Version 2.0

Team Fire Scout

Software Design Document

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This document blueprints the plans for Fire Scout's software development through the end of April. It will serve as a guide for all members of the team, and will be edited as needed to reflect any minor changes in design decisions.

Table of Contents

1.0 Introduction

Each year wildfires across the globe take lives and cost the economy billions in damages. They burn homes, businesses, national lands, and cannot be fought without risking the lives of first responders. In 2020, the California Wildfires burned down an estimated 4.2 million acres of land and cost 33 lives. Additionally, the indirect death could total more than 1,200 individuals from reduced air quality.

When fighting wildfires, collecting and analyzing information is crucial to prevent the spread of fire and fully contain it. Fuel sources need to be analyzed, the location and direction of the fire need to be known, and ideally, this information should be coupled with the location of individuals relative to fires to prevent loss of life. Currently, satellite imagery and manned aircraft are used to collect this kind of information, however, these methods are expensive and not real-time. This leaves a critical information gap between what is happening amid a wildfire, and what the stakeholders and decision-makers think is happening.

As technology advances, the methods and tools used to fight fires need to as well. One way to revolutionize fighting wildfires is with Unmanned Aerial Vehicles (UAVs), also known as Unmanned Aerial Systems (UAS's), but commonly called drones. UAVs are relatively inexpensive and can be outfitted with sensors and cameras to collect thermal and visual imagery, which can allow artificial intelligence models to analyze the fire. These analyses can be performed on the drone or from where the drone was deployed to provide comprehensive and near-real-time information on where fires are located, how they are clustered together, where they are spreading, and if they are threatening bystanders. Most importantly these drones remove humans from the heart of the fire and allow them to collect data in a way that is not only more precise than ever before but safely and remotely.

The Fires Scout Project aims to harness these advantages that were identified by Dr. Fatemeh Afghah, a member of the School of Informatics, Computing, and Cyber Systems at NAU. Dr. Afghah recognized the need to revolutionize how fires were fought, and with the help of her Ph.D. candidate, Alireza Shamsoshoara, created the "Wildfire Drone: Aerial Imaging, Fire Detection, Classification, and Clustering" project, referred to by the computer science development team as "Fire Scout." After receiving a $550,000 grant through the National Science Foundation's Faculty Early Career Development Program, Dr. Afghah brought together a group of Electrical Engineering and Computer Science students to help develop small, inexpensive, and intelligent drone systems that can observe, understand, adapt, and respond to changing environments, like wildfires, on their own.

Since using drones to assist in fighting wildfires is a somewhat novel solution, there are strict requirements and tasks that the Fire Scout system needs to meet. These requirements will either be implemented on the drone with the mini-computer and cameras it is carrying (referred to as the Drone System) or on the laptop where the drone is sending its data (called the Ground System).

The first set of requirements Fire Scout must adhere to are Fire Analysis Requirements. The Drone System, in real-time, must classify images from its HD camera as having wildfires in them or not. Next, the Ground System must signal the Drone System to segment wildfires out of a given image to allow the current team or future teams to analyze the fire for size or other not yet discussed characteristics. Finally, the Drone System aims to predict the fire's path allowing future developers to use path prediction to program the drone to fly ahead of a fire.

The second set of requirements are Object Detection Requirements. These include the other objects and items besides fire that the Fire Scout System must be able to detect such as trees, humans, and vehicles.

Next, the system must meet certain Data Communication Requirements. These are closely coupled with the electrical engineers also working on the Fire Scout Project. Ultimately, the Drone System and Ground System must be able to communicate with each other through software-defined radios (SDR) so that users can view the information and images captured by the drone in a meaningful way. The information from the drone will be displayed on a graphical user interface (GUI) that will also allow users to control what information the drone is gathering and sending back such as the camera feeds (HD or thermal).

Finally, all of this must run on hardware provided by the client. Currently, this includes a DJI Phantom 3 Pro for the drone, as well as the hardware it will carry: an Nvidia Jetson Nano, a software-defined radio (SDR), 1 thermal camera, and 1 HD camera that together compose the

Drone System. The Ground System includes the other SDR and a laptop that the GUI and other Fire Scout software will run on.

2.0 Implementation Overview

To meet these requirements, specific technologies and frameworks were chosen. After researching the limited fire detection software that exists, Convolutional Neural Networks (CNNs) were chosen to satisfy the fire analysis and object detection requirements. Tensorflow and Keras will be used to create the CNN's that will run on the Nvidia Jetson Nano. Both frameworks have wide user bases, can ease development, and have been used to classify images with fires in the past.

