database can update the map to show where this device is located, and someone can be dispatched to see why the trigger was activated. The Primary Post must be able to communicate this information via cellular tower so that the database can store the required information. By using this information, an approximate path of the fires can be determined by the Posts triggers that are being received. This testing is primarily software based and initial testing could use dummy Posts to emulate the process. After completing initial testing, the devices can be triggered in real-time to show the database updating along with the mapping used. The testing involved is primary setting these values and triggering devices purposely to examine results.

A primary function of the ESP-32 devices outside of transmission and information collecting is the use of the lower power state to cycle between a wake state and sleep state. This feature is necessary to save power with the device and work in a fashion that is effective to sampling the surrounding area often enough. Initial testing began with allowing a single device to be able to cycle between states on a set period. After this process could be repeated, during wake state the Posts must sample from the sensors. Another component of this design is to ensure that the devices stay powered on while the trigger is active until it has been confirmed the trigger data has reached the Primary Post. The final step in this testing process was to ensure that all devices within the grid would enter the sleep and wake states at the same time so that the devices do not get desync. This form of testing was to account for propagation delay between devices by doing hands-on testing and to guarantee that devices enter the proper state based on potential active triggers and resets. This feature set creates a solidified grid and works with the power module to prevent the devices from dying.

The final components to test are the case and method to secure the Post in its location. The case was cut using plexiglass cut constructed to prevent weather, debris, or other components from causing destruction to the case, and to allow the sensors to work effectively. The first portion of testing the case is to try and intentionally destroy the case by throwing objects at it, dropping it, and getting it wet. This testing was not complete due to a malfunction in the 3D-printer, so for our current design we used the Plexiglass class and would move toward a uniform designed case that would protect against potential damage. The Posts are meant to be a stationary object so the team has decided the best option for this is to store it in a location that can make the best use of the solar panel and to ensure the Post stays in the location entered in the database for its GPS. This testing also requires hands-on experiments to force the device to move out of location.

This device test plan provided a significant amount of insight to our project and allowed us to pinpoint any possible downfalls. While the majority of our testing proved to be successful, we did run into a couple complications along the way. The power module testing showed that we required a more powerful charge module that would allow us to make a better use of the power in vs power feature set. We were able to work out the largest portion of our flaws and were able to complete our testing and make the necessary adjustments to our design while fixing any potential bugs.

II. SOCIETAL PROBLEM

A. Wildfires, Intensity, Duration and Frequency

A wildfire is an uncontrolled grassland, brushland, or woodland fire. These fires have several conditions that increase their intensity, frequency, and duration. These conditions include “drought, heat, and wind [which all] participate in drying out timber” and other ‘fuels.’ Drought slows access to water, kills trees, and allows dead vegetation to dry. Wind feeds oxygen into wildfires. High temperatures also dry out vegetation that would normally be non-combustible.[1]

Wildfires are often characterized by their frequency, intensity, and seasonal duration. Fire occurrence was predominately periodic, which followed a seasonal cycle of wildfires that would burn away brush, dead trees, and other flammable/decaying matter. This seasonal behavior allowed forests to become “fire adapted” and would actively “prevent or mitigate wildfires.” [1]

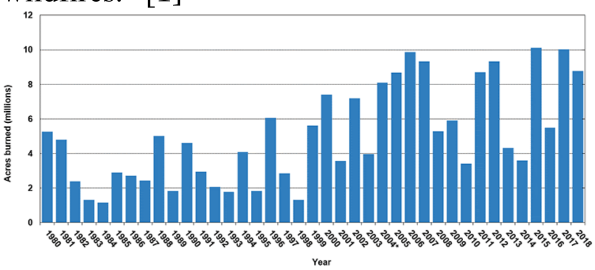

FIGURE 1. Number of acres burned by year. Note how the number of acres burned increases every year [1]

A common misunderstanding of wildfires is that they are damaging to an environment. Wildfires often “promote ecological health.” Wildfires do this because they burn away decaying matter that would otherwise “prevent organisms within the soil from accessing nutrients or block animals on land from accessing the soil.” Often fires are intentionally set to burn away this decaying matter. These are called controlled burns and are used in forest management.[2]

Over the last few decades, the intensity, frequency, and duration of wildfires has been increasing. Figure 1 shows that the intensity of these wildfires in the United States has more than doubled between 1980 (With 4.5 million acres burned) and 2018 (With 8.3 million acres burned). The intensity peaked in 2015 at 10.1 million acres burned. [1]

Between January 1st and September 8th, 2019 and during the same period in 2020, the number of fires increased from 35,386 to 41,501. The number of acres burned also increased during this period from 4.2 million to 4.7 million acres. The number of fires peaked in 2017 with 71,499 wildfires, an increase from 65,575 from the previous year.[3]

Out of these tens of thousands of fires, only 10 percent of them occur naturally (Lightning, light refraction, or other natural phenomena). Humans and their increasingly negative impact on the environment cause the other 90 percent. Many of these wildfires are caused by unattended campfires, damaged power lines, cigarettes, and, unfortunately, malicious acts of arson. [3]

Humans extended the duration of the wildfire season. The season was extended to include the spring, fall and winter months. During these periods, humans added more than 840,000 wildfires, which is 35 times more frequent than naturally caused lightning fires. The vast majority of naturally occurring lightning fires (roughly 78%) started during the summer months, but human-caused wildfires often start in the spring, fall and winter months (roughly 76%). Human impact on the environment extended the wildfire season to include the entire year. [4]

B. The Costs of Wildfires

Wildfire prevention is expensive. Fire suppression costs exceeded $2 billion in 2017. Over the past few years “Forrest service spending on fire suppression … has gone from 15 percent of the budget to 55 percent of the budget.” Forrest management is often forced to hoard money because they’re “afraid [they’re] going to need to actually fight fires.” This actively takes funding away from “prescribed burning, harvesting, or insect control” further increasing the problem. In response, Congress allocated an additional $1.6 billion of funding to the Forrest Service, but even this extension wasn’t enough. Within the third quarter of the fiscal year, the Forrest Service spent it’s entire budget.[5]

PG&E is cited as the source of many of these fires. They've been making efforts to remedy the damages done by rebuilding homes and paying settlement fees. Despite these efforts, PG&E is still more than a billion dollars short of what they need to pay their settlement fees, and already declared bankruptcy. Court Justice John Trotter warned that an "estimated 80,000 victims of these wildfires won't get all the money they were promised by PG&E." Victims will ultimately be paid, but the funding will come from trusts, and stock sells, which will negatively impact the market as a whole. Victims eventually agreed to take stock as payment, but still lost money due to the share value dropping as a result.[6]

Many thousands of homes were destroyed and tens of thousands threatened during the 2020 California wildfires, including one National Geographic photographer, and California resident, France Lanting's home. Lanting described the fire as a "biblical plague" where "[miniature] tornadoes hit the area." Despite the threat the fires proposed to his life and home, and the orders to evacuate, Lanting decided to stay and create records of the fire, staying true to his career. His photos included walls of fire taller than any tree, foundations of homes with nothing remaining but cement and ash, and pools of metal that once resembled a car. Nothing is safe in these massive fires.[7]

C. Wildfires Widespread Effects on the Environment

As already discussed, wildfires release large quantities of particulates and nanoparticles into the atmosphere. These particulates are harmful to human health. They can enter the blood stream through the respiratory system. The particles and nanoparticles released by the fires get even more toxic the further they get from the site of the fire. The particles, when carried by the wind undergo a chemical reaction called 'oxidation'. The chemicals are aged in this process which converts the particles into highly reactive compounds that have an even greater capacity to damage cells and tissue than when they were first produced.[8] This wildfire smoke can potentially hang in the atmosphere for up to several months depending on how large and long the ongoing the fire is. This has an adverse effect on the environment as this superheated smoke and ash particles rising into the air can trigger fire-induced thunderstorms. The wildfire smoke also travels huge distances, sending this toxic smoke across continents and even oceans sometimes.

For example, in 2019, smoke from forest fires in Alberta, Canada, was tracked spreading across the Atlantic and into Europe. Smoke from the Australian fires was carried by pyro cumulonimbus events over New Zealand, where it impacted air quality and visibly darkened snow on mountains. The smoke even made it to South America.[9]

In 2019, after consultation with the U.S. Government Accountability Office (GAO), a CIPA Capstone team conducted research on the air quality and public health effects of wildfires. They found a positive association between wildfire smoke and particulate matter 2.5, respiratory morbidity and mortality. This may entail issues with asthma, chronic obstructive pulmonary disease, bronchitis and pneumonia.[10]

The areas burned by the fire also have implications on global carbon emissions, ecosystems and society. A 2012 study on Mediterranean shrub lands showed that wildfires affect soil organic matter (SOM), mainly resulting in losses of the most labile fractions (in particular carbohydrates), an increased abundance of recalcitrant fractions and, specifically, an increase in SOM aromaticity.[11]

The intensity of the wildfire increases with the increasing air temperature, and therefore we can conclude that the areas that are experiencing higher atmospheric temperatures in the fire season associated with global warming would experience more intense fires.[8]

The impact of fire on global warming works in a compounding fashion, meaning the more global warming (due to various reasons such as pollution, carbon emission) leads to more intense fires, which, in turn again leads to more global warming. The latest fires in the western United States are also consistent with models of fire activity expected from global-climate-change projections over the next few decades. The links to climate change are thus based on established relationships, operating at different scales of space and time, between climate and fire activity in various environments.[12] According to climate models, anthropogenic warming since the late 1800s has increased the atmospheric vapor-pressure deficit by approximately 10%, and this increase is projected to double by the 2060s. Given the exponential response of California burned area to aridity, the influence of anthropogenic warming on wildfire activity over the next few decades will likely be larger than the observed influence.[9]

While wildfires are necessary for the health and longevity of a forest, today's fires are damaging to both forests and wildlife. The 2020 wildfires caused "a steep decline in vertebrate species," but not just in areas where these fires occur. Due to the ash these fires spew into the air, and the resulting warming of earth, many species on many continents are impacted by the fires. This creates "tinderbox conditions" where fires can, in the long-run, cause fires on entirely different continents. Due to increases in fencing around private property, and the rise of human populations in forested areas, wildlife can't move away from the fire, and eventually get trapped and burned. It's estimated that millions of animals died in the 2020 wildfires, maybe even species that we haven't encountered yet. [13]

D. Wildfires and the effects on Human Health

Aside from the clear danger of the fire itself, the smoke created from these fires are very dangerous. Inhalation of this smoke can enter our lungs and bloodstream having lasting negative effects. The smoke from these fires can contain many different solids, nitrogen dioxide, carbon monoxide, and many other toxic materials burned. On top of everything it may find to burn in its "natural" environment, we have to also consider all of the materials that can be burned if the fire were to pass through cities. Particulate matter is the accumulation of all liquid and solids burned in the wildfires and travel within the smoke. Particulate matter is measured in the 2.5-10 micrometer range. PM_{10} falls into the category of *course* (larger particles) and includes things such as soil, dust, brush or waste burning and bacteria. $PM_{2.5}$ are *fine* particulates, which includes carbon, lead, sulfates, and many other toxic materials.

The Air Quality Index (AQI) is a measurement used by the Environmental Protection Agency (EPA) to report air quality. The higher the value, the worse the air quality is. These measurements are taken for the concentration of pollution in the air. The pollutants measured are ground-level ozone, particle pollution, carbon monoxide, sulfur dioxide, and nitrogen dioxide. The measurements for ozone is every 8 hours and particulate matter is every 24 hours. These preventative measures allow individuals to check the air quality in their city and take the appropriate precautions to stay healthy. This is a very important tool to have because it may not be as obvious how far smoke from wildfires travel and how poor the air quality can get in those areas. Sacramento, California is a valley and it is very common during wildfires in Northern California to cause smoke to settle for many days after the fire has ended.

AQI Basics for Ozone and Particle Pollution

Daily AQI Color	Levels of Concern	Values of Index	Description of Air Quality
Green	Good	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Yellow	Moderate	51 to 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Orange	Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
Red	Unhealthy	151 to 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Purple	Very Unhealthy	201 to 300	Health alert: The risk of health effects is increased for everyone.
Maroon	Hazardous	301 and higher	Health warning of emergency conditions: everyone is more likely to be affected.

FIGURE 2. Air quality index zones [10]

Health-impacts in areas with pollution and particulate matter created from wildfires can be very dangerous. It has been shown there is a significant increase in damage to the respiratory and heart systems from smoke inhalation. People closest to the fires are the most affected, but the smoke that travels can still reach toxic or very unhealthy ranges. The health impact of wildfires has shown that the largest impact is particulate matter.

Children, senior citizens, and pregnant mothers are at a higher risk when inhaling this smoke. Children's lungs are still developing; senior citizens are more likely to have undiagnosed heart or lung complications. Exposure to these pollutions show a significant increase in hospital visits and respiratory conditions such as bronchitis. Pre-existing conditions fall into an even larger risk with wildfire smoke. Conditions such as asthma see a significant surge in symptoms and complications. The mortality rate of people with these conditions sees a very significant increase the closer you are to these wildfires. It was shown from 2013-2018 in Canada that even in short-term exposure to $PM_{2.5}$ accounted for an increase of mortalities between 54-240 directly related to the smoke. Even though the further out you are from these fires, the pollution travels a very long distance and puts many lives at risk. [14]

The long-term effects of breathing in the $PM_{2.5}$ is often harder to track, but it has been shown that this fine particulate enters into the bloodstream and is a direct cause of respiratory issues such as bronchitis. It is estimated that long-term exposure to $PM_{2.5}$ is associated with 570-2500 premature mortalities. [14] Also during these wildfires there are a significant increase in the amount of hospital visits related to respiratory complications from exposure to $PM_{2.5}$. This was tracked in the California fires in 2008.[15]

Table 1
Acute health impacts and economic valuation[a] from wildfire $PM_{2.5}$, for 2013–2015 and 2017–2018 [95% confidence intervals].

	2013	2014	2015	2017	2018
Acute mortalities	54 [22–87]	70 [26–113]	97 [39–156]	240 [95–389]	131 [50–210]
Acute mortality valuation[b]	**$410M** [$120M–830M]	**$520M** [$160M–$1.1B]	**$730M** [$220M–$1.5B]	**$1.8B** [$530M–$3.7B]	**$980M** [$280M–$2.0B]
Acute respiratory symptom days	1,400,000 [0–2,850,000]	1,900,000 [0–3,740,000]	2,500,000 [0–5,100,000]	6,100,000 [0–12,200,000]	3,400,000 [0–6,760,000]
Asthma symptom days[c]	100,000 [21,000–185,000]	140,000 [29,000–248,000]	190,000 [40,000–336,000]	420,000 [91,000–739,000]	240,000 [52,000–431,000]
Child acute bronchitis episodes	2600 [0–5700]	3400 [0–7700]	4600 [0–10,200]	10,000 [0–22,200]	6000 [0–13,000]
Respiratory emergency room visits	170 [114–230]	230 [150–300]	310 [200–410]	710 [470–950]	420 [280–570]
Respiratory hospital admissions	34 [23–46]	45 [29–61]	61 [40–83]	140 [90–190]	83 [54–112]
Cardiac emergency room visits	60 [32–88]	75 [41–110]	110 [56–155]	250 [130–380]	140 [75–210]
Cardiac hospital admissions	46 [24–67]	57 [31–84]	80 [43–117]	190 [102–283]	110 [58–160]
Restricted activity days	750,000 [439,000–1,057,000]	1,000,000 [579,000–1,419,000]	1,400,000 [791,000–1,899,000]	3,200,000 [1,910,000–4,520,000]	1,800,000 [1,074,000–2,543,000]
Acute morbidity valuation[b]	**$73M** [$13M–$177M]	**$97M** [$17M–$240M]	**$131M** [$24M–$320M]	**$310M** [$58M–$750M]	**$170M** [$33M–$420M]

[a] The dollar values are socio-economic values associated with small changes in the risk of various health outcomes. AQBAT provides economic valuation estimates of those health impacts, considering the potential social welfare consequences, including medical costs, reduced workplace productivity, pain and suffering, and the impacts of increased mortality ris
[b] Values represent mean valuation of multiple iterations; [2.5th–97.5th percentiles].
[c] Asthma symptom days are only estimated for children (5–19 years of age).

Table 2
Chronic health impacts and economic valuation[a] from wildfire $PM_{2.5}$, for 2013–2015 and 2017–2018 [95% confidence intervals].

	2013	2014	2015	2017	2018
Chronic mortalities	570 [290–840]	730 [390–1080]	1000 [530–1490]	2500 [1300–3600]	1400 [730–2000]
Chronic mortality valuation[b]	**$4.3B** [$1.5B–$8.2B]	**$5.5B** [$2.0B–$11B]	**$7.6B** [$2.7B–$15B]	**$19B** [$6.7B–$35B]	**$10B** [$3.8B–$20B]
Adult chronic bronchitis cases	530 [0–1080]	710 [0–1400]	960 [0–1900]	2300 [0–4480]	1300 [0–2540]
Chronic morbidity valuation[b]	**$230M** [$0–$620M]	**$310M** [$0–$830M]	**$420M** [$0–$1.1B]	**$1.0B** [$0–$2.6B]	**$560M** [$0–$1.5B]

FIGURE 3. Emergency visits and mortality rates in Canada[16]

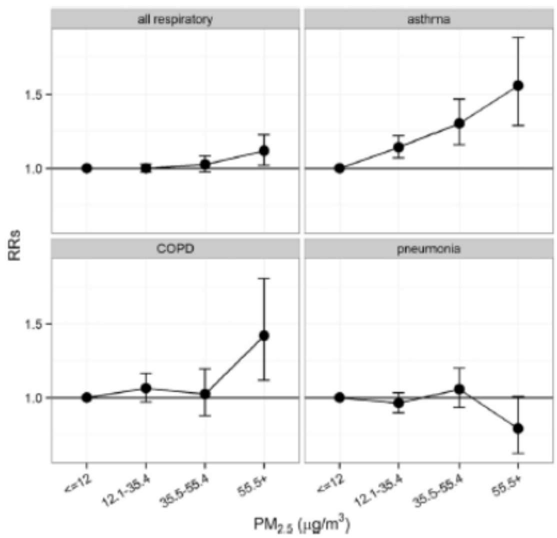

FIGURE 4. Relative risk of cardiopulmonary from California 2008 wildfires[7]

Smoke from wildfires can travel great distances causing health-impacts on people that may not be near the fires at all. This is impossible to prevent outside of doing our best to nullify the fires as fast as possible. In the most recent fires in Northern California and Oregon, the smoke has travelled about 4,000 miles. The smoke from these fires could be seen from other states such as Ohio. The amount of smoke and how far it travels is highly based on the size of the fires and how the wind moves the smoke. As we continue to have more frequent and constantly growing wildfires, the threat of Particulate matter will only get worse.

Our frontline workers take the biggest risks while fighting these fires. The CDC has previously conducted studies on the rate and risk of heart disease, cancer, and other various illnesses that result from being exposed to carcinogens, high temperatures, and sounds while fighting the fires. The results of these studies showed that the most common death for firefighters is a sudden heart attack, or other complications with the heart. Firefighters also have a high rate of hearing loss due to constant exposure to loud noises (Fire alarms, explosions, rushing water, ect). A long-term and permanently debilitating issue career firefighters experience is Rhabdomyolysis. This is a breakdown is muscle tissue due to prolonged exposure to high temperatures. This can cause permanent disability, kidney failure due to the massive amount of dead tissue being processed by the body, or even death. Firefighters honor their duty, but for their own safety we should try to limit their exposure to high temperatures, smoke, and exhaustion. [17] After further research, we've found that firefighters are exposed far more often to low AQI. Despite the heavy protective gear, they still suffer permanent and debilitating health issues.

