Spectral Imaging for Forest Fire Detection

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Nomenclature

fps	=	frames per second
K	=	potassium
LEO	=	Low Earth Orbit
PCO	=	Pioneers in Cameras and Optoelectrics
psd	=	power spectral density
Na	=	sodium
nm	=	nanometers

Abstract

In the past decade, forest fires were responsible for approximately 32,230 deaths, up 20.5% since 2009, and 157.9 billion dollars of damage, up 90.6% since 2009 (U.S. Fire Administration). Furthermore, countless habitats and water resources were destroyed, and pollution increased due to fires. Advanced space technology has been employed to monitor the earth and mitigate potential damage inflicted by forest fires. The primary technology used for this purpose is the GOES Series of satellites in geosynchronous orbit and equipped with infrared imagers. These imagers provide images at a ground resolution of 1 km, a resolution that is insufficient to detect fires in their early stages. Another method of observing forest fires from space is through the use of spectral imaging performed by smaller imagers, ideally incorporated on the many Low Earth Orbit communication satellites being developed. The significantly lower altitudes of Low Earth Orbit satellites may provide better ground resolution to detect early fire stages. These smaller imager utilize spectral imaging to create an electromagnetic "signature" of burning biomass. If a scientific camera can adequately acquire this data, and the data can be analyzed and reported as a fire signature, this imaging technique could be implemented with aerospace systems, including drones or balloonsats, to monitor high fire risk areas. This experiment analyzes the wavelength signature created when pine needles are burning. When combustion takes place within pine needles, potassium is emitted around 770-780nm. The experiments conducted in this research use an array of PCO imagers and filters close to controlled fires to detect the potassium emission released in burning pine needles during the combustion process. Overall, this project aims to analyze the validity and effectiveness of this imaging technique, which the future application of incorporating the imagers on LEO satellites in mind. Through the process of collecting biomass samples, igniting these samples and observing the fire with a PCO camera and camera acquisition software, executing post-processing analysis of the images, the effectiveness of this technique should be reasonably determined.

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I. Introduction

FOREST fires occur at an alarming rate across the world, threatening domestic and wild land, as well as lives. In 2019 alone, 4.9 million acres of land were destroyed because of wildfires. Imaging technology has been employed to detect the presence of, and gather data regarding these detremental fires, and research regarding this technology is an essential aspect of preventing destruction resultting from fires. This research aims to protect destruction resulting from fires ranging from economic impact, to the depletion of resources, to the harm of wildlife and human life, to the homeostasis of secosystems. Further still, it is crucial to monitor forest fires due to the fact that the resulting radiation can disturb the earth's energy balance and gaseous composition, as well as the processes by which energy is transferred through the earth's atmosphere. Given these complex and essential aspects of life on earth and their vulnerability to harm from fires, the nature of imaging research for forest fire detection is compulsory. The purpose of this project is to analyze the use of smaller scientific imagers for early-stage forest fire detection. Currently, remote sensors monitoring forest fires, such as the GOES-R series satellites, utilize infrared imaging to monitor earth's weather and natural disasters. This type of imaging is beneficial because it allows for the surveying of large areas over extended periods of time. However, due to the fact that large areas are surveyed, smaller fires can be missed because they are sub-pixel ocurrances. Furthermore, if the sensor is only equipped with one waveband, false alarm fires are likely to occur. Infrared sensors in general are not as sensitive as other systems, and a more sensitive system would be preferred when monitoring this type of phenomenon. Infrared sensors also require cooling, which can be an expensive component to add to an aircraft or spacecraft. Infrared sensors can become saturated when a large fire's signal exceeds the range of the system, resulting in inaccurate readings. Adding all of these components up, infrared imaging takes up significant allotted weight on a spacecraft. Spectral imaging is a different technique that has been proposed as an additive component on an already existing spacecraft, such as the SpaceX Starlink Satellites. If successful, spectral imaging could be used on aerospace systems to detect fires with the hopes of reaching these fires before they become detremental. The research conducted in this study aims to determine if a small spectral imaging system can be used to acquire wavelength characteristics emitted by burning biomass samples. If this data can be acquired, this type of imaging could be further developed and applied to see its potential for detecting fires on a mass scale from an aerospace system.