OpenCV will also be used as needed throughout the product. OpenCV will allow access to video/image feed from cameras and ease preprocessing of the datasets used to train the image classification, object detection, and image segmentation models.

To keep the programming languages Fire Scout uses to a minimum and simplify development, TkInter was chosen to build the Ground System's GUI. TkInter, like Tensorflow, Keras, and OpenCV, uses Python. This means that only Python is needed across the whole project.

As mentioned, much if not all of the hardware was chosen by the electrical engineering team and the client with some input from the software engineers. The Nvidia Jetson Nano was chosen because of its extensive ports allowing for thermal and HD cameras to be installed through the GPIO pins or a CSI port. Additionally, its onboard GPU and TensorRT (Nvidia's proprietary software) allow trained neural networks to run on it with ease.

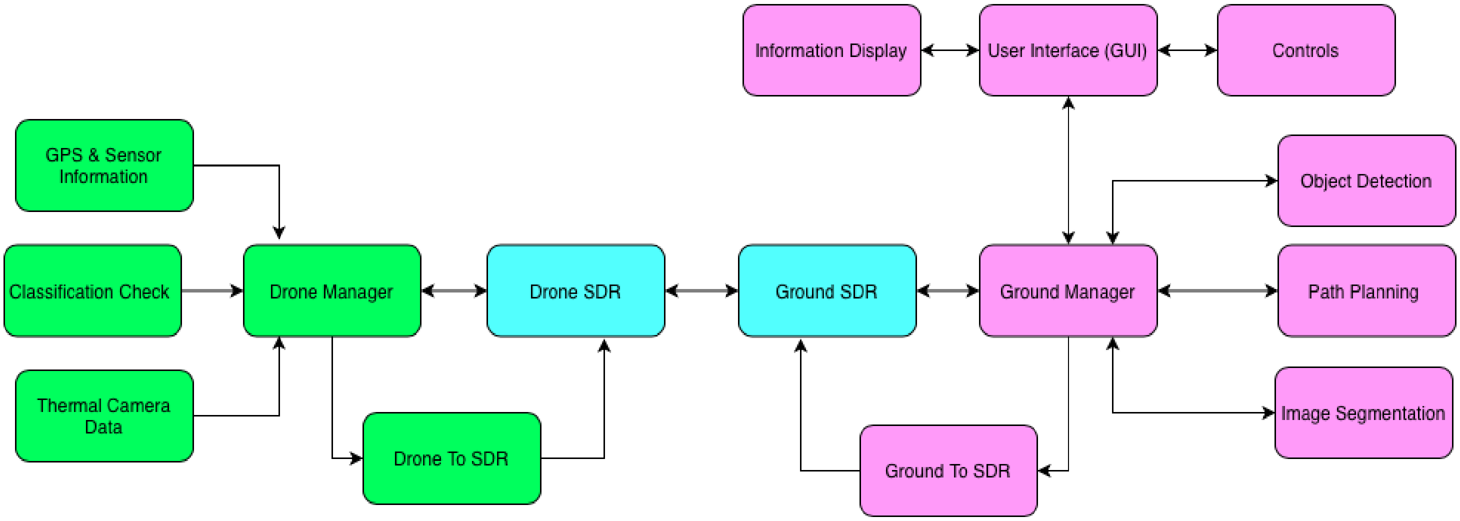
Finally, the electrical engineering team and computer science team have been provided a FLIR thermal camera and a PiCam V2 camera to capture images and live feed. The electrical engineering team has been provided SDR's to transfer data between the Drone System and the Ground System. While the software engineers will help the electrical engineers however they can, it is ultimately their responsibility due to their expertise in getting the SDR's communicating.

3.0 Architectural Overview

To piece these components together in a meaningful way, Fire Scout created the Drone and Ground Systems. The Drone System (Green) is responsible for collecting information while the drone is flying. It is worth noting that none of these components are installed or programmed into the drone directly, rather, they consist of the aforementioned external hardware carried by the drone.

All the information gathered by the Drone System (Green) and signals sent from the ground station (Pink) passes through the Software Defined Radios (SDR) (Blue). There will be two SDRs: one on the Ground System and the other on the Drone System. These two devices will send and receive information even in remote locations. These SDRs are being programmed and implemented by the electrical engineers working on the Fire Scout project which is why they are not considered a part of the Drone or Ground Systems directly.