III. DESIGN IDEA

A. Project Proposal Overview

The wildfire detection system uses a grid of smoke/temperature detection posts that can communicate with each other using radio transceivers. These units are deployed in forested areas that are normally unobserved by people. If a single post detects heat or smoke, it transmits its device ID to neighboring units, the neighboring units then transmit the ID to its neighbors until the data reaches a Primary Post. The Primary Post is equipped with cellular communication so the data can leave the grid. Once the Primary Post receives the ID of the triggered Secondary Post fire detector it sends out a 'stop' with that ID to stop the transmission of that ID for a period of time (as to prevent an infinite loop of transmission of an ID or to prevent false detections from small camp fires for a period of time).

This addresses the societal problem by providing fire fighters with early warnings about potential fires starting in high-risk areas. The idea is to stop fires before they grow too large to control, which requires constant observation of forests. With so much fuel readily available in these areas, wildfires often grow at an exponential rate, so it would be best to have early information about them and stop them before they become a problem.

We used a DHT22 temperature sensor and MQ2 smoke detector to monitor these areas. Combined with radio communication and cellular communication to allow data to pass through the grid, through the cellular tower, and eventually arrive at a central location that can translate the ID of the detector to a location on a map using a database containing all devices. We used lithium batteries design to last years and resist seasonal temperature changes.

Our solution is unique in the sense that it provides a rapidly deployable 'brute force' and inexpensive method to monitor large sections of forest without the need of line of sight. The idea is to have many disposable and replaceable units so when one unit stops working, a new unit can be placed where the old one is without the need to modify the entire grid.

Other solutions monitor the sky for smoke, but these devices need to wait for a fire to release enough smoke and require line of sight. Our solution can be triggered the moment fire reaches it, or the moment the area becomes filled with smoke. Forrest Fire management is also attempting to create clearings, but often cannot keep up with the requirements to prevent these fires due to a lack of funding and resources, so the next best option is to know where the fires start shortly after they start.

B. Features and Measurable Metrics

A power source is needed to allow for constant use while sensor is deployed. This is a rechargeable source with a lithium-ion battery. The requirements needed for this would be a battery that could hold a charge long enough for the solar panel to regenerate its energy so that the power output is less than the power input. These requirements are weighted heavily on the location of the sensor, the size of the battery, and the amount of power the device needs to maintain power. A battery that can maintain a long shelf life is also a priority to the design. Ideally, the battery has a slow degradation rate on charge capacity so they device requires minimal maintenance or replacement. The cost of these batteries typically range from \$5-\$25 dollars depending on the size. Along with this power source, there is a component to hold the rechargeable battery and pass a charge to the device. The requirements for this component are to fit in the overall design of the device and provide a reliable connection to our microcontroller. The component is a charge controller costing \$1 per module that works in line with the battery to allow for charging and connect to the microcontroller powering the device.

Our solution to power this device is a solar panel. The solar panel must provide enough power to replenish the battery to full capacity during the day. The solar panels are to be placed in a proper direction to gather as much solar irradiance as possible. The panels must also be small enough to be attached to the device in a convenient way for placement and to not increase the overall size of the design. The panel sizes can range based on the need of the battery requirements. The typical sizes of a solar panel range from 80-540 millimeters x 30-340 millimeters. Thee panels range in price from about $5- $20 dependent on size.

Combining these components required the use of a soldering iron to attach the solar panel to the battery charger and the device that supplies power to the microcontroller. Use of a multimeter, is required to ensure that our devices are receiving power and that the charge is being transferred properly. The tools used for measurement and connection are already available from previous classes and side projects. This portion of the design was complete when we ensured the battery can stay charged while providing enough power to the microcontroller in any weather conditions. This was tested in a multi-step process. Starting with making sure a charged battery can power the microcontroller, followed by connecting a solar panel to the battery charger to show that the solar panels provided enough power to recharge the battery. Finally, the battery was tested while running the microcontroller at varying power levels to see how long it can last and testing the solar panel it different weather conditions to provide enough information on its charging capabilities.

One out of every few detectors needs the ability to communicate with cellular towers so the information about which devices have triggered can exit the grid and arrive at a central database. Cellular communication is used sparingly to reduce costs and distribute the work of communication among the grid of detectors. By allowing the ‘grid’ of detectors to communicate with its neighbors, it creates a ‘chain’ of communication that will eventually reach the cellular communication unit. A few measurements that can be taken from this is the rate at which data can exit the grid, the success rate of data transmitted/received, and the accuracy of the received/transmitted data. This was finished when the data rate meets the minimum requirement to transmit the several (in our case two) 32-bit numbers in a span of a tenth of a second. (The rate of transfer is arbitrary, and we’ll more than likely exceed this by several orders of magnitude). This feature is microcontroller dependent, but it should take anywhere between 32-64 hours to get it fully functional, assuming there is no default software available. If the device already has software available, it should take 16-32 hours to implement it.

As the data leaves the ‘grid’ of detectors it travels through cellular towers, and enters the internet, eventually arriving at a central computer database/server. The number received by the software corresponds to a longitude/latitude location stored in a database. The location is retrieved and translated to a visual map, giving firefighters the exact location of the detector that was triggered. Measurable values include the location of triggers, time of the trigger, number of triggers, the rate of triggers, the number of triggers per unit area (Likely in square meters), and combined measurables can be used to measure the approximate velocity and acceleration of the fire. The software is finished at a minimum when it can display the location of the trigger on a map, and the approximate time of the event. This portion of the project is handled by Adam and should cost in the range of $0 to $50 depending on the use of publicly available libraries, or the need to purchase a license for a map, database, or other library.

The parts that make up this design aren’t weatherproof or shockproof. The sun, rain, wildlife, physical shock, and other natural phenomena can damage many of them. This requires a ‘case’ that houses all the components and shields them from outside hazards. This case needs to provide durable and long-lasting protection. The case will also provide the user who deploys it a quick and easy way to secure it to the ground or to a tree. Measurable values include: the type of material used to manufacture the case (More than likely plastic for the prototype), the dimensions of the case, which include the volume of the case, and physical area of ground or tree it covers, which possibly includes how well it resists impact VIA a large mass dropped onto it. This portion of the project is handled by Adam. This should not cost more than $50 depending on the size of the components. For the prototype, a basic 3D-printed case can be used, but if the size of the parts exceeds the bed of the printer, then a custom model needs to be ordered/printed online.

To discuss the features of the Temperature and Smoke detectors, we first need to understand what the difference is between these two detectors, as we often confuse the terminology and use it interchangeably. Temperature detectors are intended to minimize property damage by reacting to the change in temperature caused by a fire, whereas, smoke detectors are intended to protect people and property by generating an alarm earlier in the development of a fire because people need time to react, and every second is critical during an actual fire event. When property protection is the primary objective, heat detectors can be a reliable and virtually trouble-free solution. In some cases, heat detectors are chosen because of their low cost and greater immunity to contaminants and environmental extremes. In other cases, the temperature detectors are used to trigger fire sprinklers or other types of fire suppression systems. Modern-day smoke detectors are designed to tolerate higher levels of airborne contaminants, broader temperature ranges, and although smoke detectors are generally more costly than temperature detectors, they respond much earlier [18]. Because of the individual special features of both of these detectors, our design prototype used both.

Minor revisions of the design removed redundancies and made the project more efficient. After reviewing our implementation of this design, we realized that we can keep our method that allows for a rapidly deployable low-cost grid that can observe different areas of forest at all times. With the smoke and temperature detectors, as well as the transceivers, we can successfully monitor an area from a distance with minimal costs to parts. We've successfully performed a single "chain" of communication in testing, gathered data from the smoke detectors, stored triggers in a database, and displayed those trigger locations on a generated map, indicating that our design has all the necessary components to monitor and report a fire. We believe that our design will lead to a reduction in exponentially growing wildfires, efficiently targeted forest management, reduction in property damage, a healthier environment/people, and saved lives.

TABLE I

Punch List

Feature	Measurable Metric
Smoke Detector will detect nearby smoke from fires	Detects ionized particulates in the air and concentrations of CO from 200 – 10000 ppm which corresponds with output 0V -5V
Temperature Detector will detect rises in temperature.	Detects Rate of change higher than 12-degree increase per 60 seconds or reaching a fixed temperature of 93 degrees Celsius (200 F).
Local area regeneration like solar power to allow device to stay charged	Size of solar panel Power generated from solar panel Power In exceeds Power Out Output of 5v 2 years for all secondary post devices 2-5 years for all primary post devices
Transmit/Receive signals from all primary and secondary posts.	100-500 meters between devices Signal transmitted contains device ID, type of trigger, and time of trigger
Primary post send signals to communication tower	1 kilometer for primary to send signal to secondary posts 100-500 meters to send signal to communication tower.
Primary post stores logs in database and clears out secondary posts periodically.	Retrieves Telemetry from other sites, time-stamped alerts based upon preexisting flag of conditions stored in a database off-site.
Secondary post identification	Every device stores its own Identification number capable of transmitting that information
Database of transmitted Signals received from Primary posts outside of grid network storing all triggers and linking Device ID's to mapped coordinates of devices.	Receives log information from Primary Post Device ID Type of trigger(smoke/temperature) Time of trigger Device stores ID Time of trigger received Links Device ID to mapped coordinate in database Database stores all triggers from Device ID's until manual deletion.
Post devices stationary based upon geographical location	Each post location in an off-site database. Rooted to physical location fixed to ground.
Post devices alternates between sleep/awake modes searching for ppm/temp changes during current awake session. Data Gathered independent of each wake cycle.	Alternates between sleep and awake state every 5 minutes sampling smoke/temperature changes during current awake session. If change detected stay awake, constantly monitoring changes. If changes continue to rise to trigger levels send alert and continue to monitor until primary post resets device.
Mapped Software to track updates of Post triggers activity	Live updates of received Post ID's that display on a monitor showing location and timestamps of triggers. Display approximate velocity and acceleration vectors of fire.

C. Project Budget

Our current price range is about $250 - $500, but this is without refining the idea behind individual components used, cost of bulk purchasing, and refining the complete design to reduce costs. This current price range should include at least 3 modules so that we may test the communication parameters of the project.

IV. FUNDING

Currently, Team 12 group members will provide all funding for the project budget.

TABLE II
Project Funding

Part	Purchase Site or Address	Buyer	Cost
Case	N/A (IBS 3D print)	Adam	$0-$50 (Depends on if my printer can fit the print)
Microcontroller with transceiver	ESP-32	Don	$20-$40
Temperature Sensor	Https://Amazon.com	Ria	$5-$15
Smoke Sensor	Https://Amazon.com	Ria	$5-$15
Solar Panel	Https://Amazon.com	Lance	$5 - $25
Batteries(li-ion)	Https://Amazon.com	Lance	$5 - $25
Battery Charger	https://www.amazon.com/ESP8266-Lithium-Battery-Charging-Arduino/dp/B07PR9RSW2	Lance	$13.00
Software	N/A	Adam	$0 - $50 (Depending on licenses of libraries)

V. PROJECT MILESTONES

A. Milestone 1: Communication

Complete communication was accomplished when communication between a post and its neighbors was established, communication between the primary post and the database was established, and chain communication between secondary posts was established. There were several tasks that had to be completed to reach this milestone, which starts with the cellular communication and secondary post communication, these tasks were completed concurrently.

All tasks below Feature 7 and Feature 4 had to be completed to cross this milestone. This included setting up cellular communication and transceivers. Cellular communication included establishing a connection between the parent and child ESP32s in the Primary Post. This was accomplished with the RX/TX pins with UART communication. After this connection was established, the connection between the Primary Post and the Database (Feature 1) was established using cellular communication. This allowed data to leave the grid. For communication though the grid of Secondary Posts, Transceivers were used. The Transceivers were attached to each parent ESP in both the primary and secondary posts. Each post must communicate with its neighbor posts without forming 'loops' of retransmission. This included Activities 4.1.1, 4.2.1, 4.2.2, 7.1.1, 7.1.2, 7.2.1, and 8.2.2. This milestone was accomplished November 30th, 2020.

B. Milestone 2: Data Collection

The data collection milestone was crossed when the posts become 'aware' of their surrounding temperature and PPM of smoke. The microcontroller needed to sample data though the DHT11 temperature detector, store the data for a period, and calculate the rise in temperature over time. The microcontroller must also collect data from the MQ2 smoke detector, convert the value read into PPM and keep track of the increase/decrease of smoke PPM over time. This included Features feature sets 5 and 6, and activities 5.1.1, 5.1.2, 5.2.1, 6.1.1 and 6.2.1. This milestone was crossed by November 30th, 2020.

C. Milestone 3: Local Area Power generation

Local area power generation was accomplished when the primary and secondary posts were able produce more power than they consume. This was accomplished when power produced from solar panels is regulated, fed though a lithium battery charger, and is finally fed into the battery. This power is used to power all our modules in Feature sets 4, 5, 6, 7 and 8. This is detailed Feature 9 as well as in activities 9.1.1, 9.1.2, 9.2.1, 9.2.2, 9.3.1, and 9.3.2. This milestone was accomplished by November 20th, 2020.

D. Milestone 4: Functional post

This was accomplished when Features 3, 4, 5, 6, 7, 8 and 9 were implemented. This also required milestones 1, and 3 to be crossed. We crossed this milestone when we have a functional (although still a prototype) primary and secondary post. The posts were capable of communicating with their neighbors though the transceivers, the primary posts were capable of communicating with the main database through cellular communication, secondary and primary posts collected data from the smoke and temperature detectors, process detector data on the microcontroller to obtain the increase of temperature and PPM over time, and have local area power generation. A fully functional primary and secondary post (We must build two of the secondary posts) was constructed when this milestone was crossed.

E. Milestone 5: Database and map

This milestone was crossed when Feature 1 and Feature 2 are implemented. The first feature implemented was the database that stores and accesses post IDs and locations, as well as past triggers, type of the trigger, the location of the trigger and the time of the trigger. The interactive map (Feature 2) came after the database because the map needs to convert the incoming trigger IDs (Transmitted from the Primary Posts though cellular communication) to geographic locations that are pinged on a map.

The cellular communication was split into several activities, which started with simply obtaining a sim card. The ESP32 that is cellular communication capable is a child of the ESP32 that isn't and is only part of the primary post. This requires communication between the parent and child ESP 32, which was accomplished with the RX and TX pins on the microcontroller and UART communication.

F. Milestone 6: Complete Prototype

The complete prototype milestone was crossed when all activities are completed in the detailed work breakdown structure. One of the most important milestones crossed was complete communication, where every post can communicate with its neighboring posts, primary posts can communicate with the database though cellular communication, and the Parent and Child ESP32s can communicate with each other in the primary posts.

Another milestone/feature set that was accomplished is local area power generation. Each post was capable of generating its own power though the attached solar panels, store that power for future use, and take steps to reduce over-all power consumption.

Each post was 'aware' of its surroundings in such a way that it can read PPM of smoke and temperature. This was accomplished in milestone 2, where the microcontroller successfully samples data from the MQ2 smoke detector and DHT11 temperature detector, stores the data over time, and measures the increase in PPM smoke and temperature over time, which is responsible for 'triggering' the post.

Finally, the data that escapes the grid and arrives at the main database was able to appear on a map to show the location of the triggers. This was accomplished in milestone 5 and was finished when Features 1 and 2 were implemented.

The complete prototype milestone was crossed by December 7th, 2020 so it's ready for presentation on December 7th.

The timeline outlines the overall level of effort for the entire project. Each individual task was shown through the GANTT chart with set deadlines to achieve specific goals within the project. Our initial working prototype currently has a set date to finish by December 11th for presentation. All components are modular and capable of working in the "over-the-wall" fashion required during the pandemic. The total cost is averaged from $40-60. The PERT diagram highlighted our critical path including milestones for the project. The design of the total timeline progressed over a 1-week duration.

VI. WORK BREAKDOWN STRUCTURE

Database, feature 1, provided the project with the ability to store and access post ID's and their associated locations. Allowed the storage and access of past triggers, type of the trigger, time of the trigger, ID of the trigger and the location of the trigger. This allowed us to calculate the relative velocity and acceleration of a fire. Database is in the form of an SQL server. Management and access of the database was done with a python script. The python script will constantly listen for incoming triggers (packets) and will respond accordingly.

Interactive map, feature 2, provided a live feed of smoke/temperature trigger locations. Using the data of recent previous triggers from feature 1, an approximate velocity and acceleration can be shown as arrows on the map. The user can navigate the map freely. Triggers are shown on the right of the map in a list, and when clicked on, automatically show the location of the trigger on the map. The interactive map will use a python script to display and run and will have access to the SQL server with python's SQLlite library.

Protective case, feature 3, each case of each post protects the sensitive components from outside hazards while allowing the detectors to collect information unimpeded. The case needs to be secured to an object that would normally be immovable without tools. This case will be designed using a student version of solid works and 3D printed.

Cellular Communication, feature 4, primary posts have a child ESP32 microcontroller that communicate with cellular towers. Communication functions were set up to allow simple packet-based transactions between the server that runs the interactive map/stores the database and the primary post. Functions for communicating between the ESP-32 parent and child were set up as well. This was written in C and used standard UART communication. This was completed when information from the parent ESP32 traveled though the child, and eventually arrive at the server running the interactive map.

Feature 5 and 6 talks about the thermometer that we utilized in our project. For the thermometer and the smoke detector, we used the DHT11 and MQ2 respectively as these are best suited for the requirements of our project. The main task was connecting these detectors to the microcontroller. We used an ESP 32 microcontroller to accomplish this. The microcontroller was then programmed to calculate the smoke particles parts per million in the air, and the temperature.

Transceivers, feature 7, are part of every post, primary and secondary. A system was made to allow each of the posts to know and communicate with their nearest neighbors. The secondary posts needed to be able to re-transmit until the 'trigger' eventually arrives at a primary post.

Microcontroller, feature 8, Program micro-controller (during awake period) to determine if there is a fire (based on temperature observation data from thermometer and smoke detector). Compute the rate of rise in temperature.

Charger Module, feature 9, provides power to post devices. Solar panels were used to charge the lithium-ion batteries. These solar panels were soldered on one side and connected to the voltage regulator to step down the voltage provided to charging module. The solar panels provided 5V, which must be stepped down to 3.7V. These lithium-ion batteries were recharged using a regulator module and provided power to our microcontroller and other modules. The batteries were connected to a charger module that will allow for recharge of these batteries. The microcontroller has a low-power state and an "on" state so the batteries will need to maintain power to the device at all times. While the device is in the low power state, it will not require much charge to keep the device on and during this time the solar panels will be recharging the batteries. Between the charging module and batteries will require a voltage step-up device because the microcontroller requires 5V to power, but the batteries run at 3.7V. The combination of these devices together will always allow our device to stay powered properly.