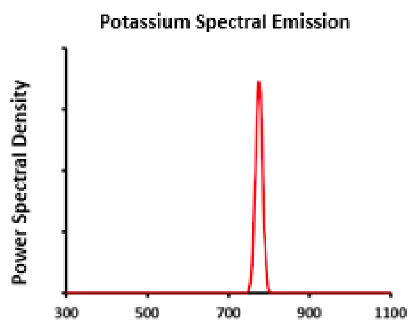


Figure 1. Potassium Spectral Emission Spike.

A. Background and Optimal Results

When biomass samples are burning, the spectral emission can tell significant information about the combustion process that is occurring. Carboxylate, which consists of the combination of sodium and potassium, is found in pine needles. Once samples of pine needles are ignited, this molecule begins to break down and small amounts of sodium and potassium are released. The proof of this release of sodium and potassium emissions can be seen a considerable spike on a power spectral density vs. wavelength graph, asuch as the one in Figure 1. The emission of potassium is the element that will be sought after in this project, and this emission ocurrs around 780nm. The potassium emission will be targeted by using three bandpass filters of different wavelengths on three different cameras. When each camera takes an image of a controlled fire with different filters, each camera will hypothetically produce images with differing intensities due to differences in the presence of materials. Optimal results of this project would show that the images taken with the 780nm filter will have the highest average intensity values, denoted by the average grayscale value of the pixels in the image. This is based on the premise that the potassium emission happens around 780nm and will be picked up by the imager. Ideally, the other two filters would have lower intensities resulting from a lack of the presence of the potassium emission. The ability of the PCO camera with accompanying filter to detect the presence of a potassium emission at 780nm from burning pine needles may procude the implication that further this imaging technique could be used to detect forest fires in their early stages using the presence of a sodium emission, given that additional research and implementation takes place.

II. Experimental Methods

A. Materials
The materials utilized in the experiment are as follows:

Three PCO Cameras	Thorlabs 760nm Bandpass Filter
Camware Software	Thorlabs 770nm Bandpass Filter
Desktop Computer	Thorlabs 780nm Bandpass Filter
Pine Needles	Aluminum Grated Basket
Black Sheet	Filter Holders
Digital Balance/Scale	Grill Top
Small Fan	Overhead Projector Lamp

B. Equipment Specifications
The biomass samples used in this study included pine needles indigenous to Mississippi. A large sample of needles found on the ground in an area of surrounding pine trees was collected, and carefully dried in an oven for approximately 30 minutes to ensure that the needles were not saturated with moisture and were able to ignite. Pine needle samples were placed in an aluminum grated basket for ignition. The basket used had a diameter f 5.2 inches and a 1.5 inches. The mechanism used to retrieve images of the fires was a complementary metal oxide semiconductor camera from Pioneers in Cameras and Optoelectrics. The model of the PCO camera is an Edge 5.5 camera, which has a spectral range of 370nm to 1100nm. Three identical lenses were attached to each camera. A bandwidth was created with three bandpass filters from ThorLabs, with wavelength values of 760nm, 780nm, and 800nm. Each of these filters has a Center Wavelength that is $\pm$2nm of the bandpass value, and a Full-Width Half Max value that is 10$\pm$2nm. The cameras were connected to a desktop computer that ran an accompanying software called Camware. This data acquisition software allowed the user to adjust the camera settings, parameters, and step through sequences of images as a whole to see the progression of the images from start to finish.

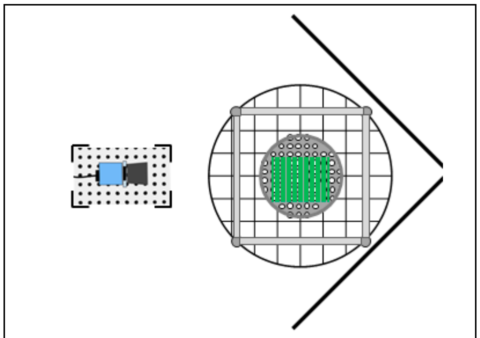


Figure 2. Experimental Setup of PCO Camera, Aluminum Grate, and Lasers.