The Ground System (Pink) will be a laptop connected to the Ground SDR and will display the graphical user interface (GUI). The GUI will have controls to send signals to the Drone System (Green) through the SDR pipeline and receive the sensor and camera data gathered from the Drone System. This component may also include AI models that may be too intense for the mini-computer on the Drone System to run.



An example run of this system would be a drone flying in the air with the Drone System attached, gathering information from the sensors, HD, and thermal cameras to be processed by the drone manager and be sent down the drone's onboard SDR pipeline. This text and image information will then be presented to the user, while also having the option to take selected images to run object detection and segmentation locally. Finally, the user of the Ground system GUI will be able to press a button that will send a signal from the Ground Station SDR to the Drone System SDR to request thermal video data. Once the drone receives the signal, the requested thermal image information will be sent down the SDR pipeline and displayed to the user continuing the cycle.

3.1 Drone System

The Drone System consists of the hardware and the software that Fire Scout is designing and deploying on the drone. The hardware includes:

- PiCam V2 HD Camera
- FLIR Thermal Camera
- Nvidia Jetson Nano
    - Any accessories such as a GPS chip
- Software Defined Radio
    - Ground SDR
    - Drone SDR
- Mobile battery

None of these components control the drone's flight itself. Instead, the drone will be flown through its proprietary controller while a second user manages the Fire Scout System from the Ground System. The following is an explanation of the software that runs on the aforementioned hardware.

Drone Manager

The Drone Manager consists of the programs that manage the hardware and software on the Jetson Nano. It could be thought of as the brains of the Nano and is responsible for making sure all components in the Drone System are running correctly and facilitating communication between them. Since the Jetson Nano is being modified for Fire Scout specifically, the drone manager program will run at startup.

Classification Check

The Classification Check model is responsible for taking images from the HD camera and running binary classification to sort the pictures into “fire” and “no-fire” categories. It will be running Fire Scout’s Convolutional Neural Network (CNN) and will pass the output images to the Drone Manager for further processing.

GPS & Sensor Information

These components will gather information beyond imaging. The current aim of the project is to attach a GPS chip with a compass, a CO2 sensor, and a temperature and humidity sensor. The output from these will be sent to the Drone Manager and displayed on the GUI.

Thermal Camera Data

The data from the thermal camera will provide information related to the fire during instances when the drone may not be able to see the fire. For instance, if smoke is blocking the view of the fire this will give users on the ground the ability to see when the standard HD camera can not. Its information will be sent to the drone manager.

Drone to SDR

This component receives all processed information and output from the Drone Manager and prepares the data for transmission to the ground station. It is responsible for packaging the data in a way that the SDRs can send and that the Ground System Manager can understand.

3.2 Software Defined Radios

The SDRs will be used to transfer signals from the drone to the ground station and vice versa. This will be developed by the electrical engineering team.

3.3 Ground Station

Like the Drone System, the ground station consists of hardware and the Fire Scout software that will be deployed on the hardware. In the case of the Ground Station, the primary hardware is another SDR and a laptop that it plugs into. As long as a user has a laptop powerful enough to run the Ground Station software and a USB port to attach the SDR, Fire Scout can be deployed on it.

Ground Manager

Much like the Drone Manager, the Ground System Manager is responsible for controlling the components and software running on the Ground System. The main difference between the two is that while the Drone Manager is primarily responsible for embedded system programs, the Ground System Manager is responsible for managing the Ground System's front-end/back-end architecture.

User Interface (GUI)

The GUI will interact directly with the Ground System Manager and is the front end of the Fire Scout architecture. It consists of two components: the System Controls and Information Display, all built with TkInter.

Controls

This component represents the GUI's elements that let the user choose and select options for the Drone System and Ground System. For instance, the user will be able to toggle image segmentation, object detection, and path planning. It also can toggle the Drone Systems camera settings.

Information Display

This component represents the GUI elements that display information gathered from the Drone System sent through the SDRs, as well as images processed on the Ground Station.

Image Segmentation

This program will segment fires out of images received from the Drone System. This allows for fires to be analyzed directly for further processing.

Object Detection

This component detects objects in images received from the Drone System. It displays them through the GUI with bounding boxes and class labels. Object detection will allow for multiple objects to be recognized within a single image including people, trees, fire, and vehicles.

Path Planning

This program will convert image and sensor data from the Drone System into a potential path the fire may be heading. Information from this estimate will be saved to a file as a prediction map and can be displayed on the GUI.