TABLE III
Work Breakdown Structure

Level 1	Level 2	Level 3
Feature 1: Database stores IDs and their associated locations on a map 0-$50 Adam Reed		
	Subtask 1.1: Set up database storage functions	
		Activity 1.1.1: Set up an SQL database 1-5 hours
		Activity 1.1.2: Set up functions that can easily store new post IDs and their associated IDs 5-10 hours
		Activity 1.1.3: When a signal is received, store the type of signal, time of signal and location of signal 5-10 hours
	Subtask 1.2: Set up database access functions	
		Activity 1.2.1: Set up functions that can access the database by feeding in an ID and returning a location 5-10 hours
		Activity 1.2.2: Set up access functions for past triggers, trigger IDs, trigger locations, type of trigger and time of the trigger. 5-10 hours
Feature 2: Interactive Map 0-$50 Adam Reed		
	Subtask 2.1: Display Interactive Map	
		Activity 2.1.1: Show the interactive map on the screen 1-5 hours
		Activity 2.1.2: For ‘interaction’ allow user to navigate around the map 1-5 hours
	Subtask 2.2: Fire detection live update pings on map	
		Activity 2.2.1: Show trigger on map as well as it’s time. 5-10 hours
		Activity 2.2.2: Show approximate velocity and acceleration of the

fire on the map based on recent trigger locations and times

5-10 hours

Feature 3: Protective case

5-$10

Adam Reed

Subtask 3.1: Case

Activity 3.1.1: Develop case that protects the sensitive devices from hazards

5-10 hours

Activity 3.1.2: The case needs to be some-what secured from theft, locked down to a secure object

1-5 hours

Feature 4: Cellular Communication

$10-20

Adam Reed

Subtask 4.1 Sim Card

Activity 4.1.1: Obtain a sim card with a data plan for the ESP32 child

1-3 Hours

Subtask 4.2 Communication Scheme

Activity 4.2.1: Set up communication between the parent and child

microcontrollers

5-10 hours

Activity 4.2.2: Set up communication between primary post and server running the interactive map

10-20 hours

Feature 5: Temperature detector/thermometer

$10

Rashamjot Kaur

Subtask 5.1: Choosing thermometer for the project

Activity 5.1.1: Thermometer- DHT11 Temperature Humidity Detector Module Digital Temperature Humidity Detector 3.3V-5V

5-10 hours

Activity 5.1.2: Connect it to microcontroller/ESP32

1-3 hours

Subtask 5.2: Connecting with microcontroller

Activity 5.2.1:
Using C language, microcontroller can be programmed to use the thermometer to calculate rise in temperature.

1-5 hours

Feature 6:
Smoke detector

$10

Rashamjot Kaur

Subtask 6.1:
Choosing smoke detector for the project

Activity 6.1.1:

Smoke detector- Smoke detector Board Module MQ-2

1-3 hours

Subtask 6.2:
Connecting with microcontroller

Activity 6.2.1:
Microcontroller can be programmed to use the smoke detectors to detect the smoke parts per million.

1-5 hours

Feature 7:
Transceivers

$15

Don Nguyen

Sub-task 7.1:
Transceivers hardware

Activity 7.1.1:
Find the ideal Transceivers for the project(REYAX RYLR896 Lora).

1-3 hours

Activity 7.1.2:
Establish connection between transceivers and Micro-controller.

5-10 hours

Sub-task 7.2:
Transceiver: Transmission protocol.

Activity 7.2.1:
Program micro-controller to transmit, receive, and relay the following phrases (exact phases) and data telemetry.

If smoke being being detect, the phrase “SMOKE” will be transmit, along with the average ambient temperature, and the temperature of the individual thermometer with the highest temperature reading.

If fire being detect, the phrase ”FIRE” will be transmits along with average ambient temperature, and the temperature of the individual thermometer with the highest reading. The calculated probability of actual wild fire also will be transmits.

If the ror in temperature is higher than 4 degree per minute, the following phrase will be transmit "POSSIBILITY OF FIRE" will be transmit along with average ambient temperature. The calculated ror in temperature with the calculated probability of fire will also be transmits (from the individual thermometer with highest rate of rise in temperature).

5-10 hours

Feature 8:
Micro-controller

$10

Don Nguyen

Sub-task 8.1
Micro-controller hardware

Activity 8.1.1:
Find a low power consumption and build for communication in mind micro-controllers (ESP-32, and ESP-32 SIM).

1-3 hours

Sub-task 8.2
Micro-controller protocol

Activity 8.2.1:
Program micro-controllers to process data accumulates from sensors (smoke detector, and thermometers) then output appropriately.

5-10 hours

Activity 8.2.2:
Listen to neighbor post, and relay all incoming traffic.

5-10 hours

Activity 8.2.3:
Program micro-controller to be at sleep and awake at specific time interval.

1-5 hours

Feature 9:
Power Module used to keep device on at all times reliably

$10

Lance Nevis

Subtask 9.1:
Solar Panels

Activity 9.1.1:

Connect Panels to Module getting any charge by soldering

1-5 hours

Activity 9.1.2: Secure all connections after charging is successful

1-5 hours

Subtask 9.2: Voltage Regulator

Activity 9.2.1: Connect Solar panels and step down voltage

1-5 hours

Activity 9.2.2: After proper voltage measured, connect to Charger module.

1-5 hours

Subtask 9.2: Batteries

Activity 9.3.1 Connect batteries to charger module and measure charge received from module.

1-5 hours

Activity 9.3.2 Test how long batteries can keep microcontroller charged.

1-5 hours

Subtask 9.3: Voltage Step-up

Activity 9.4.1 Connect to battery output taking in 3.7V and output ~5V reliably

1-5 hours

Activity 9.4.2 Connect to micro controller powering the device properly

1-5 hours

VII. RISK ASSESSMENT

A. Technical Risks

The MQ2 smoke detector and the DHT11 temperature detector both have minor chances of failure. There are two possibilities of failure, one fails, or both fails. In the circumstance where one fails, the other can compensate, still allowing the post to act as a detector for fires even if it's half-blind. In the circumstance where both detectors fail, the entire post is non-functioning, and the prototype will cease all necessary function. There's also the possible risk that the malfunction prevents us from meeting our measurable metric of being able to accurately measure temperature and PPM of smoke. This would be an event where the sensors have to be completely replaced and tested. This would have an intolerable impact on our project, delaying things far too long to recover from.

When connecting all the modules, there is a chance that the connections aren't secured or are incorrect. The detectors will be powered directly from the booster/battery (Voltage dependent), but the connections to get the data off the detectors and into the microcontroller need to be checked several times before powering the modules. This is to ensure that the microcontroller and detectors aren't damaged. The likelihood of this happening is slightly higher than others, but the impact it will have on the project is minimal.

There are several points where communication can be broken. Communication between the primary and secondary posts can be lost due to the posts being placed too far apart, communication between the primary post and database can be lost as with several causes. One cause of loss of connection to the database could be the caused by a loss of communication between the parent and child ESP32s in the primary post due to bad wire connections. Another loss of communication between the database and primary post can come from weather conditions. This can cause critical failure in the overall project, having an extremely high impact on the prototype. Caution must be taken to mitigate the risk of loss of communication. This loss could happen at any point up until the compete product in May 2021. If communication isn't achieved, it will prevent the entire project from continuing forward.

The overall design of the detection system places a heavy importance into its power source as it is a critical path for completion of the design. The power source portion of the design introduces some potential technical risks that our team must attempt to avoid. These Post modules will primarily be placed in wooded areas that experience different types of weather, sunlight, and seasonal changes. All of these different changes can create a risk in our design which relies on solar energy to keep our device charged at all times. If our device is unable to keep the batteries charged enough to keep the microcontroller turned on, then we will have a non-functioning device. This requirement must guarantee that power generated is greater than power consumed. To combat this possible risk, testing will be done in different types of environments to see how much power is being passed to our charging modules and testing timing on how the batteries take to reach a full charge. If the current setup of solar panels does not provide enough power, some possible solutions will be to be to move the devices to an area that the solar panels can receive more light from or to add more panels. The downside of adding more panels will be a possible increase in the overall design. Another risk involved with the power system will be how long the battery or batteries can keep the microcontroller on in both low-power and full-power modes. The batteries must hold enough charge to keep the microcontroller on during times that it may not be getting enough charge passed from the module and solar panels. Some easy solutions to this would be to add more batteries or larger batteries to compensate for "down-time" when the batteries are not being charged. Since these devices will be sitting in seasonal weather changes, we must also consider the risk of these batteries overheating or experiencing any damage. If these lithium-ion batteries overheat or swell, there is the possibility that they may combust or no longer provide power to the device. Moving forward, the team will need to research the given temperature tolerance ranges to ensure the battery does not experience any failures. To compensate this, a cooling device may need to be added or the location of the batteries in the module may be enough to avoid any complications. The completion of the power source as a whole is a significant milestone in the project.

When the posts are placed though out the forest, the location is logged and stored according to the Post's ID. While storing these IDs and locations, there is a chance for human error. This should be moderately easy to spot and check on the interactive map. The chances for this are high, but it should have little to no impact on the project.

B. Environmental Risks

One of the largest challenges introduced to the design of the project has been the Covid-19 pandemic which presents systematic and environmental risks. The entire campus is closed to students for anything that is non-essential. The tools and workspaces that would usually be available to us are no longer an option. The introduction of the pandemic is what encouraged the design of our early detection system. Every component needed for the design can be purchased by each team member at an affordable cost allowing for a no-contact project between team members. All of our coding is handled by Git source control to allow any component to easily be duplicated on a home computer and adjusted as needed for the device. Everyone was able to purchase their own microcontroller and use the code given by the team. Using this method, we are able to greatly reduce the physical contact of our team and meet the requirement of an "Over-the-wall" type of project. Not only that, but the project itself is built to be placed on-site in a fashion that can be handled by 1 person and does not require a team of people to install them. Overall, this makes for an ideal type of project during this pandemic. Even though this significantly reduces the chance of exposure to Covid-19 between team members, this still requires trust in the team follow safety procedures put in place to protect themselves. The pandemic along with other life crisis such as other classes may have an impact on the project. To prevent this, we use chat applications and email, which allow for easy and constant communication between team members so if an emergency does arise, the rest of the team can prepare and accommodate for any changes needed. This also makes for an easy way to pass information on any changes that may need to be made in the overall design. Moving into the Spring semester of 2021, we will continue to take advantage of the tools we have in place to ensure that we can produce a working project by our deadlines.

C. Systematic Risks

There is as slight chance that the testing of the prototype causes a wildfire, although this chance is minimal, as most testing will be conducted in a controlled environment. There is also a chance, although small, that the prototype itself causes a fire due to an overheating battery, spark, or other malfunction. This shouldn't be much of a concern because testing will not include starting fires beyond the scale of a book of matches. A match can be used to test the temperature detector, and the smoke detector. Caution must be taken to collect the butts of these matches and make sure they're extinguished. As an extra precaution, a fire extinguisher will be brought during testing, but it will likely be unnecessary due to enclosed, small-scale, and controlled testing.

With the use of online tools available to us, the cost is reduced to zero and still allows for an efficient work environment. The cost of the module for people range from $40 - $60 based which type of Post they are working with. For the power portion, the effort involved will range from 2-10 hours per week and will be a passive work project because the wait time associated with leaving the devices on and tracking how long the microcontroller can stay powered on a full charge. In addition, tracking the time it takes for solar panels to charge the batteries. By compiling all of these risks into a meaningful format allows for us to assess each possible complication and create a schedule reducing the total level of effort needed.

The posts will be secured in a way that prevents vandalism from wildlife and people. There is a chance, although small, that a human or an animal happens by the post, and maliciously destroys or steals it. In this nightmare scenario, the entire post would need to be rebuilt. The probability of this happening is low, but the impact it would have on our progress would be devastating. We must take care to monitor our prototypes and final products all the way though May 2021.

Most of the effort for risk assessment would involve taking simple precautions to mitigate the risks. For example, during the testing phase, all sources of potentially flammable debris need to be removed, and a fire extinguisher be ready for access and use.

PROBABILITY

>.9 Unavoidable					
.8 Very Likely					
.6 Likely					
.3 Considerable			Loss of communication between primary posts, secondary posts, or Database	Lithium Battery Overheating Individual Life Crisis of team member Covid-19 Infection of a team member	Power consumption greater than power generated
<.1 Unlikely	Bad connections between physical components	Primary and Secondary posts logged at incorrect locations		Malfunctioning Smoke and Temperature Detectors	Wildfire caused by prototype or prototype testing Destruction of posts by wildlife/natural disasters/people
0 No Impact No chance	1 Low Impact Quick Correction	2 Slight Impact Fixable	3 Medium Impact Tolerated	4 High Impact Difficult Recovery	5 Intolerable Impact Unrecoverable Replacement

IMPACT

FIGURE 5. Risk Assessment Grid *Generated with Microsoft Excel[19]*

VIII. DESIGN PHILOSOPHY

Our primary mission with our design is to create an early fire detection system to mitigate the spread of wildfires. With this system, we can alert authorities of fires before the fire has time to grow to uncontrollable sizes. Using a grid of devices with sensors for smoke and temperature throughout wooded areas or areas typical of wildfires, potential fire threats can be detected and send alerts to nearby devices. Each device will contain a unique identification number that can be referenced for location. This ID along with any information processed will be passed along from device to device until it reaches a “primary” post that can communicate with cellular towers to alert the proper authorities of the location of the fire detected and all other information. These devices should be self-sustaining with a rechargeable power source so “touch labor” for on-site maintenance should be minimal. Ideally, these devices should be able to stay in place for about 2 years or until destroyed. Our secondary goal is to make these as cost effective as we can so that they can be easily replaced and swapped.

IX. DEPLOYABLE PROTOTYPE STATUS

A. *Test Overview*

Most of our testing involved cascading from the furthest secondary post, all the way up to the database and map, but there are tests that are independent of each other and don't impact other testing. These tests are based on the punch list and move downward to ensure that we are testing the required measurable metrics. Many of these measurable metrics are binary, and record only a true/false value, but some require the measurement of voltages, currents, and time.

B. *Test 1*

Assigned To: Adam

Test 1 started with the MQ2 smoke detector. *Test 1.1* started with measuring MQ2 voltage levels and ensuring that the output of the detector is between the required zero to five volts. This test was done by safely exposing the MQ2 detector to smoke from a sheet of paper or wood over a stove or some other controlled environment. The value measured here was the voltage, and it was monitored for high and low values. *Test 1.2* required measuring voltages while the output of the detector was connected to the input of the analog to digital input of the microcontroller. The values of the sensor should still be within the required zero to five volts. *Test 1.3* involved measuring the result of the detector on the microcontroller and translating the zero to five volts on the AtoD input then translating those values to the 200 to 10,000 parts per million. This was accomplished by monitoring the values VIA a serial interface between the microcontroller and a host computer. *Test 1.4* is the final test for *Test 1*. This test involves monitoring the trigger function for the smoke detector. The ppm values reached the detection threshold, it triggered and cascaded into the next test, *Test 14.1*. This can also be tested VIA a serial interface by simply monitoring for a "smoke triggered" output from the microcontroller.

TABLE IV

Test 1 results

Test	Expected	Result
1.1	0-5 V	2-3.3v (varies)
1.2	0-5 V	2-3.3v (varies)
1.3	0-4095	2000-3300
1.4	200-10,000ppm	N/A

Test 1.4, while meant to provide us with an accurate measurement, no longer applies. This is because the sensitivity of each sensor must be adjusted accordingly and must be triggered intentionally to match the desired amount of smoke.

```
Temperature F for Sensor 1: 74.30
Smoke threadshold: 2155
Temperature F for Sensor 1: 74.30
Smoke threadshold: 2157
Temperature F for Sensor 1: 74.48
Smoke threadshold: 2143
Temperature F for Sensor 1: 74.48
Smoke threadshold: 2143
Temperature F for Sensor 1: 74.30
Smoke threadshold: 2151
Temperature F for Sensor 1: 74.30
Smoke threadshold: 2155
```

FIGURE 6. Temperature and Smoke Sensor output from Microcontroller *Output generated from serial reader [19]*

We can see the results of our sensor outputs in *Figure 6*. Here we can see the sensors outputting the current outdoor air temperature (74F) and the value for the smoke sensor (2155). These values are printed out from the serial output of the microcontroller.

C. *Test 2*

Assigned To: Adam

Test 2 was changed due to a misunderstanding of how the sensor works. We, instead, monitored the output of the sensor while increasing the temperature with a lighter.

TABLE V

Test 2 results

Test	Expected	Result
2.1	0-5 V	N/A
2.2	0-5 V	N/A
2.3	0-4095	N/A
2.4	0-180F	90-150F

Test 2.1-2.3 do not apply, as the sensor itself does not output a constant voltage signal, but rather a digital signal that must be captured with proper timing. We did manage to make this

part of the project fully functional and obtained the proper behavior with it. The output of the circuit is in Celsius and is then converted into Fahrenheit.

D. *Test 3*

Assigned To: Lance

Test 3 involved the power system of the posts. *Test 3.1* started with measuring the voltage output of the solar panel and ensuring that it's outputting up to five volts. *Test 3.2* involved regulating the voltage from the solar panel and dropping it down to 3.7 volts. This value should be measured and recorded. *Test 3.3.* involves monitoring battery voltage over time. The battery voltage should increase over time up until 3.7 volts, indicating a charging battery. Voltage values of the battery should be measured over time. *Test 3.4* involves boosting the voltage to five volts and monitoring the output of the voltage booster. The value of the voltage booster is to be measured and recorded. The final test, *Test 3.4*, involves connecting the power supply to the microcontroller and other devices and measuring the life cycle time of a single battery charge. The time the device stays powered is to be recorded.

TABLE VI

Test 3 results

Test	Expected	Result
3.1	0-5V	1.29V-4.99V
3.2	3.7V	3.10V
3.3	N/A	Battery voltage declined faster than anticipated and drained over time rather than charged.
3.4	5V	Life Cycle Time on 3.7V 1000mAh battery: 4 Hours

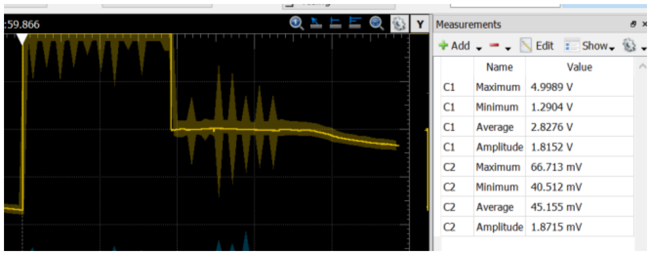

FIGURE 7. Voltage output solar panel over 2.5 hours. *Generated with Analog Discovery 2 [19]*

E. *Test 4*

Assigned To: Adam

Test 4 involved transmission of data and the range of transmission. *Test 4.1* required measuring data transmission at different ranges. The testing indicated meeting the desire range of 100 to 500 meters. *Test 4.2* involved data integrity. The transmitted data maintained the correct values for the device ID, trigger type, and time of the trigger.

TABLE VII

Test 4 results

Test	Expected	Result
4.1	100-500M	210M
4.2	N/A	Data integrity dropped off rapidly after ~200 meters.

F. *Test 5*

Assigned To: Adam

Test 5 involved communication between the primary post and local cellular towers. *Test 5.1* required a distance measurement between the primary post and the nearest cellular tower that the primary post connects to. Cellular towers couldn't be found because the locations aren't public knowledge. *Test 5.2* involved checking for communication between the primary post and cellular tower.

TABLE VIII

Test 5 results

Test	Expected	Result
5.1	N/A	Cellular tower locations aren't public

		knowledge? WE had full connection to the tower, however.
5.2	N/A	Primary post and cellular tower connection successfully established and maintained

G. *Test 6*

Assigned To: Lance

Test 6 involve monitoring data stored by posts during wake cycle. *Test 6.1* involved checking for data collection. Ensured that the posts are gathering the data they need to operate. *Test 6.2* involved checking the post for its stored IDs of recently received triggers during its wake cycle. *Test 6.3* involved monitoring the behavior of posts and ensuring that it's not retransmitting an ID that's stored within it's temporary memory during this independent wake cycle. Transmit once and done.

TABLE IX

Test 6 results

Test	Expected	Result
6.1	N/A	N/A
6.2	N/A	N/A
6.3	N/A	N/A

H. *Test 7*

Assigned To: Adam

Test 7 involved monitoring the connection between the primary post and cellular tower. *Test 7.1* requires a connection between the cellular tower and monitoring the information that is sent to the database. *Test 7.2* involves monitoring the database for incoming data. The primary post should be able to communicate with the database. *Test 7.3* required the database to store the received information in the proper tables.

TABLE X

Test 7 results

Test	Expected	Result
7.1	N/A	Connection between primary post and cellular tower established
7.2	N/A	Database retrieved data sent from SIM 800L
7.3	N/A	Data stored in proper tables

I. *Test 8*

Assigned To: Lance

Test 8 involved monitoring devices and their associated IDs. *Test 8.1* required that each post has it's own unique identification number. *Test 8.2* involved checking each post and ensuring that they all have identical IDs. Any duplicate IDs were fixed to avoid indicating at trigger in an incorrect location.