C. Procedure
To begin testing, it was imperative to first set-up the cameras at a constant radius away from the basket of pine needles to ensure that each camera was seeing as simultaneous of a view as possible. The grill top aluminum grate was first clamped onto the tops of stands that screwed into an optics board. Each camera was then placed on stands on the optics board at constant distances away from the basket stand. The orientation of the three cameras formed a semi-circle-like shape, and the Camware software was used to ensure the angle of each camera was as similar to the others as possible. A large black optics background was placed behind the camera set-up spanning slightly past the region seen by the cameras. Once the materials and equipment were collected and the cameras were tested for proper orientation, the sample of pine needles was weighed on the balance until the sample weight reached approximately 10.50 grams. Then, the bundle was placed into the aluminum basket and ignited by placing an overhead projector lamp close to the top of the bundle (Figure 3). The lamp was turned on slowly and amplified slowly to its maximum intensity over a period of approximately 6 seconds. The PCO cameras began collecting once the fire was ignited and the overhead projector light was turned off to ensure there was no traces of light from the projector in the

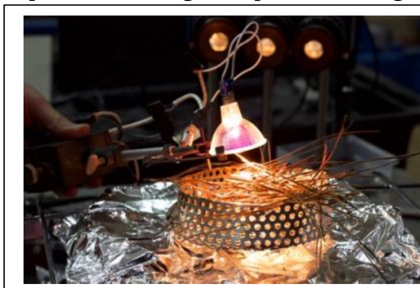


Figure 3. Ignition of Sample

data. The Camware software collected images from the rough genesis of the fire and throughout the seven second trial length. To ensure that fire alarms or sprinklers were not triggered by the experiment, a small fan was turned on its lowest setting and pointed near the fire, which is why the flames in the images appear to be traveling to the right of the frame. The images were collected at a fram rate of 17fps. Three Thorlabs bandpass filters were used in the trials at wavelengths of 760nm, 780nm, and 800nm. An aerial view of the experimental setup can be seen in Figure 2. This procedure was repeated 28 times total, though not every trial was used in image processing. Various views of the experimental set-up

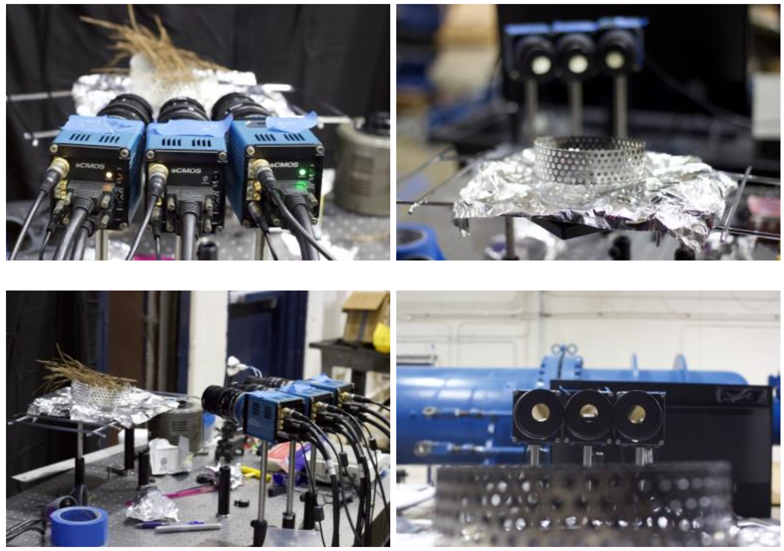


Figure 4. Imaging Orientation and Set-Up

D. Image Processing

To analyze the pixel content of each image taken with each filter in each trial, a Mathcad code was written with for loops to step through each camera's 100 images in a given trial. The output of these for loops calculated the mean grayscale value of all of the pixels in each image for one camera and its respective sequence of images taken during that trial. From there, an "average of the averages" was performed using the calculated mean gray values for each of the 100 images. This code was repeated three times per trial, one for each trial, using the image data from trials 14, 16-22, and 25-28. Trials 1-13 were considered test trials, and trials 15, and 23-24 were considered mistrials. After performing trials 1-13, it became apparent that the results were not consistent with the hypothesized behavior, meaning that the images with the highest intensities were not consistenly those of the 780nm filter. A testing matrix system was organized to see if any discrepencies in the camera radius, or cameras themselves were contributing to these unexpected results. Thirteen trials were performed, switching the filters in every possible orientation with the 3 filters and 3 cameras, as can be seen in Figure 5. Each orientation of filter and camera was tested twice to increase accuracy of possible trends in the data. Therefore, each of the 13 rounds of image processing gave 300 mean gray values, and three averages based on each of 100 mean gray values. Overall, mean gray values of each photo for each camera in each trial was acquired, and one average of averages value was aquired per camera. Performing these trials with all possible filter orientations allowed for data to be analyzed without the worry of possible interference from the camera abgle or radius, or even the different cameras themselves. Image-processing was conducted using these trial values. After obtaining all of these values, plots were made showing the mean gray level of all of the pixels for each image in the sequence for all trials with the respective filters.