Ground to SDR

This component will be used to send signals requesting thermal data from the Ground System to the Drone System. It is in charge of formatting the messages in a way that the Drone System can interpret them.

4.0 Module and Interface Descriptions

Now that the flow of information between modules and components has been established, a detailed description of each is needed. The following aims to elaborate on the responsibilities of each component and outline how each component meets its unique responsibilities, and by extension, the project's requirements.

4.1 Drone System

As mentioned, the Drone System consists of the external hardware attached to the drone and software running on it. What follows is a detailed description of each section's responsibilities and design.

Drone Manager

The drone manager as its name implies manages the software running on the Nvidia Jetson Nano. Its responsibilities and the components/software it manages include:

1. Starting the Fire Scout Drone System. Since the Nvidia is being customized for Fire Scout's purposes, this will be a script that runs when the Nvidia is powered on. This script will start all other processes and components that the Manager is responsible for.

2. Gathering feed from the HD camera, and running the fire classification model through the onboard GPU. This model will be trained in Tensorflow but deployed on Nvidia's proprietary TensorRT.
3. Collecting data from the GPS and other sensors. Since the manager is running directly on the Nano, and the sensors are attached to the Nano's ports, this is intuitively the place for the sensors' software to live.
4. Gathering feed from the Thermal camera.
5. Running the Drone to SDR component. This is what prepares all the information gathered by the Drone Manager, and packages it in a way for the SDR to send.
6. Processing signals received from the drone's SDR. While information must be prepared and sent through the Drone to SDR component, the manager itself is able to interpret information sent from the Ground System that has been prepared by the Ground to SDR component. This includes toggling the HD and Thermal camera data.

Ultimately the Drone Manager is responsible for running all of the software aboard the Jetson Nano and facilitating the flow of information between software and hardware.

Fire Classification

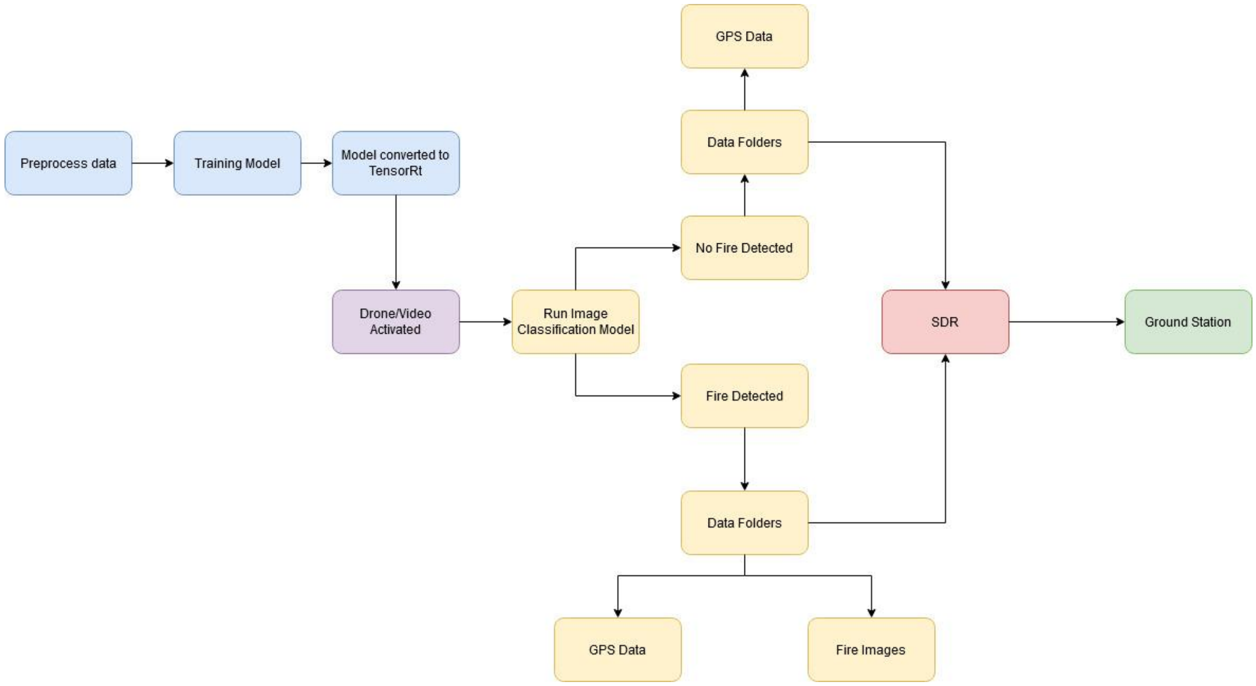


Image Classification allows the drone to detect if a fire is currently within the HD video feed. To generate an image classifier data needs to be collected, models need to be trained, and the final model needs to be deployed on the Jetson Nano.