TABLE XI

Test 8 results

Test	Expected	Result
8.1	N/A	Each post has it's own unique ID programmed into it
8.2	N/A	No identical IDs detected

J. *Test 9*

Assigned To: Adam

Test 9 involved monitoring the behavior of the database. *Test 9.1* required checking if tables to ensure the required information is stored. *Test 9.2* had us create test data, and store that test data in the database to test data integrity. We made sure that the stored data is stored in the correct location and the correct value is stored. *Test 9.3* involved checking test data for individual parts, including the device ID, type of trigger, time of trigger and time of trigger received.

TABLE XII

Test 9 results

Test	Expected	Result
9.1	N/A	Tables have proper information/formatting
9.2	N/A	Test data successfully stored
9.3	N/A	Test data has every part including ID, Type, and time(s)

K. Test 10

Assigned To: Lance

Test 10 involved securing the post to the ground or some other location, then testing the durability. Can we forcibly remove it? How much effort does it take to remove it?

TABLE XIII

Test 10 results

Test	Expected	Result
10	N/A	Untested

Couldn't find a method to secure it to the ground.

L. Test 11

Assigned To: Adam

Test 11 involved monitoring the behavior of the sleep/wake cycles of the posts. *Test 11.1* started with monitoring the functions for the sleep/wake cycle. Checked if the code meets the required behavior. *Test 11.2* involved monitoring the post for its sleep/wake cycle. Ensured that the posts are alternating between sleep/wake and that they sleep for five minutes. *Test 11.3* involved monitoring the behavior of the wake cycle and ensuring that the wake cycle is collecting the required data from sensory input. *Test 11.3* required test inputs that would cause both a smoke and temperature trigger. Checked if each type triggered.

TABLE XIV

Test 11 results

Test	Expected	Result
11.1	N/A	Required behavior met, but changed to suit testing environment
11.2	N/A	Posts are successfully synchronizing and sleeping at the same time
11.3	N/A	Both types successfully triggered

M. Test 12

Assigned To: Adam

Test 12 involved the map software behavior. *Test 12.1* required that the map software can access the database for triggers. *Test 12.2* involves the retrieval of triggers from the database based on time. Most recent triggers required. *Test 12.3* involves displaying the triggers on the map. Most recent triggers should show up as points. *Test 12.4* involves showing the approximate direction a fire is heading with vector arrows.

TABLE XV

Test 12 results

Test	Expected	Result
12.1	N/A	Map successfully accesses the database for triggers
12.2	N/A	Most recent triggers retrieved only.
12.3	N/A	Most recent triggers successfully displayed on map.
12.4	N/A	FAILED. Couldn't figure out how to get arrows to display on map.

The python script that regenerates the map successfully accessed the database for the most recent triggers (set for within 30 minutes).

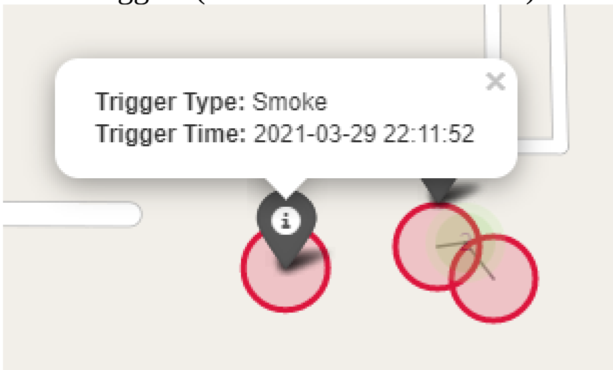

FIGURE 8. Triggers successfully displaying on map with associated type and time. *Generated with Folium for Python [19]*

N. Test 13

Assigned To: Adam

Test 13 involves a 3D printed case. *Test 13.1* requires a minimum durability test by throwing rocks at the case. The case should survive minimal impacts without breaking open and exposing the modules inside. Test *13.2* involved pouring water on the case, simulating rainfall, to ensure that the modules within are not exposed to water.

TABLE XVI
Test 13 results

Test	Expected	Result
13.1	N/A	N/A
13.2	N/A	N/A

A 3D printed case was opted out. We instead went with a simple box to house all the modules due to the 3D printer breaking, and the bed size of the printer not being large enough. We will, instead, create boxes out of different types of plastic found at hobby/hardware stores.

O. Test 14

Assigned To: Lance

Test 14 is a combination from *Test 1* and *Test 2*. *Test 14.1* required that the microcontroller monitor the triggers from both temperature and smoke, from tests *1.4* and *2.4*. This was combined into a single behavioral trigger. *Test 14.2* involved the transmission of this trigger. *Test 14.3* required that the neighboring post retrieve the trigger with the required ID, Time, and Type of trigger information. *Test 14.4.1* involved the retrieval of the trigger at a secondary post. If this occurs, the post must store the trigger ID, then retransmit. *Test 14.4.2* involved the retrieval of the trigger at the primary post. The primary post was then told to send the data of to the database VIA cellular connection.

TABLE XVII
Test 14 results

Test	Expected	Result
14.1	N/A	Microcontroller successfully monitoring data from sensors
14.2	N/A	Secondary posts successfully triggering based on sensor data
14.3	N/A	Data successfully retrieved and retransmitted
14.4.1	N/A	Secondary post successfully retransmitted its data to the next post in line
14.4.2	N/A	Primary post successfully retrieved the trigger and retransmitted it to the database

P. Test 15

Assigned To: Lance

Test 15 is a collection of tests from *Test 14*, *Test 7*, *Test 9*, and *Test 11*. This is the beginning of the cascading communication test. *Test 15.1* required that the trigger cascade though the network and arrive at the database. *Test 15.2* required that the cascaded trigger be stored in the database. *Test 15.3* involved updating the map. When the trigger is stored in the database, the map grabbed the trigger from the most recent set of triggers (based on time) and displayed the trigger on the map when it updated. *Test 15.4* was the complete cascade though the network. Starting from the lowest test and ending up here.

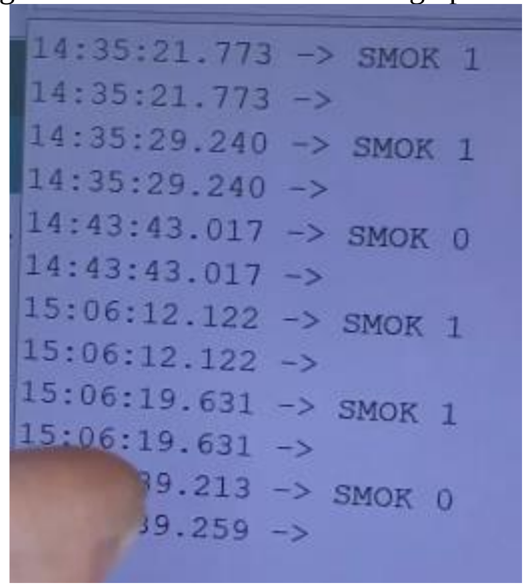

FIGURE 9. Trigger successfully cascading though network *Output generated from serial reader [19]*

TABLE XVIII
Test 15 results

Test	Expected	Result
15.1	N/A	Triggers did successfully arrive at database
15.2	N/A	Trigger successfully stored in database
15.3	N/A	Map successfully updated and regenerated
15.4	N/A	Complete Cascade achieved

The complete/intended behavior of the device is complete. The trigger successfully cascaded though the network, arrived at the database, and updated the map. With this test complete, the over-all functionality and intention behind our prototype has been accomplished.

X. MARKETABILITY FORECAST

A. Purpose

To reduce the damages a wildfire would have on homeowners and businesses. Reduce the work required by CalFire and other firefighting institutions. The environment also benefits from our design by preventing the spread of a fire and reducing the need for forest regeneration. There are other designs that accomplish this same goal, but generally cost more, and take more time to deploy. Our design is rapidly deployable and can expand tens of kilometers radially from the origin. Our design reduces the cost by making each post cheap, disposable, and replaceable. Our design allows us to deploy in areas without cellular communication by chaining each Post until we reach an area with cellular communication. This allows our design to monitor areas that would otherwise be unobserved for long periods of time.

B. Industry Outlook

Due to the increasing frequency and intensity of wildfires, we believe that our wildfire detection system can compete with other designs on the market. The principles behind our design is redundancy and replaceability. The demand for our devices will continue to grow with the frequency of wildfires, and steadily after they decline due to general maintenance of the detection grid.

Given the modular design of our product, it can easily be updated, changed, and improved as technology changes. Sensors, batteries, and other modules can be replaced due to their general control by generic microcontrollers. This gives us an option to further reduce the cost of manufacturing as technology, and other inputs that determine manufacturing costs, improves.

C. Client

Our clients would include CalFire, the US taxpayer, and various other firefighting institutions and government organizations. The benefit for the consumer includes preservation of life, property, and resources lost due to wildfires. Our design can reduce the cost of damages due to wildfires by preventing their spread. Our design can reduce the dangers associated with fighting fires by stopping the fire at the origin. Forest preservation is an additional benefit to the client (CalFire and forest management) because it shifts the focus of clients from monitoring to fighting.

Another major client could include residents and small businesses within areas where fires are frequent. By reducing the frequency of wildfires in these areas, the impacts including health, loss of life, and long-term damages. Our design can also reduce the need for evacuation from towns or cities impacted by wildfires. Areas that may never recover from a major fire will have a bit more security knowing that a fire is potentially stopped before reaching their town.

D. Competitors

Two major competitors include SmokeD, and Insight Robotics, which both use the same concept of a high-quality camera for smoke detection. SmokeD uses a single camera while Insight Robotics uses two cameras for depth measurements. These two companies are backed by IBM and a few other robotics corporations. Our competitive edge surrounds cost. SmokeD and Insight Robotics are far more expensive than our design. The loss of a single device from SmokeD or Insight Robotics exceeds the cost of a large group of our devices, as our design is meant to be cheap and replaceable. Our design is rapidly deployable and can be established nearly anywhere while our competitors are bound to areas with communication infrastructure.

E. Costs and profitability

Our design is low cost and high volume. By reducing the cost of individual posts, we can profit though the large volume of posts required to monitor a section of forest. Some success factors include repeated prevention of wildfires by stopping a fire at its origin. Homes, businesses, and other assets protected by our design. Long term success of addressing the previously mentioned societal issue could be measured in the rate of successfully contained fires vs unsuccessfully contained.

XI. CONCLUSION

A. *Conclusion - Problem Statement*

Wildfires are uncontrolled/unplanned brushland, grassland, or woodland fires. These fires have become increasingly more frequent and devastating. The variables of these wildfires, frequency, and intensity have doubled in the last twenty years. The seasonal duration of these wildfires has extended to include the entire year and are still increasing.

The costs of wildfire management have increased by six times in the last 35 years. The damage done by these fires often exceeds the budget, forcing the federal government to push aid for affected people that numbers in the hundreds of billions of dollars. The yearly budget for forest management often exceeds $2 billion, but the damage done by these fires often exceeds $200 billion, exceeding the cost of management by several orders of magnitude.

Wildfire smoke particulates have been shown to travel large distances and negatively affect the environment. Depending on the intensity of the fire, the smoke can travel to entirely different continents. These fires also significantly contribute to global warming and climate change. The particulates are trapped in the upper atmosphere for several months, capturing heat from the sun and slowly warming the entire planet.

The particulates from these fires negatively affect the Air Quality Index (AQI) in all surrounding areas. The index is a measurement produced by the EPA to report on the air quality and its relative safety to human health. The range of the AQI goes between 0-300+ with anything above 100 being harmful respiratory organs. These fires release carbon monoxide, sulfur dioxide, nitrogen dioxide, and other toxic chemicals. As the AQI increases, the number of hospital visits shows a significant increase in relation to respiratory complications. Mortalities is also positively correlated with an increase in AQI.

It has been shown that the smoke causes serious harm to our health. Wildfire smoke that contains pollutants and particulate matter continues to cause short-term and long-term effects to our cardiopulmonary systems every year. It is an increasing threat to people with pre-existing conditions and continues to cause an increase in premature mortalities. While there are preventative measures to assist with inhaling this toxic smoke, it can be almost impossible to avoid when entire cities are covered in a smoke. The combination of all the factors show highlight the very serious damages caused by wildfires every year easily reaching over 20 million affected people. Anything that can be done to reduce the spread of these wildfires would be a great benefit not only to our society, but to our planet as well.

B. *Conclusion - Design Idea*

With our grid of early detection modules, we offer constant observation of high-risk and unmaintained forested areas. With constant observation, firefighters will be warned early, preventing fires from growing too large, and allowing them to be contained early.

Powering our microcontroller module requires a reliable and rechargeable power source that can withstand weather conditions and have little to no maintenance. A battery charger module connected to the microcontroller is used to charge the batteries used. Using a rechargeable lithium-ion battery source allows our microcontroller to stay powered during standby and active modes. The battery module is to solar panels on the outside of the module to ensure that the battery will stay charged year-round in all weather conditions. Battery size and solar panel size were to meet the requirements of the microcontroller and the maximum power gain the solar panels can gain based on location, time of year, and weather restrictions. Using a self-recharging module allows for a rapid and easily deployable product with low maintenance.

Cellular communication provides the grid a path for data to exit to the world outside its detection area. Cellular communication is expensive, and requires a periodic cost, so it is used sparingly, with most of the communication handled by radio communicators within the grid between Secondary and Primary posts. The cellular communicators uses SMS or a basic ethernet connection to transfer its data to a central server whenever there is a potential fire near the surrounding device.

The software takes a number, looks it up in the centralized database, and translates that number to the actively generated map so the potential fire is immediately reported to the local fire department. The software is also capable of taking the received numbers and calculating the approximate velocity and acceleration a fire is traveling so residents of a city/town can be warned to leave long before the fire becomes a threat to the city. This information is processed by tracking the Posts that are triggered to estimate the trajectory of the potential fires.

The case for this project protects the components from outside hazards from both natural phenomena, such as rain, and wind, or wildlife/human interaction, such as potential shock damage. The case needs to be able to hold every component in a small area to reduce the impact it will have on the environment, and to prevent modifying the behavior of local wildlife. This case currently has a preliminary design using plexiglass due to a 3D printer malfunction, but moving forward would be transferred to a uniformly designed case.

The smoke sensor used in all Secondary in Primary posts and is capable of tracking the particulates in the surrounding atmosphere triggering when it reaches above a threshold. Once triggered, this information is sent to the microcontroller to be passed along the grid until it reaches the Primary post transferring that information to our database. The temperature sensor follows this same process except sampling the temperature in the surrounding area tracking the current temperature and a rate of change for a potential fire in the surrounding area.

The combination of all of these components will create the overall design of our Primary and Secondary Posts. Placing these devices throughout a wooded area creating a grid will prevent the potential for wildfires to grow out of control. This low-cost rapidly deployable design creates the potential to easily secure any potential danger zone fast and effectively reducing the potential damage to the environment, loss of property, and loss of lives.

C. Conclusion - Work Breakdown Structure

Each feature has been split into sub-tasks and then into one or more activities. Each of these activities contributes a small piece to the over-all project. The intention is to show a break down of the over-all project into several functionalities, then those functionalities into sub-tasks, and finally, those sub-tasks into small activities that can be completed mostly independent of one another. Using this method created an easy to follow path and delegation of the feature sets to be completed by each teammate.

Adam was responsible for the database, interactive map, cellular communication and protective case. The interactive map and database is implemented with python. The interactive map is capable of providing live feedback of ‘triggers’ and their location, updating whenever a new there is a new trigger available for viewing almost instantaneously. The interactive map relies on the database because the database contains the locations of the posts. Cellular communication is written in C when controlled by the microcontroller and written in python when controlled by the main database. Providing this functionality is essential to tracking potential fires and reporting it to first responders.

Ria is responsible for the smoke and temperature detectors. The detectors are to be monitored by the microcontroller. This is done with two functions written in C to collect data from the detectors. There’s a need to use the built-in analog to digital converter to get the information from the MQ-2 smoke detector and use serial communication for the temperature and humidity detector. Upon completion, we were able to confirm that MQ2 was capable of collecting the particulates in the 200-1000 ppm threshold and transmit the data successfully to the ESP-32. The temperature sensor also triggered when reaching our thresholds up to 170 degrees Fahrenheit and passes information to the microcontroller. Testing these separately and with integrated design was a major component of our early wildfire detection.

Don is responsible for the transceivers and micro-controller related tracking. The transceivers are controlled by the microcontroller and must allow communication with nearest Post neighbors. Transmission contains information about the ID of the trigger, the type of the trigger and the time of the trigger. The microcontroller needs to store the most recent received triggers to prevent a permanent loop of transmission. It must know which transmissions it has received, and which transmissions it has sent. There also needs to be a simple Acknowledge/Not Acknowledged protocol so the posts know when their neighbors successfully received the trigger.

The combination of these parts allow us to move towards integration of our design. This work was split between the group and because of the modular design we were able to easily communicate our progress and show testing between the group. Working through this work breakdown structure led to the success of our project by ensuring ever individual feature was ready for final integration.

D. Conclusion - Project Timeline

The Features, Subtask and Activities list in the work breakdown structure have been assigned due dates and compiled into milestones. This includes Milestone 1 Complete Communication, Milestone 2 Data Collection, Milestone 3 Local Area Power Generation, Milestone 4 Functional Post, Milestone 5 Database and Map, and Milestone 6 Complete Prototype. By setting these timelines, we were able to create a project timeline for the design and implementation of our early wildfire detection system.

Milestone 1 was completed when Feature sets 4 and 7 were implemented. This includes several communication schemes. The primary posts parent and child ESP32s are capable of communicating with each other though UART (The child has cellular communication capability). All posts must are of communicating with their neighbors though the transceivers. Finally, primary posts are capable of communicating with the database though cellular communication. This milestone was complete November 30th, 2020.

Milestone 2 was completed when Feature sets 5 and 6 are implemented. The microcontroller accurately samples data from the MQ2 smoke detector and the DHT11 temperature detector. It also stores and processes that data so it can monitor the change in temperature and change in PPM smoke over time. This milestone was complete November 30th, 2020.

Milestone 3, local area power generation, was completed when Feature 9 was implemented. This included setting up the solar panels, regulating the voltage from the panels, feeding the regulated voltage into the lithium battery charger, and finally feeding the power into the battery, storing it for future use. This milestone was completed November 20th, 2020.

Milestone 4 functional post was completed when Milestones 1, 2, and 3 were completed. This included total communication, where each post can communicate with its neighbors, and primary posts can communicate with the database. Data collection, where the microcontroller can accurately sample and process data from the MQ2 smoke detector and the DHT11 temperature detector. Local area power generation where each post can generate its own power in the area. This milestone was completed November 30th, 2020.

Milestone 5 Database and Map was accomplished when Feature sets 1 and 2 were implemented. The database stores post IDs and their associated locations, as well as previous triggers, the type of the trigger, the location of the trigger and the time of the trigger. As these triggers arrive at the database, they appear on the map implemented from Feature 2. This milestone must was completed November 25th 2020.

Milestone 6, complete prototype, was accomplished when all previous milestones were complete, creating our over-all prototype is functional. This includes allowing each post to communicate with its neighboring posts, primary posts capable of communicating with the database, posts sampling data from the detectors, and the database and map working together to display the triggers, and other relevant data mention in Feature 2. This milestone was completed on April 20th, 2021.

All these milestones were completed to implement the complete prototype for display on April 20th, 2021. There is two complete secondary posts, and one complete primary post. To display the functional prototype, the furthest secondary post was triggered with a bee smoker, and it triggered data was transmitted to the next secondary post. This secondary post receives the trigger, and retransmits it to its neighbors, where the first secondary post ignores it (To prevent a loop), and the primary post receives the trigger, passes it on to it's child ESP32, and finally sends the trigger to the database where it's displayed on a map. Our goal to implement a basic prototype that chain communication to the database was achieved.

The total level of effort to the entire project is given in the timeline portion of the project. By examining the GANTT chart we are able to see assigned dates, tasks, and goals in a calendar based format. Looking at the PERT will allow us to see a visual representation of the project design highlighting the critical path and milestones to reach. For the timeline assignment, the level of effort was at no cost except labor hours to create the document. This portion of the project was essential to set hard end dates and give the team a clearly defined time structure to follow

E. Conclusion - Risk Assessment

There are several environmental, systematic and technical risks we must take to continue this project. Malfunctioning parts, loss of communication, bad connections, and destruction of the posts are some of the few. During this project, we always took care to be aware of these potential risks while working through our project.

There's a potential risk, although small, for the sensors to malfunction, or full cease function. If this happens, our post loses and ability to observe the environment. The fix for this was to keep extra sensor on hand in case we had any failures during testing. This was categorized as a technical risk. While testing our posts, the potential of creating a wildfire was a risk. The probability of this happening was extremely low, as all testing was done in controlled environments, the size of the flame never exceeded one produced from a book of matches, and a fire extinguisher was present during testing. This was categorized as a systematic risk, as the system we use to test our posts could increase or decrease the potential to start a fire. Another technical risk mentioned was the possibility of forming bad connections between hardware modules. This could potentially destroy/fry the motherboard and destroy the sensors. A systematic error arises when primary and secondary posts locations are distributed and logged, the probability for human error increases as the number posts are distributed, but the impact this has on the project is minimal, as the solution would be to simply change the location stored in the database. A major technical risk we take is loss of communication. There are several points where communication could be lost. The probability for loss of communication is minimal, but it would block the progress of our project. One major risk we take is the complete destruction of a post by an animal or person, and the potential theft of the post by a person. If this occurs, an entirely new primary/secondary post would have to be constructed.

While the Covid-19 pandemic has introduced many challenges to our project design and overall lifestyles, we have learned to adapt and achieve what is necessary to avoid any environmental and systematic risk. The design of our early wildfire detection system is built in the ideal modular fashion set forth as a requirement for this senior project. By using a selection of individual components and a microcontroller with a low combined cost, each team member is capable of buying all parts and working on it without ever having to meet in person. This greatly reduced the chance of spreading or contracting Covid-19. Along with the physical components, all of our code was maintained with Git source control to allow the code to be cloned, managed, and updated at any time. Using online communication tools, we were able to send each other schematics, designs, and stay in constant communication when any problems were introduced. If any team member had any life complications, this was communicated to allow for quick accommodation and adaption for the ongoing project. These online tools are invaluable during these times when an “over-the-wall” project is our goal for the entire year.

The power portion of our design was critical to the overall function of the project and had some technical risks involved. Without a consistent and reliable power source, our microcontroller will not stay powered on rendering the device useless. To avoid the risk that the solar panels pass enough power to the batteries, testing was completed to show that enough power is given to allow for a full charge of the batteries on any given weather condition. When there was not enough power, then the solar panel size was be increased, more panels were used, or the direction the panels faced was adjusted. Another component of the power system was the battery or batteries used to keep the microcontroller powered on during the low power and fully powered states. Since the solar panel functionality was correct, this was tested separate from that and focused directly on total time the batteries kept the microcontroller on in both states. When it was unable to maintain power based on the charge received from the solar panel power, a bigger battery or more batteries was used to compensate the charge time needed for the batteries. One other risk associated with the batteries was be ensuring that they do not overheat or experience conditions outside of their expected range, which can lead to swollen or non-functioning batteries. To compensate for this, a cooling device can be introduced to avoid any complications. The overall design of the power feature is a critical path of the project and with the reliable power source will create a product that is more marketable. This milestone allowed us to place our device anywhere and have confidence in knowing that it will stay powered year round.

The total level of effort associated with the risk assessment created a potential schedule for any pitfalls we may encounter. This portion of the project does not have a cost except for hours spent compiling the information. The cost associated with the project is $60 - $80 for primary/secondary Posts. The total time associated with the battery and solar panel portions was 2-6 hours per working day and was a passive workstyle because we are measuring how long it took for the device to charge and how long it stayed powered. Other levels of effort came from the attention to details and attention to safety. Precautions were taken during the testing phase as to mitigate the risk of a fire down to nearly zero.

F. Conclusion - Problem Statement Revision

Wildfires are uncontrolled/unplanned brushland, grassland, or woodland fires. These fires have become increasingly more frequent and devastating. The variables of these wildfires, frequency, and intensity have doubled in the last twenty years. The seasonal duration of these wildfires has extended to include the entire year and are still increasing.

Recently, wildfires have become far more costly. The costs of wildfire management have increased by six times in the last 35 years. The damage done by these fires often exceeds the budget, forcing the federal government to push aid for affected people that numbers in the hundreds of billions of dollars. The cost of wildfires has been increasing tremendously. The yearly budget for forest management often exceeds $2 billion, but the damage done by these fires often exceeds $200 billion, exceeding the cost of management by several orders of magnitude. AT&T failing to maintain their power lines is one of the primary sources of these fires. They’ve made efforts to pay people for the homes they’ve burnt down but are still behind by over a billion dollars. Many of the victims of these wildfires accepted AT&T shares in a settlement. Shortly after accepting these shares, the value of them declined.

Wildfire smoke particulates have been shown to travel large distances and negatively affect several environments. Depending on the intensity of the fire, entirely different continents can be affected. These fires also significantly contribute to global warming and climate change.

The particulates can be trapped in the upper atmosphere for several months, capturing heat from the sun and slowly warming the entire planet. This global warming is often accredited to creating “tinderbox” conditions where forests are dry and ready to ignite from the smallest ember. As these fires spread, wildlife is often trapped by fencing, homes, and other man-made structures. It's estimated that millions of animals have burned to death in the global 2020 wildfires.

The particulates from these fires negatively impacts the Air Quality Index (AQI) in all surrounding areas. These fires release carbon monoxide, sulfur dioxide, nitrogen dioxide, and other toxic chemicals. The index is a measurement produced by the EPA to report on the air quality and its relative safety to human health. The range of the AQI is between 0-300+ with anything above 100 being harmful respiratory organs. As the AQI increases, the number of hospital visits shows a significant increase in relation to respiratory complications. Mortalities is also positively correlated with an increase in AQI.

It has been shown that the smoke from wildfires causes serious harm to our health. Wildfire smoke that contains pollutants and particulate matter continues to cause short-term and long-term effects to our cardiopulmonary systems every year. It is an increasing threat to people with pre-existing conditions and continues to cause an increase in premature mortalities. While there are preventative measures to assist with inhaling this toxic smoke, it can be almost impossible to avoid when entire cities are covered in a smoke. Firefighters are often the primary victims of these carcinogens. The primary death of a firefighter is heart failure, which can be attributed to the exposure of these airborne carcinogens. Firefighters also suffer from hearing loss and muscle disintegration due to their exposure to high temperatures and loud sounds. The high-stress conditions of working as a firefighter also contributes to damaging their hearts.

By further researching Wildfires and the damages they cause extends further past our original statement. These fires create long-lasting problems for anyone involved. The compensation expected from fires due to negligence on maintenance leads to people not being able to rebuild their lives. The damage dealt to the front-line workforce leads to damaging of their health and well-being sometimes permanently. Our design idea does not have any changes that will directly alter our overall project, but only focuses on a few changes made in the way the data is gathered and used. Through further research, we realize we may not have a direct approach if a wildfire were to break out, but rather an indirect approach by detecting fires before they ever have a chance to grow to a dangerous state. This type of early detection could lead to an overall reduction in damages, negative health impacts, and the spread of wildfires.

G. Conclusion - Device Test Plan

As we developed the feature set of our project, we also developed a set of tests from that feature set. These tests accurately modeled the list of features in our punch list and measured that our prototype met the requirements. Tests were generated from the ground-up, becoming more complicated and inclusive as time moved on.

The temperature and smoke detectors started with a reading of the voltage on their output, moved towards measuring the output of the sensor while it was connected to the breadboard and finally ended up on measuring the temperature and smoke as Celsius or PPM particulates rather than voltages. By working in a controlled environment we were be able to successfully determine the effectiveness and range of our sensors. This gave us one measurement metric on how close each Post must be to the next available to Post to effectively cover a radius around the device to ensure we can detect fires. These values that represent temperature and smoke were used to trigger the microcontroller. This is where serial communication was used to determine if the triggers are occurring or not. These tests are measured in test sections 1 through 3.

Some tests conducted are independent of each other. For example, test 10 simply tested the security of the post, and test 13 tests the durability of the case. These tests helped us to build a case that would provide an effective module that can survive through weather and any other extreme environmental conditions. Due to the 3D printer malfunction, a preliminary case was created and moving forward we would like to create a more secure case while in the wooded environment.

Power testing determined how long our device effectively stayed "online" when placed at its designated location. Testing the length of time required to charge the microcontroller using the battery with other components helped us to determine how much power was being the solar panel sizes needed. The battery lifetime will also determine how large the batteries needed to be to keep the device charged while the solar panels were unable to charge the batteries. This portion of the testing required a large amount of time to record lengths.

Cellular communication and radio communication were tested separately, but eventually arrived at a more complicated "cascade" test that checked the entirety of the network. To ensure our ranges were met, post communication was tested by sending test data from one post to the next (Secondary to primary) and ensuring data integrity is kept. This test is described in test sections 4, 5, and 7. Distance between posts was measured, and met the 100 to 500 meter range. By completing the field test, we were able to test the effective range of each individual Post and the entirety of the grid.

As the testing got more complicated, behavioral tests were conducted as well. This started in test sections 9 and 15. This is where testing was conducted on nearly the entire network in one go. Thanks to our modular design, each component was tested separately and effectively. This allowed us to determine what parts of our designs needed to be adjusted or modified to meet our punch list feature set. The level of effort required for the device testing will contribute significantly to the project. This required us to review the punch-list and the detailed measurable metrics in it to determine an overall test design for each feature and its subset. Upon completion of testing, the complete Post was nearly ready to be moved into a deployable prototype.

H. Conclusion - Market Review

Our design provides a solution for homeowners, businesses, and government institutions to monitor forests for wildfires. We believe that our client (Primarily CalFire) would benefit from our design by shifting focus away from monitoring, and towards prevention and fighting, as the monitoring is automated. Our design is rapidly deployable and modular, so each area that needs to be monitored could easily be equipped with our detection grid. Given that our design is modular, cheap, disposable and replaceable, we believe that it can provide fire monitoring while maintaining a growing market.

Given that wildfires are increasing in frequency, we believe that our design can quickly overtake the market and provide firefighting institutions with the ability to monitor areas of forest. The increasing frequency of fires will also increase the demand for our design and will provide a stable after market as maintenance and damaged posts are replaced.

Our client is primarily CalFire, but can be expanded to include other government organizations, private entities, and individuals that want to monitor an area for incoming fires. A client could include anybody who inhabits a forested area that is at risk of a fire. We can measure the success of our design, and the profitability, by measuring the rate of successfully contained fires vs unsuccessfully contained fires.

While we do have competitors on the market, we believe that our design addresses the societal problem in a more cost-effective manner. Our competitors, SmokeD and Insight Robotics, use far more expensive parts to accomplish the same task of monitoring a forest for fires. While these two companies can monitor a much larger area with a single device, it would be costly to lose that device in the fire. Our design addresses the destructive nature of the fire by making each post disposable and easily replaceable.

After completion of testing and implementation of our project design, we realized that the primary functionality of our design could be implemented into other modules. Instead of only being used to detect fires, we could write new libraries and use different sensors to create different uses. An example of this would be an irrigation system capable of measuring soil samples and reporting any deficiencies in the area. The low-cost rapidly deployable design would not change and could easily be adopted to work with any new set of sensors and libraries. This greatly increases the relevance and marketability of our product.

I. Conclusion - Testing Results

Designing our initial test plan created a path to success for our complete early wildfire detection design. This project consisted of many individual components that we tested as standalone components before integration allowing us to pinpoint any possible flaws in the design. After testing of individual components, we slowly began to integrate these different modules until reaching our full design to test as a total Primary and Secondary Post.

The ESP-32 microcontroller was the driving force of our overall module and held control over communication, passing power to sensors, modulating between sleep/wake states, and maintaining synchronicity between devices. Initial testing of this device created a system for our device to work through the sleep/wake states over a specified interval. Once this was complete, the next goal was to create a method to ensure that all Secondary posts within the grid were synchronized to sleep/wake cycles and have the ability to stay awake when an alarm was triggered or reset once the trigger has been reset. This was all completed through programming and running the code on the device and tested in line on a single device followed by using the transceivers to pass this signal to the other posts while accounting for propagation delays. This test set was successful and proved to work regardless of the number of devices added to the grid. The next portion of testing within the ESP-32 set was to receive the temperature and smoke triggers, processing that data, and being able to pass that information to its surrounding neighbors until reaching a primary post. We were able to trigger our sensors and see the temperature and smoke PPM along with the time of the triggers on the communication channel. After gathering this data, the information is formatted to follow a specific string set and passed to nearby devices. This information is viewed using another Post to view any information that had been passed to it. This test also proved to be successful and could pass data not only to multiple secondary devices, but also follow in a chain like fashion from Secondary Post (Post# 0) to Secondary Post (Post# 1) and finally to Primary Post (Post #2). The final testing of our ESP-32 was to work in line with the Cellular Communication device to pass this information along to our database so that all Posts and potential fires will be tracked. This testing was again completed through software and we can successfully pass that information and store it in our database. The combination of these tests accomplished our measurable metrics within the feature set for the microcontroller.

Using our two sensors we can detect potential fires near our Posts. The DHT22 temperature sensor is installed and controlled through our ESP-32. This sensor was monitored over the Arduino serial comm port and is programmed to trigger when reaching a temperature threshold of 150 degrees Fahrenheit or when a rate of change 12 degrees per 60 seconds occurs. The voltage was also measured to ensure that it is provided proper power to the device while in wake state. The MQ2 sensor was also tested for voltage measurements to correspond between 0V and 5V and to detect particles within the range of 200-10,000 ppm. By writing code and evaluating the data being passed to the device, we could determine both values. These sensors and values were both successfully monitored and sampled data that was viewed successfully through the serial port. These sensors can be successfully triggered within the expected levels and reset via the ESP-32.

Making use of our power module is a primary component to maintain our low-power rapidly deployable design. Initially, our power module used cheaper lithium-ion batteries at 1000mAH to measure how long the device could be powered in both low-power and high-power states. The batteries have been upgraded to 10,000 mAH with protection circuitry so that the voltage would not below threshold making the batteries unusable. The charge module was also upgraded with a more powerful module that had more efficient performance alongside the solar panel and outputting to the ESP-32. The solar panels were measured using an oscilloscope and were capable of outputting between 4.7-5V from sunrise to sunset regardless of cloud coverage or rain. Shaded areas also did not have a large effect on the output of the panels which was measured with our Analog Discovery oscilloscope. These panels were put in line with the charge module to drop the voltage down to 3.7 to charge our lithium-ion batteries. This voltage was measured from the charge module to ensure we were providing the power to our battery. The battery was also connected to the charge module and from the charge module out to our step-up voltage meter. The charge module dropped the voltage to 3.3V and after leaving the step-up voltage measured at 5V to provide the necessary power to our ESP-32 device and sensors. The combination of all of these components meets the feature set for power in vs power out, but further testing would be needed to test our measurable metric of 2 years for secondary and primary Post lifetimes.

After gathering the trigger information, time, and device ID on the primary post, the information uses the cellular communication microcontroller to transmit this packet to the database through the SIM800L module. This process was first tested by sending "dummy" packets to through our microcontroller to ensure the server received the right string of data and could insert this into the database. After this worked properly, we introduce the Primary post intentionally triggering the sensors and having this data transmit to the database. Finally, by testing the triggers of a Secondary Post and having that data transmitted along the chain up to the database to see if all data maintained the correct string format and data was received to the database. After all the information was received within the database, the server software prepared a live update on the map showing the Posts that had active triggers, including the time and location of those devices. All this feature set has been tested and implemented within our Posts and can successfully send/receive all this data and consistently update the live map.

The final components of our feature set that will require testing before final production will be our 3D-case which was delayed due to a broken printer. A preliminary case was made instead using Plexiglass for our demonstration. The full test set for protection was incomplete because we were unable to print the case designed initially for this project. This will also include securing the Posts to their location ensuring the device will not move. After finishing this testing, we successfully met our feature set related to the case and placement of the device. This will complete the components of our feature set including our measurable metrics and put our project to near complete for the early wildfire detection system.

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GLOSSARY

Air Quality Index (AQI): Index used by government agencies to communicate how polluted the air is currently.

Anthropogenic: Environmental pollution and pollutants originating in human activity.

Communication Tower: A tower capable of connecting and communicating with 3g, 4g, LTE cellular towers.

General Purpose Input/Output (GPIO): Used to allow for attachment of sensors and other peripherals to a microcontroller.

Microcontroller: Small computer that contains a cpu, memory, input/output peripherals, and forms of ram. Allows for rapid deployment of technology.

Oxidation: Combine chemically with oxygen

Particulate Matter ($PM_{2.5}$, PM_{10}): collection of all solids and liquids burned travelling within the smoke.

Pollutants: Substance that travels in water or air that is toxic or containing contaminants.

Post: A single physical unit that can detect temperature and smoke then report it to its nearest neighbors. Also capable of logging the most recent received ID numbers , time-stamps, triggered alerts.

Primary Post: A post that is capable of all secondary post attributes as well as acting as a communication tower.

Relative Risks: Probability of an outcome of the event of an exposed group and a non-exposed group.

Secondary Post: A single physical unit that can detect temperature and smoke then report it to its nearest neighbors. Also capable of logging the most recent received ID numbers , time-stamps, triggered alerts.

Smoke: A vaporous system of small particles that contain a degree of ionized charge and carbon monoxide, primarily sources from burning organic materials measured in parts per million(PPM).

Soil Organic Matter: Fraction of soil consisting of plant and animal tissue during decomposition.

Solar Irradiance: Power per unit area received from the sun in the form of electromagnetic radiation.

Trigger: When a post detects smoke above a fixed/change in ppm or temperature rise or both causing an alert to transmit to nearby neighbors

Wildfire: Large fire that spreads quickly over wooded areas and brush.

Appendix A. User Manual

Parts Included
Primary Post
Secondary Post
Dedicated Server
mySQL Database

STEP 1: LIBRARIES AND OTHER REQUIREMENTS

1. Install Python3.0 and PIP for library management.
    a. pip install the following libraries.
        i. Folium
        ii. mysql-connector
2. Install the following libraries for your IDE.
    a. TinyGSM
    b. Adafruit_Sensor
    c. DHT

STEP 2: MAIN SERVER SETUP

1. Change the d_user, d_psw, and d_host values to match the values for your mySQL database in the database.py python script located in the database folder.
    a. Ensure that the database you set up matches the table and database descriptions within database.py.
2. Change the write destination for the html file within the generate map function of the interactiveMap.py python script to where-ever you need the html file.
3. Boot the main server up by running the command "sudo python3 mainServer.py"

STEP 3: FLASH THE POSTS

1. Primary Post:
    a. Flash the primary post parent ESP32 using the post2.command_post.ino file.
    b. Flash the primary post child ESP32 using the Child_Main.ino file.
2. Secondary Post(s):
    a. Flash the furthest secondary post with post0.ino.
    b. Flash the mid-point post with post1.ino.

STEP 4: PLACE THE POSTS

1. Find a suitable location to place the primary post.
    a. Must have cellular connectivity.
2. Ensure the secondary posts are close enough to each other and the primary post so they maintain a connection.