Preprocessing Data Sets:

Video and Images collected from the internet and previous capstone teams provided the dataset used to train Fire Scout's classification model. Each image and video are manually reviewed and then classified into fire or no fire. Before a video can be used in a training model, it must be broken down into frames using the OpenCV framework. Once the dataset is organized and formatted it can be compiled into a training model using Tensorflow, Keras, and OpenCV.

Training the model:

Importing packages and frameworks makes the process of creating a model easier. OpenCV will gather images and labels to store in a NumPy array. Once the data is in the Numpy array, it will be normalized to understand our neural network algorithms. Next, the data will be split into training and testing sets. Now organized data can process through the Convolutional Neural Network to begin making predictions on whether an image contains fire or not. Data will be sent through the neural network layers in sequential order using mathematical algorithms. Next, the model is compiled using a loss function that shows the error rate, an optimizer, and metrics that help judge the model's accuracy. In each stepper epoch where the model is initialized and trained, the model will show improvements in accuracy and loss values. The model is now ready to be tested with input provided by the video feed from the drone.

Running the model:

For the model to be run on the Nvidia Jetson Nano, the Kears model needs to be converted and compiled to TensorRT. With the model converted, the video feed can be broken down into frames using OpenCV. The frame will run through the model and output a label and prediction score to the frame being shown.

Sending Results through SDR:

Now that the Image Classification model has detected the fire, the video's frame with fire will be put into a folder to be sent through the SDR.

GPS and Sensor Information

Sensors connected to the mini-computer will analyze information such as GPS position, compass heading, external temperature, humidity, and CO2 emissions. Gathering this data will help Fire Scout determine the relative positions and locations of fires and where the fire could be heading. Information gathered from these sensors will be displayed on the GUI. This data will continuously be sent to the Ground System

Thermal Camera Data

The thermal camera will be activated when the drone receives a signal from the ground station through the SDRs. Once the signal is received the HD camera will turn off and the thermal camera will begin to capture images. The thermal camera will have three IR palettes to choose from Fusion, WhiteHot, and GreenHot.

Drone to SDR

This system will create a queue for the data and images to be sent to the ground station through the SDR. Once data and images have been sent to the ground station, they will be removed from the drone's memory in order to make room for more incoming data and images. This prevents Nvidia's memory from overflowing and allows as much data as possible to be sent through the SDRs.

4.2 Software Defined Radios

The SDR's will be implemented and programmed by the electrical engineering team. There will be one on the Drone System and one on the Ground System. They are able to communicate using two channels meaning that there can be an upstream channel from the Ground to the Drone System and a downstream channel from the Drone to the Ground System. The information transmitted upstream will include commands on what CNN models to run and what cameras to use. The information transmitted downstream will be the output of the CNN models as well as all sensor information.

4.3 Ground System

As mentioned, the Ground System consists of the external hardware attached to the drone and software running on it. What follows is a detailed description of each section's responsibilities and design.