Appendix B. Hardware

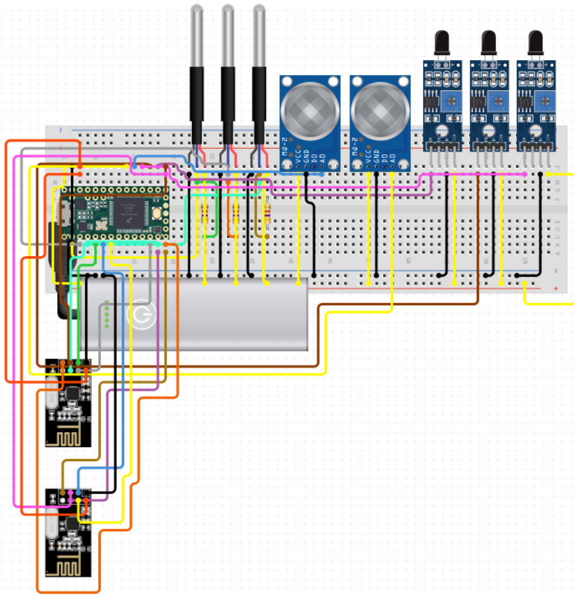

Figure B-1: Rough layout of smoke/temperature detector with all needed components *Generated using circuit.io*[20]

Build link:
https://www.circuito.io/app?components=11050,11050,11050,223347,223347,223347,398782,398782,748665,748665,771055,783869

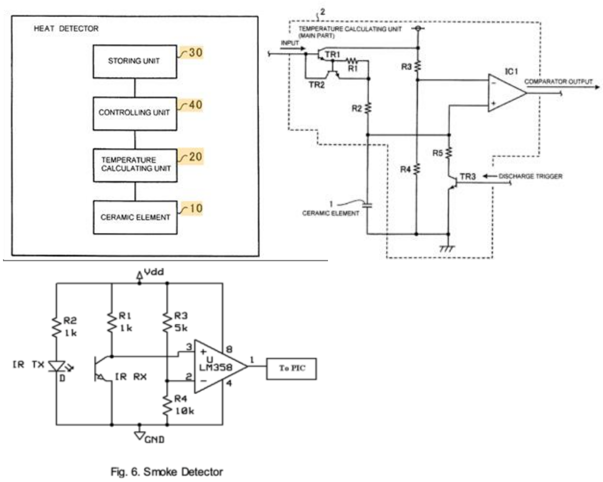

Figure B-2: Smoke and temperature detector schematics [21]

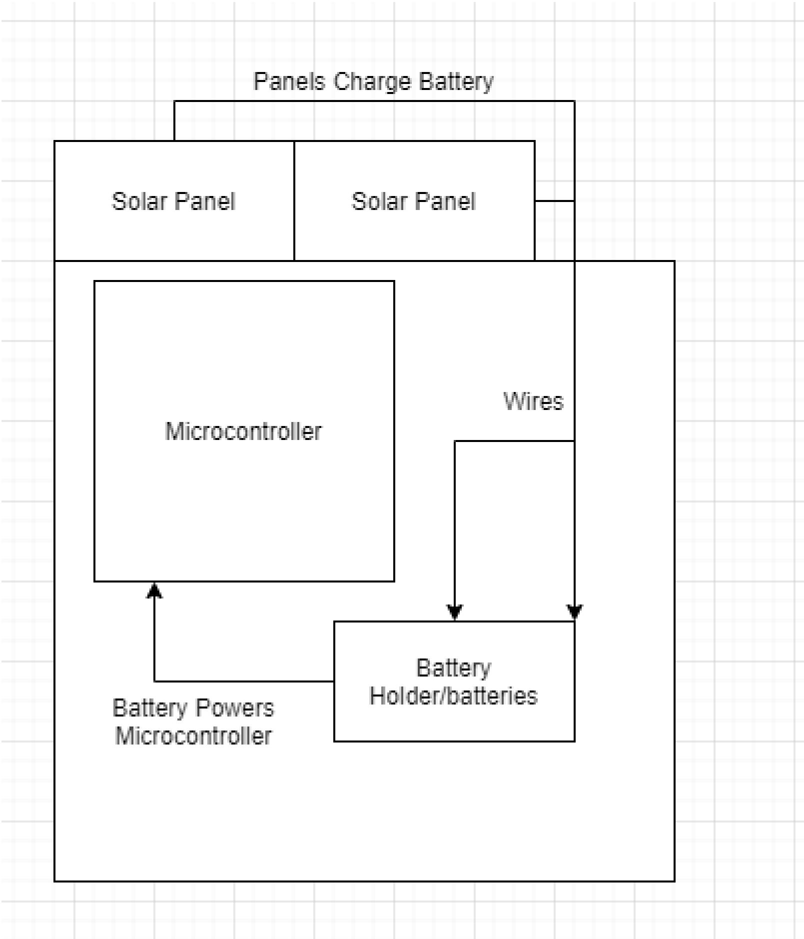

Figure B-3: Overview of the power supply, batteries, and solar panels will be connected to charge the microcontroller. *Generated using Draw.io [22]*

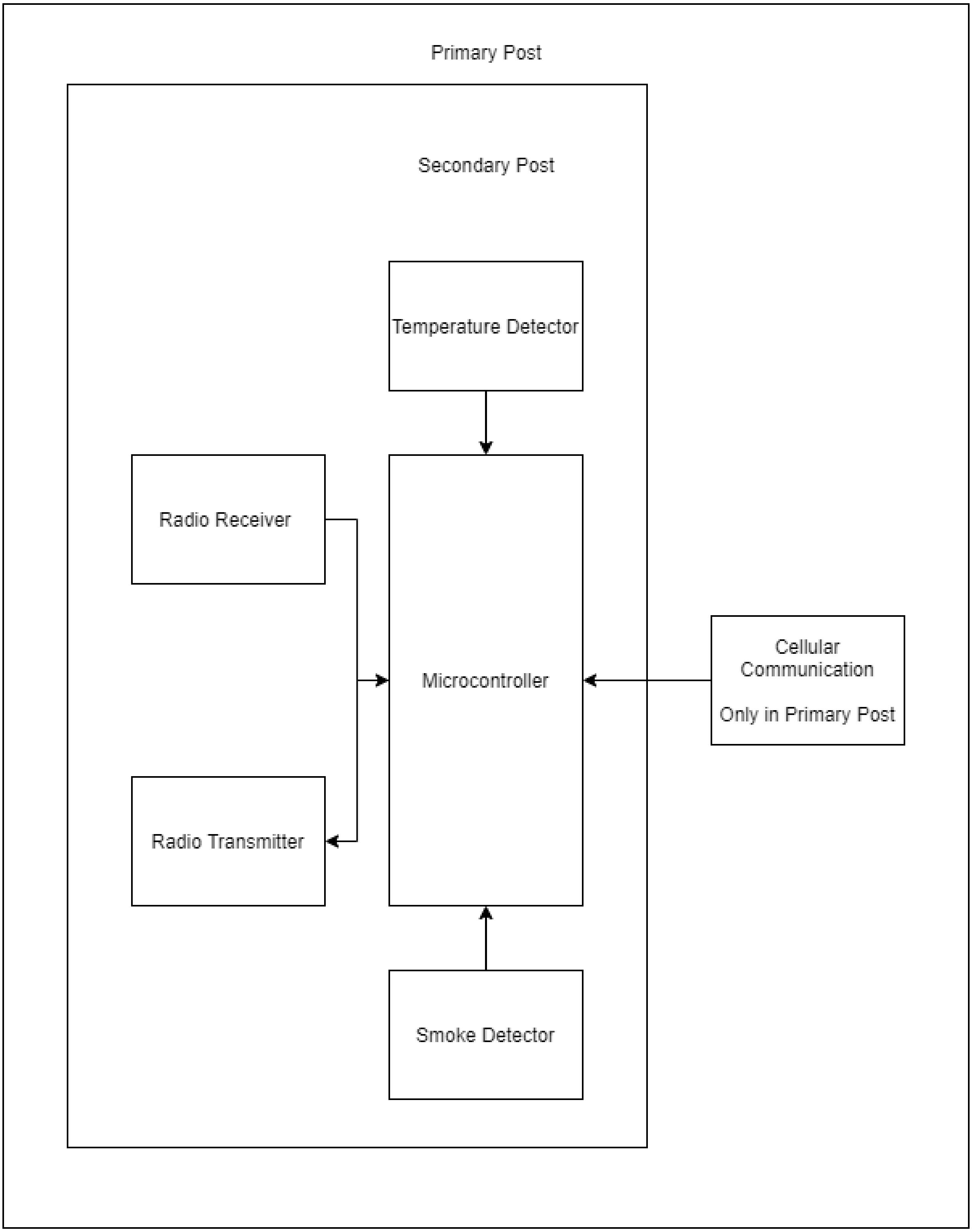

Figure B-4: Overall design of Post *Generated using Draw.io [22]*

- **Solar Panels:** will provide power to the battery charger to charge the li-ion battery.
    - Calculations needed to determine size of panels to provide enough charge.
    - Solar irradiance information needed to determine how often panels will receive sunlight.
    - Tests needed to determine how long to provide a full charge

- **Battery Charger:** Will charge the li-ion battery to provide consistent power to microcontroller
    - Determine how long to fully charge battery
    - Testing to ensure that if there is charge not needed that no overcharging occurs

- **Battery:** Will provide power to microcontroller.
    - Testing to determine how long the battery can power the microcontroller in all modes (full power and standby)
    - Determine size of battery or batteries needed to provide a charge long enough to sustain a charge even while solar panels are not providing energy.
- **Case:** Provide a protective encasement of all components and allow for solar panel attachment.
    - Measure and draw up schematics to hold all components securely.
    - Determine proper material to be rugged enough to handle seasonal weather.
        - Plastic initially for prototype
    - Ensure that casing will withstand water, temperature and shock.
    - Testing all aspects of the case against all aforementioned concerns.

- **Temperature Sensor:** Detect temperature efficiently and correctly to report of potential wildfires early
    - Communicate to microcontroller when temperature rise above certain degree
    - Test varying temperatures to ensure device is working properly
    - Test sensor within case and in different settings to show effectiveness of sensor

- **Smoke Sensor:** Detect smoke from fires and report information to mitigate potential Wildfires
    - Determine smoke is detected properly and range of sensor
    - Test communication between sensor and microcontroller to ensure signals are passed
    - Test within case in different settings and durability of sensor.

- **Microcontroller:** Receive input from sensors, produce output to other microcontrollers, and communicate with cell tower to send notice of potential Wildfires.
    - Create method to receive input from sensors.
    - Create method to reset sensors based on received input.
    - Communicate with nearby microcontrollers to pass on the warning of potential fire
    - Receive communication of potential fires.
    - Log all sensor information processed in a meaningful way
    - Output signal to the communication tower to alert proper authorities.

Appendix C. Software

Result : Format C

```
void fireAlarmProtocol() {
    loop() {
      //transmits “I AM ON FIRE” package.
      //if neighbor post reply and confirm the arrival of the package, exit the loop.
    }
    //wake up by external peripherals device (smoke sensors and flame sensors)
    Loop() {
      //wake up
      //stay awake in a for loop
      for loop(5) {
        //listen for incoming transmission from neighbor for
        //if the package of “I AM ON FIRE” receive, begin fire alarm protocol
        //pay attention to the sensors
        //if flame or smoke sensor is trigger, begin fire alarm protocol
        //if temperature sensor pick up temperature above 200 degree and increasing over a brief
            period
        //of time, begin fire alarm protocol
        //if the change in temperature are abnormal, begin observation cycle
        //observation and calculation start
        for loop(5)
        //take data sample over small interval
        //calculate observation data
        //if calculation concludes that there is a rise in probability of fire, begin fire
        //protocols
        //transmit package of “I am awake and kicking at this latitude, and longitude coordinate”,
            this allows
        //command post to do head count, and report any post that fail to transmit data.
      }
      //go back to sleep for 5 minutes
    }
```

Figure C-1: Fire alarm loop psuedo code. [19]

Map/Software pseudo Code:

Receive ID of triggered smoke detector.
Decode ID into it’s longitude and latitude location on a map.
Show Location of fire on the map.
Calculate, based on time and locations of triggers, the approximate velocity and acceleration of travel.
Display vectors on map

Appendix D. Mechanical Aspects

Our project consisted of software and hardware, but we did not have any mechanical aspects to our project. All components are secure and stationary.

Appendix E. Vendor Contacts

The team purchased all project components and we did not have any vendor contracts for the entirety of this project.

Appendix F. Resumes

Lance

NEVIS

Objective

Work in a challenging environment that will allow for creation of new ideas working in solo and team settings. Continue to gain knowledge in a professional environment.

Education

Degree Title* | *Bachelor of Computer Engineering

California State University Sacramento

Fall 2018 – Current

Graduating May 2021

Maintained a 3.7 GPA while working 30+ hours of work per week.

Work Experience

WOOD RODGERS INC. | INFORMATION TECHNOLOGY TIER 1/2

2/17-2014 – CURRENT

Worked in Operations for first 4 years before accepting offer to move into IT department.
Primary involved with setting up new computers with unique software load-outs.
Assisted with a complete overhaul of company computers to a remote environment during COVID.
In charge of Phishing campaigns and training to increase security awareness.
Create and Maintain Standard Operating Procedure forms.
Manage Tier 1 tickets for software support and touch labor.
Travel to satellite offices for support and to assist with full office moves.

Projects

Fire Detection Grid* | *California State University Sacramento

8/31/2020 – 5/15/2020

Create a smoke and temperature detection grid to mitigate wildfires. By using a cluster of low power, sensors with the capability to communicate with each other to passing a signal inform authorities of a fire before it has time to cause serious damage.

Skills

C, C++, Verilog, Microsoft Office products

Adam Reed

Address --------------- :: Phone Number --------------:: email --------------

Summary

Computer Engineering student looking for an open door. Experience with computer architecture. Designed a pipeline processor, and implemented it in Verilog. Experience with Cadence Virtuoso. Designed the layout for a mirror adder (Completed as extra credit). Knowledge of PCI Express architecture. Implemented a replay buffer and bus arbiter in Verilog with a mix between round robin and strict priority. Experiments of my own include a mandelbrot generator written in Python. Project repeated in C++/CUDA Kernel using NVIDIA's CUDA to parallelize on a GPU.

Education

California State University
Computer Engineering Senior, SPRING 2021. GPA: 3.36
Sacramento, CA.

Sierra College
Computer Science for Transfer. GPA: 3.13
Rocklin, CA.

Class Work

Completed:

- CpE 142 Advanced Computer Organization (A)
- CpE 151 CMOS & VLSI Design (A-)
- CpE 186 Computer Hardware Design (A-)
- CpE 138 Computer Network and Internet (A)
- CpE 185 Computer Interfacing (A-)
- CsC 131 Computer Software Engineering (A)
- CpE 190 Senior Design Project I (A-)
- CSC 139 Operating System Principles (B)
- EEE 108/108L Electronics (B+)
- CpE 166 Advanced Logic Design (A)
- EEE 117 Network Analysis (A)
- EEE 180 Signals & Systems (A)
- ENGR 1 Intro to Engineering
- CpE 64 Intro to Logic Design (A)
- CsC 130 Data Structure & Algorithm Analysis (A)
- ENGR 120 Probability + Random Signals (B+)

Scheduled:

Spring 2021

- CpE 191 Senior Design Project II
- CpE 159 Operating System Pragmatics

Skills

C, C++, Java, Python, Data Structures, Algorithms, Verilog, VHDL, Cadence Virtuoso, FPGAs, Vivado, Quartus, GIT

Projects

- 5-Stage pipeline processor written in Verilog
- Burning Ship fractal generator written in C++/CUDA

Rashamjot Kaur

OBJECTIVE

Bachelor of Science student actively looking for an Internship/Co-Op position in field of Computer and Electrical Engineering. Open to positions that will enable me to use my strong educational background, organizational skills and ability to work with people.

EDUCATION

Bachelors of Science in Electrical Engineering | CSUS, Sacramento
(Aug 2016- Present) (GPA: 3.5/4.0)

High School Diploma | Amritsar Public School, India
(Apr 2014- Mar 2016) (CGPA: 10.0/10.0)

PROJECTS

Wildfire detection grid | CSUS
2020 – Present
State Machine Application (Team Member) | CSUS
Designed traffic stop lights on the breadboard by connecting it to the FPGA and setting the timer and the clock in our Verilog code.
Patch Antenna Design Project (Team Member)| CSUS
Designed, Simulated, Fabricated and Measured a patch antenna using HFSS software and generating a layout.

SKILLS

Skill 1: Programming languages.
Skill 2: Circuit analysis and Data analysis.
Skill 3: Apply mathematics and physics.
Skill 4: Laboratory testing experience.

EXTRACURRICULAR ACTIVITIES

Member of the Sikh Student Association Club; Active Member of the Indian Student Association and International Hornets ʾClub at Sacramento State University.

Don

NGUYEN

Objective

"Knowledge is freedom". My passion is to further human's intellectual evolution, either through the aid of artificial intelligence, or cybernetic.

Education

Physics(as) | Cabrillo college

2007-2010

COMPLETION OF MATHEMATICS AND PHYSICS SEQUENCE FOR LOWER DIVISION

Projects

WILD FIRE DETECTION| Sacramento state

2018 – CURRENT TIME

Task with programming micro-controller to maximize the effectiveness of fire detection sensors, and the effectiveness of communication between micro-controllers (via radio frequency).

Skills

- Skill 1: high level programming languages, C, C++, Java, ect.
- Skill 2: low lever programming languages, assembly.
- Skill 3: hardware and software interface, impeded programming, system programming.
- Skill 4: Application of learning algorithm.
- Skill 5: Circuit analysis.
- Skill 6: Data analysis.
- Skill 7: Static and dynamic system analysis (both Newton mechanic and Lagrangian mechanics)
- skill 8: Apply mathematics and physics.
- Skill 9: Laboratory experiment/testing.
- Skill10: Communication

extracurricular activities

"A sound mind dwell within a sound body", the quote is one of my belief, and so I do enjoys physical activities, and healthy life style. I also condition myself to become more aware of the world around me, this help me see the world better, and better relation with my fellow human through understanding.

Appendix G: Punch List

Feature	Measurable Metric
Smoke Detector will detect nearby smoke from fires	Detects ionized particulates in the air and concentrations of CO from 200 – 10000 ppm which corresponds with output 0V -5V
Temperature Detector will detect rises in temperature.	Detects Rate of change higher than 12-degree increase per 60 seconds or reaching a fixed temperature of 93 degrees Celsius (200 F).
Local area regeneration like solar power to allow device to stay charged	Size of solar panel Power generated from solar panel Power In exceeds Power Out Output of 5v 2 years for all secondary post devices 2-5 years for all primary post devices
Transmit/Receive signals from all primary and secondary posts.	100-500 meters between devices Signal transmitted contains device ID, type of trigger, and time of trigger
Primary post send signals to communication tower	1 kilometer for primary to send signal to secondary posts 100-500 meters to send signal to communication tower.
Individual post devices log and store signals received during wake state from other devices by ID within local grid network	Signals transmitted include Device ID Type of trigger(smoke/temperature) Time of trigger
Secondary post identification	Every device stores its own Identification number capable of transmitting that information
Database of transmitted Signals received from Primary posts outside of grid network storing all triggers and linking Device ID's to mapped coordinates of devices.	Receives log information from Primary Post Device ID Type of trigger(smoke/temperature) Time of trigger Device stores ID Time of trigger received Links Device ID to mapped coordinate in database Database stores all triggers from Device ID's until manual deletion.
Post devices stationary based upon geographical location	Each post location in an off-site database. Rooted to physical location fixed to ground.
Post devices alternates between sleep/awake modes searching for ppm/temp changes during current awake session. Data Gathered independent of each wake cycle.	Alternates between sleep and awake state every 5 minutes sampling smoke/temperature changes during current awake session. If change detected stay awake, constantly monitoring changes. If changes continue to rise to trigger levels send alert and continue to monitor until primary post resets device.
Mapped Software to track updates of Post triggers activity	Live updates of received Post ID's that display on a monitor showing location and timestamps of triggers. Display approximate velocity and acceleration vectors of fire.