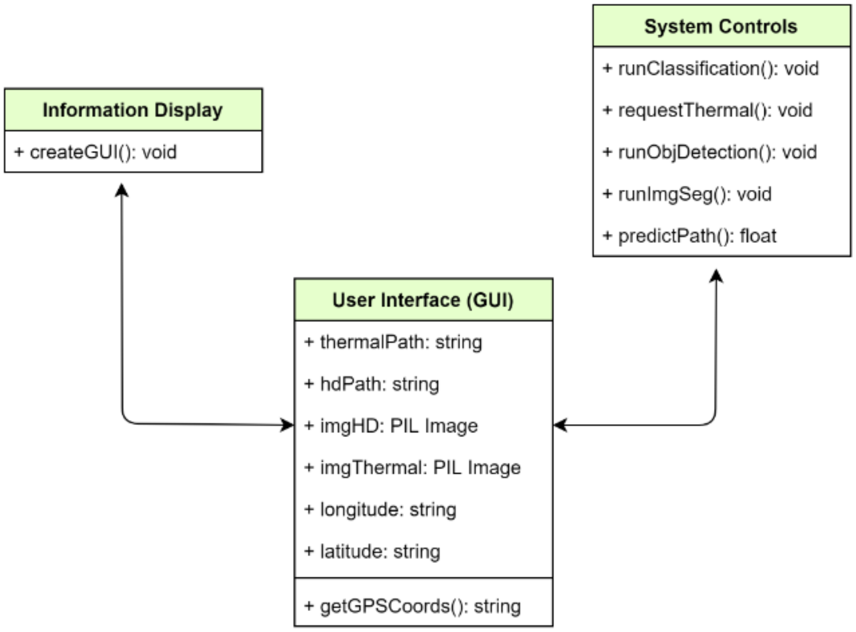
Ground System Manager

Like the Drone System Manager, the Ground Station Manager represents the main program that facilitates the flow of information to and from the different components of the Ground System. Its responsibilities and the components it manages include:

1. The GUI. The GUI will be written in TkInter and is the only front end aspect of the Fire Scout project. As such, it is imperative that it shows the users all the information they want to see and that the Drone System Collects.
2. The Ground Station Manager controls the Ground to SDR system. The responsibility of the Manager is to simply receive a signal that control was toggled in the GUI, and pass that information to the Drone to SDR system.
3. The Ground Station Manager controls the CNN models running on the Ground System.

User Interface GUI

The first component of the GUI is called the Information Display. The second component, the System Control, lets the user control what models are running on the drone, and the camera feeds the GUI receives. Together, the Information Display and the System Control will send and receive data from the SDRs to let the user interact with Fire Scout.



Fire Scout's graphical user interface (GUI) will serve as the point of contact between the drone mini-computer and the user. The GUI will update the sensor information and images as often as possible.

Information Display

The Fire Scout GUI will utilize TkInter for activating the windows, labels, buttons, and all other widgets necessary to build the front-end display. The information display is responsible for presenting the images, sensor information, as well as processing user input, which will be explained further in the next section.

System Controls

For further analysis and usability, the user can utilize a few system controls. The system controls will be button activated, giving the user options to enable object detection, image segmentation, and path predictions. Lastly, the user can toggle the thermal camera. The user will be able to select between three IR Palettes: Fusion, WhiteHot, and GreenHot. The system controls represent all user interactivity.