Appendix H: Hardware/Software Overview

- **Power Source – Provide power to microcontroller and maintain charge even during times that solar panel cannot provide enough power to recharge batteries.**
  - **Charger $30 per unit**
    - Properly charges Batteries.
    - Does not overcharge if battery fully charged
    - Properly receive power from solar panels enough to charge batteries
  - **Batteries $5 - $25 per unit**
    - Power microcontroller properly.
    - Able to withstand high/cold temperatures of year round weather conditions in area while encased
  - **Solar Panels $5- $25 per unit**
    - Properly provide power to charger.

- **Microcontroller – Receive inputs from sensors. Log received data. Pass signals to other Microcontrollers in range. If "primary" controller send signal to communication tower delivering messages of fires. $11 per unit**
  - **Receiving**
    - Receive and process data from Smoke/Temperature sensors
    - Log all data from sensors to be passed
  - **Transmitting**
    - Pass data to all sensors in range of data received from sensors
    - Communicate with Cell tower to send messages

- **Sensors – smoke sensor and temperature sensor to detect fires as soon as possible sending that information to the microcontroller $10 - $30 per unit**
  - **Detection**
    - Temperature sensor able to detect increase in temperature.
    - Smoke sensor able to detect smoke near device.
  - **Transmitting**
    - Sensors able to communicate detected alerts to Microcontroller

- **Software – Live map and database of numbers that correspond to map locations $0 - $50**
  - **Map:**
    - Updates live as ID's are received and decoded
    - Shows the approximate velocity a fire is traveling on the map
    - Shows the approximate acceleration a fire is traveling on the map
  - **Database:**
    - Able to store ID's and their related location
- **Case: Enclosure to hold all components in a safe and secure way. $0 - $50**
  - Able to protect the modules from water and impact
- **Cellular Communication:**
  - Able to send and receive packets.
  - Able to send and receive SMS messages

Appendix I: Work Breakdown Structure Diagrams

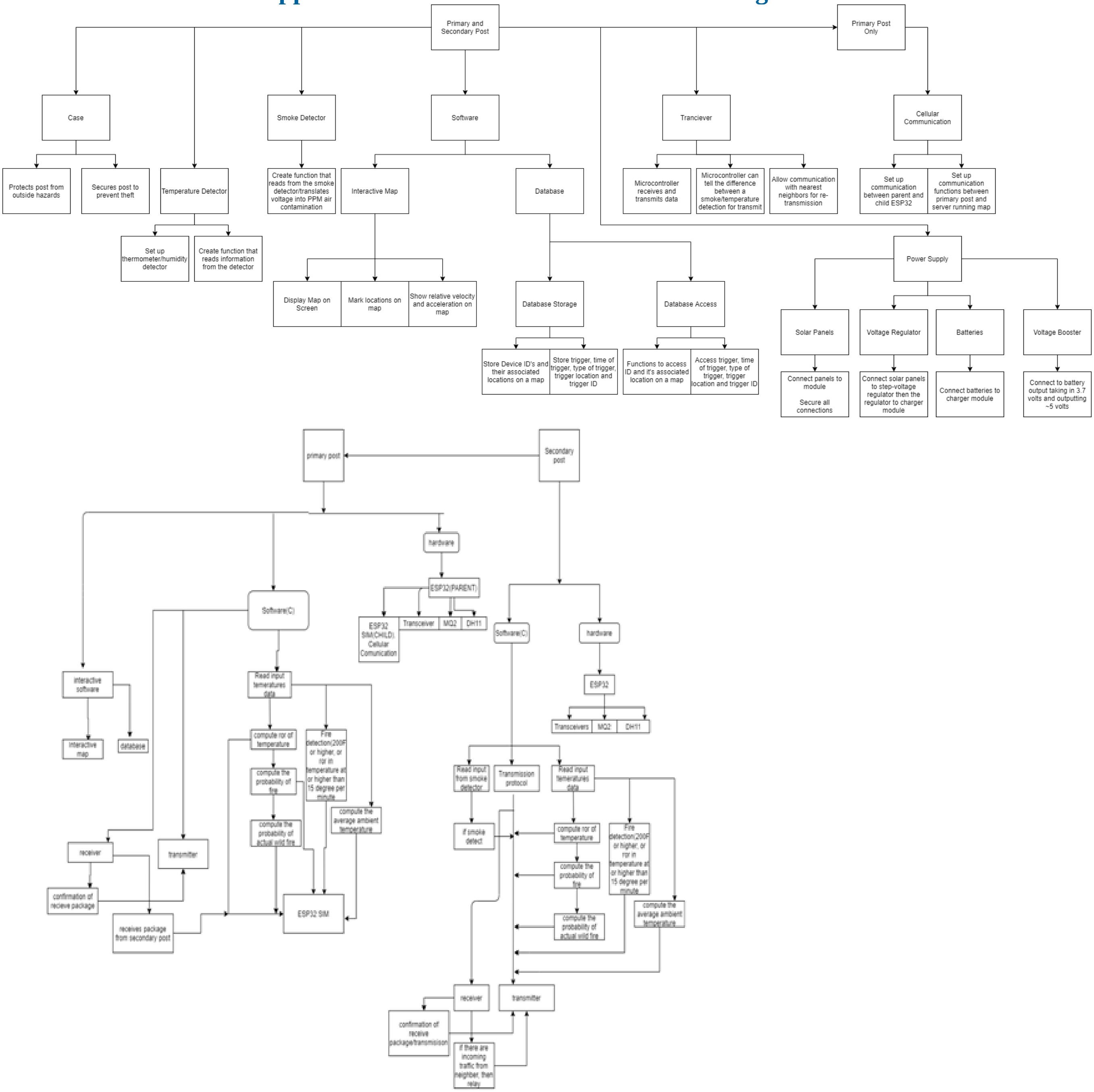

Figure I-1: Work Breakdown Diagrams. *Generated using draw.io* [22]

Appendix J: PROJECT TIMELINE GANTT AND PERT DIAGRAMS

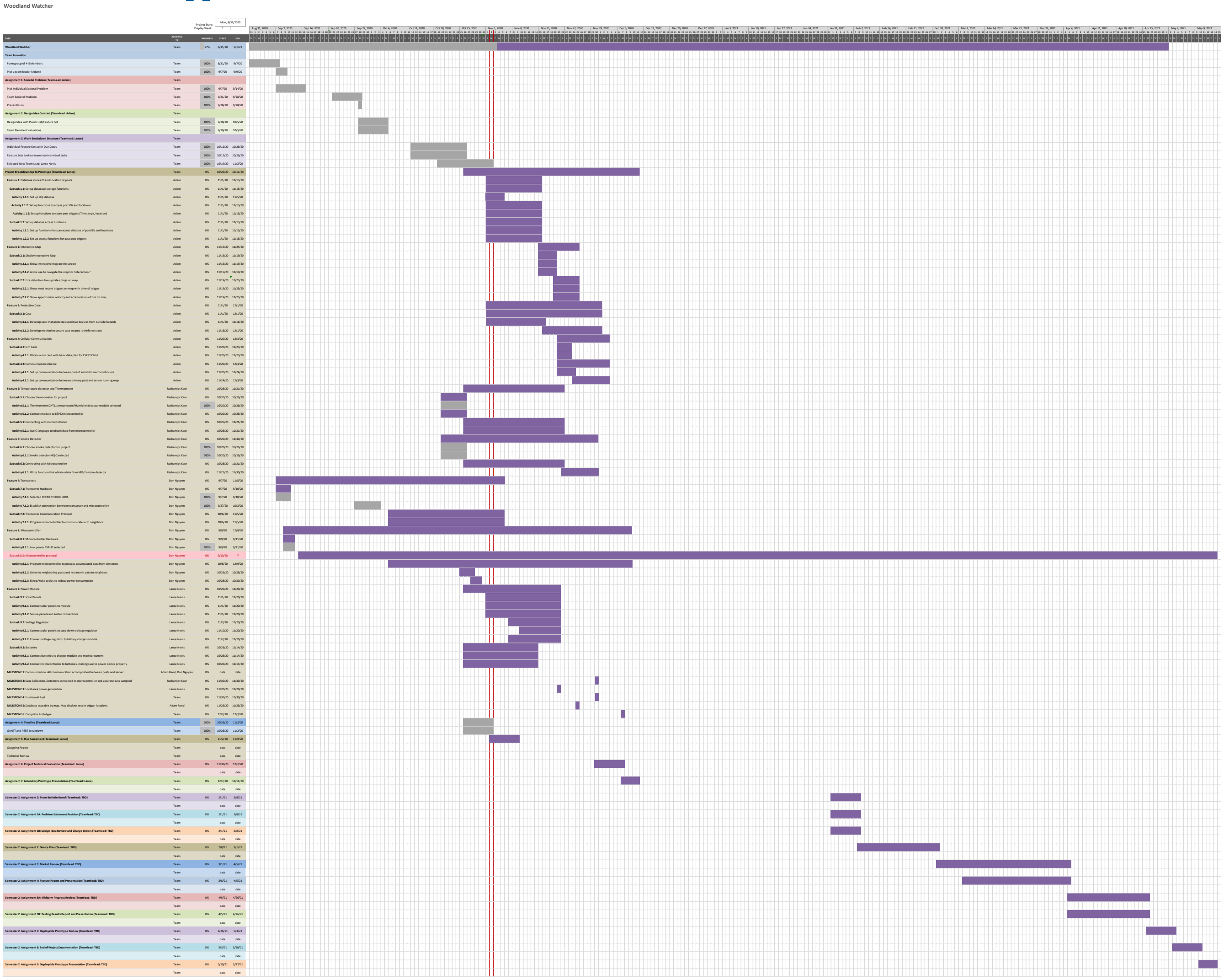

Figure J-1: Over-all Project Timeline GANTT. *Generated with Microsoft Excel*

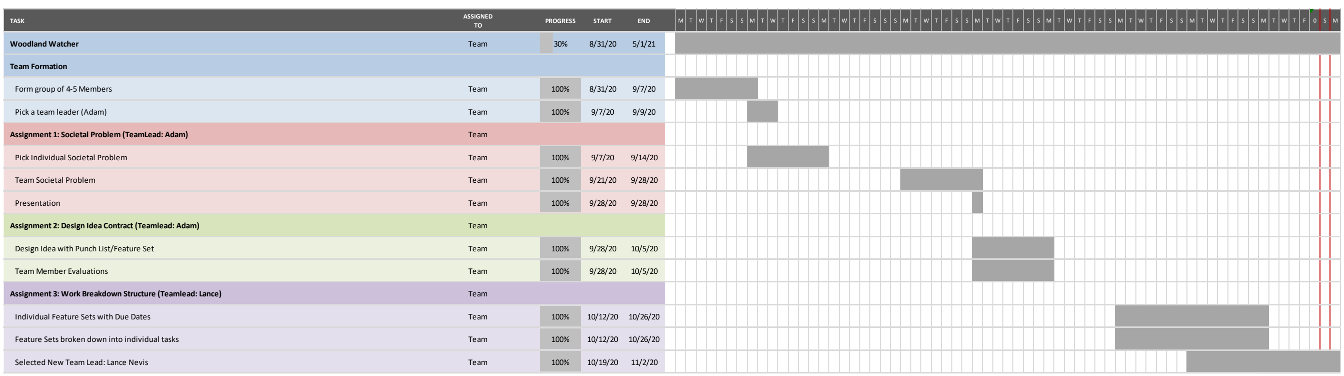

Figure J-2: Assignments 1-3 Timelines. *Generated with Microsoft Excel*

Project Breakdown Up To Prototype (Teamlead: Lance)	Team	0%	10/26/20	12/11/20
Feature 1: Database stores ID and Location of posts	Adam	0%	11/1/20	11/15/20
Subtask 1.1: Set up database storage functions	Adam	0%	11/1/20	11/15/20
Activity 1.1.1: Set up SQL databse	Adam	0%	11/1/20	11/5/20
Activity 1.1.2: Set up functions to access post IDs and locations	Adam	0%	11/1/20	11/15/20
Activity 1.1.3: Set up functions to store post triggers (Time, type, location)	Adam	0%	11/1/20	11/15/20
Subtask 1.2: Set up databse access functions	Adam	0%	11/1/20	11/15/20
Activity 1.2.1: Set up functions that can access databse of post IDs and locations	Adam	0%	11/1/20	11/15/20
Activity 1.2.2: Set up access functions for past post triggers	Adam	0%	11/1/20	11/15/20

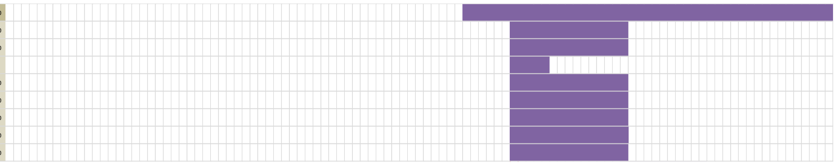

Figure J-3: Feature 1 Breakdown. *Generated with Microsoft Excel*

Feature 2: Interactive Map	Adam	0%	11/15/20	11/25/20
Subtask 2.1: Display Interactive Map	Adam	0%	11/15/20	11/19/20
Activity 2.1.1: Show interactive map on the screen	Adam	0%	11/15/20	11/19/20
Activity 2.1.2: Allow use to navigate the map for 'interaction."	Adam	0%	11/15/20	11/19/20
Subtask 2.2: Fire detection live updates pings on map	Adam	0%	11/19/20	11/25/20
Activity 2.2.1: Show most recent triggers on map with time of trigger	Adam	0%	11/19/20	11/25/20
Activity 2.2.2: Show approximate velocity and accelleration of fire on map	Adam	0%	11/19/20	11/25/20

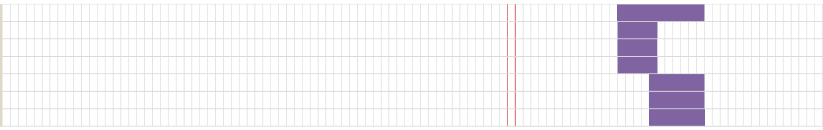

Figure J-4: Feature 2 Breakdown. *Generated with Microsoft Excel*

Feature 3: Protective Case	Adam	0%	11/1/20	12/1/20
Subtask 3.1: Case	Adam	0%	11/1/20	12/1/20
Activity 3.1.1: Develop case that protectes sensitive devices from outside hazards	Adam	0%	11/1/20	11/16/20
Activity 3.1.2: Develop method to secure case so post is theft resistant	Adam	0%	11/16/20	12/1/20
Feature 4: Cellular Communication	Adam	0%	11/20/20	12/3/20

Figure J-5: Feature 3 Breakdown. *Generated with Microsoft Excel*

Subtask 4.1: Sim Card	Adam	0%	11/20/20	11/23/20
Activity 4.1.1: Obtain a sim card with basic data plan for ESP32 Child	Adam	0%	11/20/20	11/23/20
Subtask 4.2: Communication Scheme	Adam	0%	11/20/20	12/3/20
Activity 4.2.1: Set up communication between parent and child microcontrollers	Adam	0%	11/20/20	11/24/20
Activity 4.2.1: Set up communication between primary post and server running map	Adam	0%	11/24/20	12/3/20

Figure J-6: Feature 4 Breakdown. *Generated with Microsoft Excel*

Feature 5: Temperature detector and Thermometer	Rashamjot Kaur	0%	10/26/20	11/21/20
Subtask 5.1: Choose thermometer for project	Rashamjot Kaur	0%	10/20/20	10/26/20
Activity 5.1.1: Thermometer DHT11 temperature/Humidity detector module selected	Rashamjot Kaur	100%	10/20/20	10/26/20
Activity 5.1.2: Connect module to ESP32 microcontroller	Rashamjot Kaur	0%	10/20/20	10/26/20
Subtask 5.1: Connecting with microcontroller	Rashamjot Kaur	0%	10/26/20	11/21/20
Activity 5.2.1: Use C language to obtain data from microcontroller	Rashamjot Kaur	0%	10/26/20	11/21/20

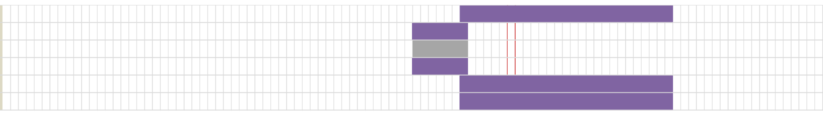

Figure J-7: Feature 5 Breakdown. *Generated with Microsoft Excel*

Feature 6: Smoke Detector	Rashamjot Kaur	0%	10/20/20	11/30/20
Subtask 6.1: Choose smoke detector for project	Rashamjot Kaur	100%	10/20/20	10/26/20
Activity 6.1.1: Smoke detector MQ-2 selected	Rashamjot Kaur	100%	10/20/20	10/26/20
Subtask 6.2: Connecting with Microcontroller	Rashamjot Kaur	0%	10/26/20	11/21/20
Activity 6.2.1: Write function that obtains data from MQ-2 smoke detector	Rashamjot Kaur	0%	11/21/20	11/30/20

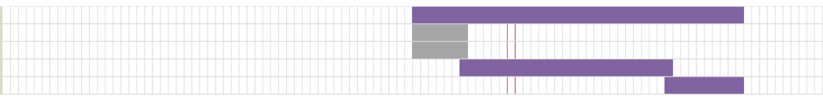

Figure J-8: Feature 6 Breakdown. *Generated with Microsoft Excel*

Feature 7: Transcevers	Don Nguyen	0%	9/7/20	11/5/20
Subtask 7.1: Transcever Hardware	Don Nguyen	0%	9/7/20	9/10/20
Activity 7.1.1: Selected REYAX RYLR896 LORA	Don Nguyen	100%	9/7/20	9/10/20
Activity 7.1.2: Establish connection between transcever and microcontroller	Don Nguyen	100%	9/27/20	10/3/20
Subtask 7.2: Transcever Communication Protocol	Don Nguyen	0%	10/6/20	11/5/20
Activity 7.2.1: Program microcontroller to communicate with neighbors	Don Nguyen	0%	10/6/20	11/5/20
Feature 8: Microcontroller	Don Nguyen	0%	9/9/20	12/9/20

Figure J-9: Feature 7 Breakdown. *Generated with Microsoft Excel*

Subtask 8.1: Microcontroller Hardware	Don Nguyen	0%	9/9/20	9/11/20
Activity 8.1.1: Low power ESP-32 selected	Don Nguyen	100%	9/9/20	9/11/20
Subtask 8.2: Microcontroller protocol	Don Nguyen	0%	9/13/20	?
Activity 8.2.1: Program microcontroller to process accumulated data from detectors	Don Nguyen	0%	10/6/20	12/9/20
Activity 8.2.2: Listen to neighboring posts and retransmit data to neighbors	Don Nguyen	0%	10/25/20	10/28/20
Activity 8.2.3: Sleep/wake cycles to reduce power consumption	Don Nguyen	0%	10/28/20	10/30/20