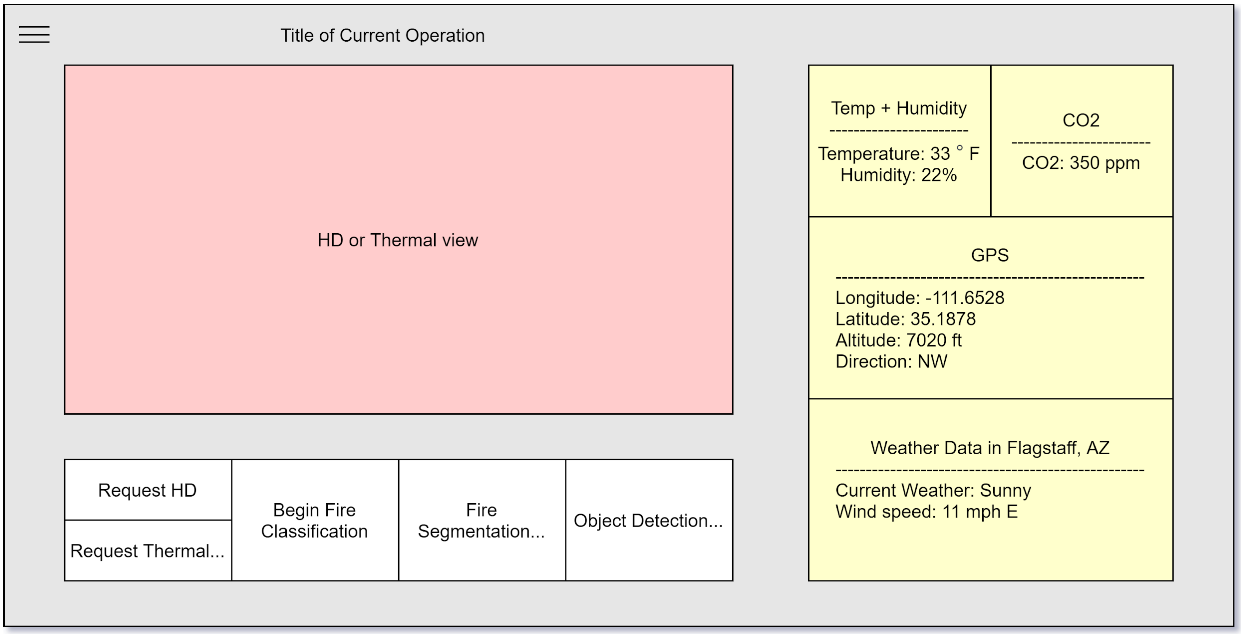


Image Segmentation

This component will use k-means clustering given the current image displayed on the GUI. K-means clustering is the process of breaking down an image into the desired number of present pixels that are the most common in the image. This can also be used with object detection to segment a particular object being detected. The use of segmentation is useful to add layers and a different perspective to an image in regards to the number of objects in an image and the red, green, blue (RGB) values representing them.

Object Detection

Object Detection will identify and locate where fire, people, vehicles, and trees are on any given image that is taken by the drone. It will output class labels and bounding boxes accurately for the objects that are being detected. In order to create an object detector for custom objects, the program will require data in the form of jpeg images that have been captured by the PiCamV2 HD camera on the drone, from there the jpeg images will be sent to the SDR at the ground station from the SDR on the drone, at which point a button on the user interface will then execute the object detection for the given image. Before this, the program will need pre-trained models with custom weights to handle objects including fires, trees, people, and vehicles. We will then need to run these training models to determine that the level of accuracy of the object detection meets the requirements of the client.

Path Planning

Path Planning will estimate the path of the fire by estimating the location of the target in relation to the drone's location, the drone's altitude, and the HD camera angle. The path planning program will be utilized on the ground station and triggered to begin planning the path of the fire or other objects when the ground station manager receives user input from the User Interface (GUI). The drone’s altitude will be important when determining the path of the fire as the difference in altitude will change the calculations needed to make precise planning on a graphical output to the user.

Information gathered from these sensors will be very important for determining the potential path of the fire. This information will be gathered using detection alongside relative position to the drone. The drone must be in place to accurately determine where the object will be heading along with other factors such as grasses and debris we hope to be able to detect. Once a fire class object is detected the sensors will create a map to show where the fire may go based on the drone’s aerial position and wind direction.

Ground to SDR

This program receives data from the Ground Station Manager and formats it to be sent through the SDRs. The Drone Manager is able to receive and interpret these signals. This data will simply be a text file that specifies:

- What models the Nvidia Jetson Nano should run
- What camera feeds the Drone System should send back
- Emergency signals such as those that reset the system