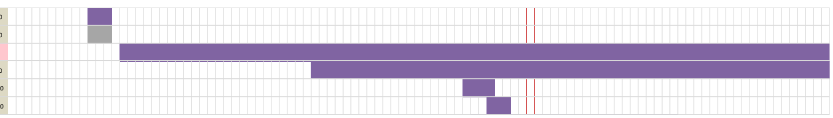

Figure J10: Feature 8 Breakdown. *Generated with Microsoft Excel*

Feature 9: Power Module	Lance Nevis	0%	10/26/20	11/20/20
Subtask 9.1: Solar Panels	Lance Nevis	0%	11/1/20	11/20/20
Activity 9.1.1: Connect solar panels to module	Lance Nevis	0%	11/1/20	11/20/20
Activity 9.1.2: Secure panels and solder connections	Lance Nevis	0%	11/1/20	11/20/20
Subtask 9.2: Voltage Regulator	Lance Nevis	0%	11/7/20	11/20/20
Activity 9.2.1: Connect solar panels to step-down voltage regulator	Lance Nevis	0%	11/10/20	11/20/20
Activity 9.2.2: Connect voltage regulator to battery charger module	Lance Nevis	0%	11/7/20	11/20/20
Subtask 9.3: Batteries	Lance Nevis	0%	10/26/20	11/14/20
Activity 9.3.1: Connect Batteries to charger module and monitor current	Lance Nevis	0%	10/26/20	11/14/20
Activity 9.3.2: Connect microcontroller to batteries, making sure to power device properly	Lance Nevis	0%	10/26/20	11/14/20

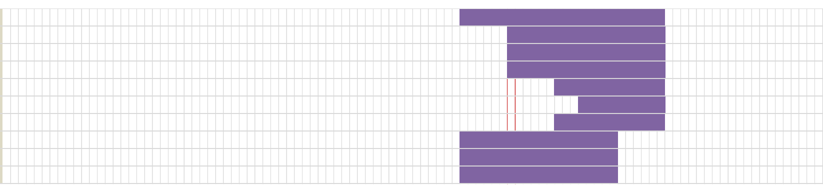

Figure J11: Feature 9 Breakdown. *Generated with Microsoft Excel*

Figure J12: Milestone Timelines. *Generated with Microsoft Excel*

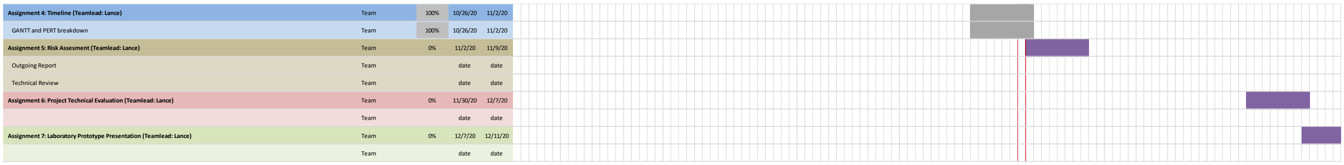

Figure J13: Assignment 4-7 Timelines. *Generated with Microsoft Excel*

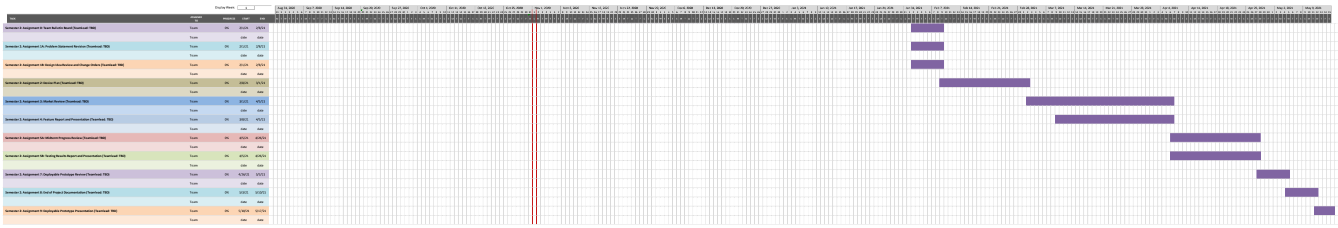

Figure J14: Semester 2: Assignment 0 – 9 Timelines. *Generated with Microsoft Excel*

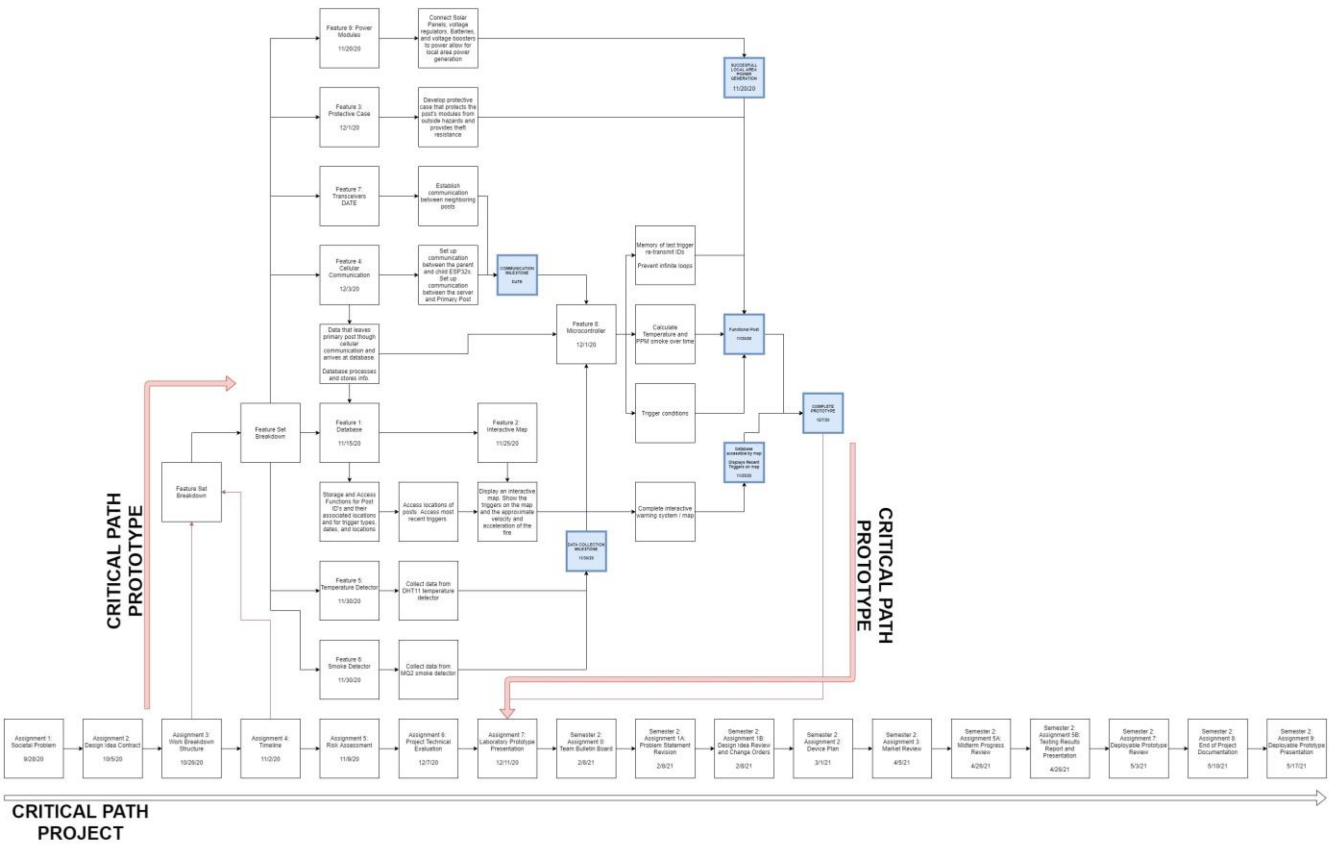

Figure J15: PERT Breakdown *Generated using draw.io* [22]

Appendix K: PROJECT TEST DIAGRAMS

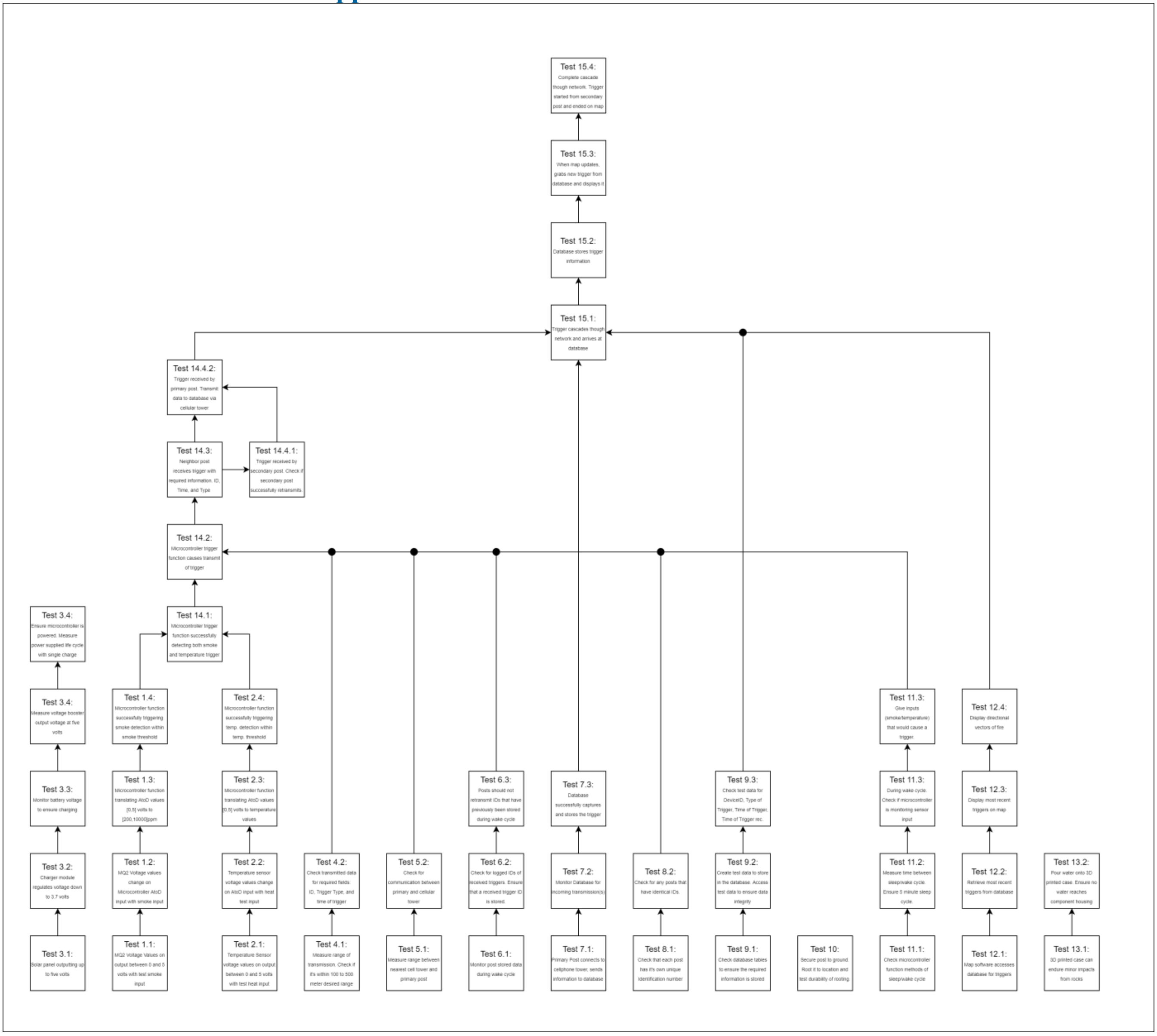

Figure K1: Project Testing *Generated using draw.io* [22]

Woodland Watcher Device Testing

Project Start: Mon, 2/1/2021
Display Week: 1

TASK	ASSIGNED TO	PROGRESS	START	END
Project Testing Timeline	Team	0%	2/7/21	3/1/21
Test 15	Lance Nevis	0%	2/20/21	3/1/21
Test 15.1: Trigger cascades though network. Arrives at database	Lance Nevis	0%	2/20/21	3/1/21
Test 15.2: Database stores trigger information	Lance Nevis	0%	2/20/21	3/1/21
Test 15.3: Map grabs new triggers when it updates	Lance Nevis	0%	2/20/21	3/1/21
Test 15.4: Complete cascade though network from secondary post to database	Lance Nevis	0%	2/20/21	3/1/21
Test 14	Lance Nevis	0%	2/7/21	2/20/21
Test 14.1: Microcontroller trigger function successfully detecting both smoke and temperature trigger	Lance Nevis	0%	2/7/21	2/20/21
Test 14.2: Microcontroller trigger function causes transmit of trigger	Lance Nevis	0%	2/7/21	2/20/21
Test 14.3: Neighbor post recieves trigger with required information, ID, type and time of trigger	Lance Nevis	0%	2/7/21	2/20/21
Test 14.4.1: Trigger received by secondary post. Check if secondary post retransmits	Lance Nevis	0%	2/7/21	2/20/21
Test 14.4.2: Trigger received by primary post. Transmit data to databse via cellular tower	Lance Nevis	0%	2/7/21	2/20/21
Test 13	Adam Reed	0%	2/27/21	3/1/21
Test 13.1: 3D printed case can endure minor impacts from rocks. Endurence test.	Adam Reed	0%	2/27/21	3/1/21
Test 13.2: Pour water onto 3D printed case. Ensure water does not reach modules.	Adam Reed	0%	2/27/21	3/1/21
Test 12	Adam Reed	0%	2/21/21	3/1/21
Test 12.1: Map software accesses database for triggers	Adam Reed	0%	2/21/21	3/1/21
Test 12.2: Retrieve most recent triggers from database	Adam Reed	0%	2/21/21	3/1/21
Test 12.3: Display most recent triggers on map	Adam Reed	0%	2/21/21	3/1/21
Test 12.4: Display direction vectors of fire	Adam Reed	0%	2/21/21	3/1/21
Test 11	Adam Reed	0%	2/20/21	2/27/21
Test 11.1: Check microcontroller function methods of sleep/wake cycle	Adam Reed	0%	2/20/21	2/27/21
Test 11.2: Measure time between sleep/wake cycle. Ensure five minute sleep cycle.	Adam Reed	0%	2/20/21	2/27/21
Test 11.3: During wake cycle, check if microcontroller is monitoring sensor input.	Adam Reed	0%	2/20/21	2/27/21
Test 11.4: Give inputs (smoke/temperature) that would cause a trigger	Adam Reed	0%	2/20/21	2/27/21
Test 10: Secure post to ground. Root it to location and test root durability	Lance Nevis	0%	2/27/21	3/1/21
Test 9	Adam Reed	0%	2/20/21	2/27/21
Test 9.1: Check database tables to ensure the required information is stored	Adam Reed	0%	2/20/21	2/27/21
Test 9.2: Create test data to store in the database. Access test data to ensure data integrity	Adam Reed	0%	2/20/21	2/27/21
Test 9.3: Check test data for deviceID, type of trigger, time of trigger, ect.	Adam Reed	0%	2/20/21	2/27/21
Test 8	Lance Nevis	0%	2/7/21	2/13/21
Test 8.1: Check that each post has it's own unique identification number	Lance Nevis	0%	2/7/21	2/13/21
Test 8.2: Check for any posts that have identical IDs	Lance Nevis	0%	2/7/21	2/13/21
Test 7	Adam Reed	0%	2/13/21	2/20/21
Test 7.1: Primary post connects to cellular tower, sends information to database (General connectivity test)	Adam Reed	0%	2/13/21	2/20/21
Test 7.2: Monitor database for incoming transmissions	Adam Reed	0%	2/13/21	2/20/21
Test 7.3: Check if database capures and stores data	Adam Reed	0%	2/13/21	2/20/21
Test 6	Lance Nevis	0%	2/13/21	2/20/21
Test 6.1: Monitor post stored data during wake cycle	Lance Nevis	0%	2/13/21	2/20/21
Test 6.2: Check for logged IDs of received triggers. Ensure that a trigger ID is stored	Lance Nevis	0%	2/13/21	2/20/21
Test 6.3: Posts should not retransmit IDs that have been previous stored during wake cycle	Lance Nevis	0%	2/13/21	2/20/21
Test 5	Adam Reed	0%	2/13/21	2/20/21
Test 5.1: Measure range between nearest cell tower and primary post	Adam Reed	0%	2/13/21	2/20/21
Test 5.2: Check for communication between primary and cellular tower	Adam Reed	0%	2/13/21	2/20/21
Test 4	Adam Reed	0%	2/13/21	2/20/21
Test 4.1: Measure range of transmission. Check if it's within 100 to 500 meter desired range.	Adam Reed	0%	2/13/21	2/20/21
Test 4.2: Check transmitted data for required firelds. ID, trigger type, trigger time	Adam Reed	0%	2/13/21	2/20/21
Test 3	Lance Nevis	0%	2/7/21	2/13/21
Test 3.1: Solar panel outputting up to five volts	Lance Nevis	0%	2/7/21	2/13/21
Test 3.2: Charger module regulates voltage down to 3.7 volts	Lance Nevis	0%	2/7/21	2/13/21
Test 3.3: Monitor battery voltage to ensure charging	Lance Nevis	0%	2/7/21	2/13/21
Test 3.4: Measure voltage booster output voltage at five volts	Lance Nevis	0%	2/7/21	2/13/21
Test 2	Adam Reed	0%	2/7/21	2/13/21
Test 2.1: Temperature sensor voltage values on output between 0 and 5 volts	Adam Reed	0%	2/7/21	2/13/21
Test 2.2: Temperature sensor voltage values ocnsistent while connected to AtoD converter	Adam Reed	0%	2/7/21	2/13/21
Test 2.3: Microcontroller function translating AtoD values [0,5] volts to temperature values	Adam Reed	0%	2/7/21	2/13/21
Test 2.4: Microconroller function triggering temp detection within temp threshold	Adam Reed	0%	2/7/21	2/13/21
Test 1	Adam Reed	0%	2/7/21	2/13/21
Test 1.1: MQ2 voltage values on output between 0 and 5 volts with test smoke input	Adam Reed	0%	2/7/21	2/13/21
Test 1.2: MQ2 voltage values consistant while connected to AtoD input with smoke input	Adam Reed	0%	2/7/21	2/13/21
Test 1.3: Microcontroller function translate voltage values to smoke ppm values	Adam Reed	0%	2/7/21	2/13/21
Test 1.4: Microcontroller function triggering smoke detection within smoke threshold	Adam Reed	0%	2/7/21	2/13/21

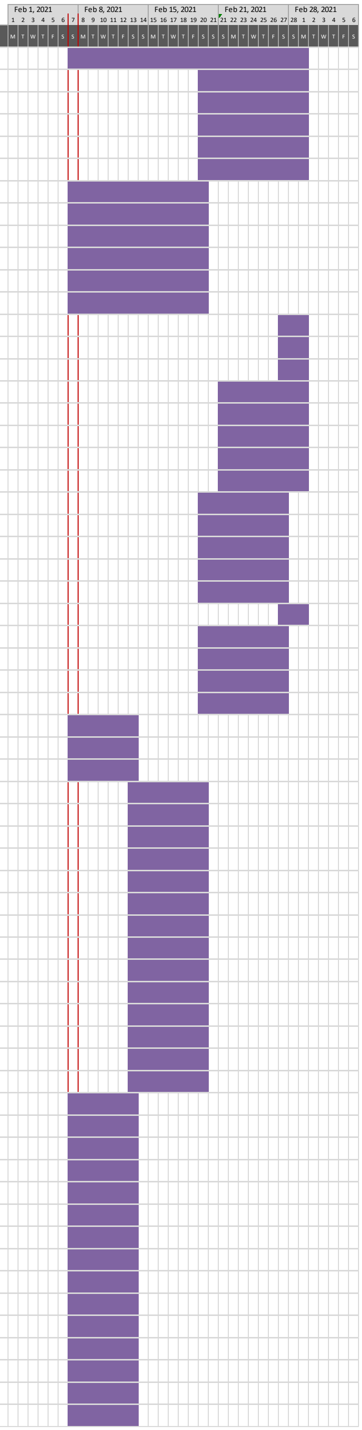

Figure K2: Testing GANTT. *Generated with Microsoft Excel*