5.0 Implementation Plan

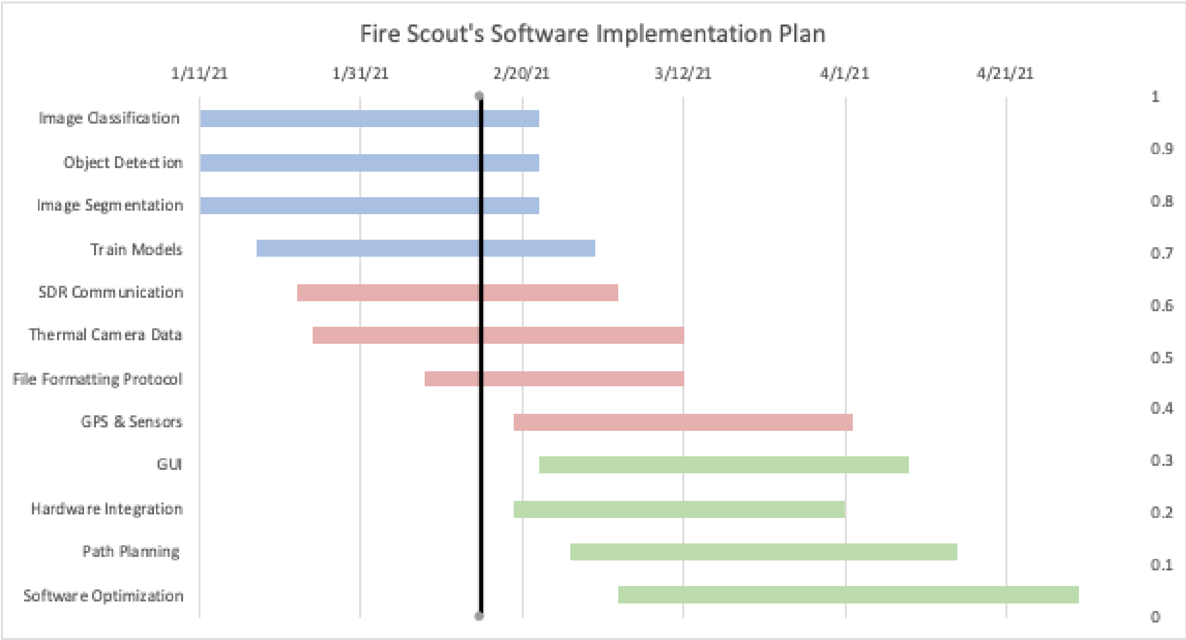


Figure 1 shows the timeline for team Fire Scout's tasks that have been selected for the Software Implementation section of this project.

TASK	PROGRESS	START	END
Phase I			
Image Classification	85%	1/11/21	2/22/21
Object Detection	70%	1/11/21	2/22/21
Image Segmentation	55%	1/11/21	2/22/21
Train Models	40%	1/18/21	3/1/21
Phase II			
SDR Communication	60%	1/23/21	3/4/21
Thermal Camera Data	50%	1/25/21	3/12/21
File Formatting Protocol	25%	2/8/21	3/12/21
GPS & Sensors	10%	2/19/21	4/2/21
Phase III			
GUI	20%	2/22/21	4/9/21
Hardware Integration	10%	2/26/21	4/5/21
Path Planning	5%	3/3/21	4/15/21
Software Optimization	5%	3/7/21	4/30/21

Figure 2 shows the percentages of completion for the tasks shown in the Gantt Chart that is presented in Figure 1.

The Drone System will be tasked with running image classification, trained models, and relaying thermal camera data, and GPS & sensor information. For Image Classification, Nick (CS team) will be working on completing this task two weeks before the team will present the Alpha Prototype to the team mentor and the client on the first Thursday of March. For the next task, the team will need to have trained models that have been prepared on a Linux desktop and can be moved over to the onboard system which is the Nvidia Jetson Nano. This task is projected to be completed by mid-February and will be handled by computer science team members Kenny, Jacob, and Nick. As for the Thermal Camera Data, this task will be completed by Jimmy (EE team) and Kenny (CS team), with both working together to complete this task by the 12th of March. The GPS & Sensors task will be worked on by Jimmy (EE team) and Drew (CS team), with the two having a goal of finishing this task by the first week of April.

The Software Defined Radios will be tasked with the SDR Communication between the Drone Manager and the Ground Station Manager. The electrical engineering team will be the main people responsible for accomplishing this task. The SDR Communication is projected to be completed by March 4th.

The Ground Station will be tasked with Object Detection, Image Segmentation, GUI, Hardware Integration, Path Planning, and Software Optimization. For Object Detection, Matt (CS team) will be the one responsible for this task and expects to complete the task two weeks before the team will present the Alpha Prototype to the team mentor and the client on the first Thursday of March. The Image Segmentation will be handled by Kenny (CS team) and will be expected to be completed two weeks before the Alpha Prototype as well. The GUI task will be completed by Jacob (CS team) and is expected to be finished by the 2nd week in April. The Hardware Integration will be completed by Susan and Ziming who are both members of the electrical engineering team. The expected completion date for this task will be April 1st. The Path Planning Task will be worked on by Kenny (CS team), Drew (CS team), and Jimmy (EE team). The task for Path Planning will be completed by the third week of April. The last task will be the Software Optimization of the project. This final task will be a continuous work in progress by both teams since there will always be more ways to improve the hardware and software setups that we utilize.

6.0 Conclusion

As it stands, current methods of fire analysis are costly and unsafe for first responders. As technology advances, the way that first responders fight fires should advance as well. Team Fire Scout aims to solve these problems by taking human lives out of the picture and replacing them with a relatively low-cost alternative. The research provided from the fall semester has led to the implementation of detecting fires on an Nvidia Jetson Nano mini-computer allowing this system to be easily attached to a drone. Working in collaboration with our partnering electrical engineering team, we will develop and integrate our final product. With guidance from Dr. Fatemeh Afghah and Alireza Shamsoshoara, and the blueprints laid out in this document, we will finish the Fire Scout project successfully.

7.0 Sources

1. https://www.fire.ca.gov/incidents/2020/
2. https://www.sfchronicle.com/california-wildfires/article/Hidden-cost-of-wildfire-smoke-Stanford-15595754.php