Figure 5. Camera and Filter Orientation Testing Matrix

Trial No.	Camera 1 Serial No. 300	Camera 2 Serial No. 279	Camera 3 Serial No. 269
14	760	800	780
16	760	800	780
17	780	800	760
18	780	800	760
19	800	780	760
20	800	780	760
21	800	760	780
22	800	760	780
25	780	760	800

26	780	760	800
27	760	780	800
28	760	780	800

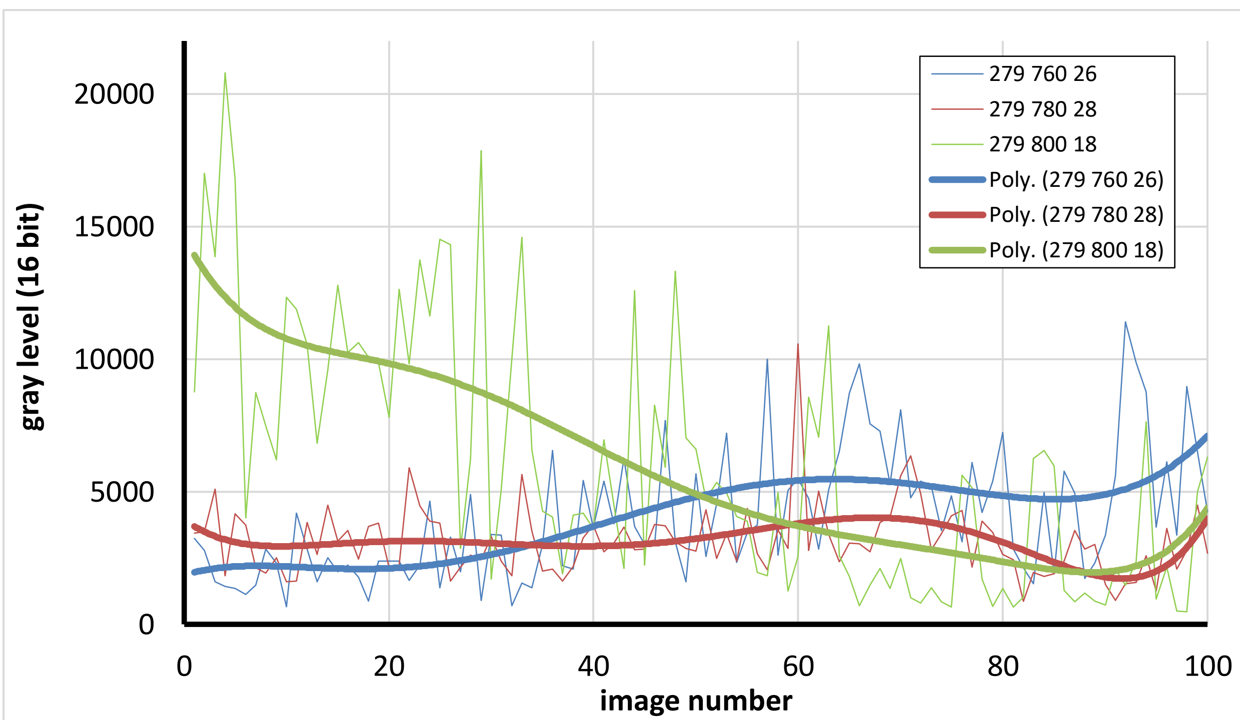
III. Data

As previously stated, each trial resulted in 300 photos, 100 for each camera, over a 7 second trial period. Each trial's image collection began roughly at the beginning of the ignition of the pine needles, but after ignition source had been removed from the frame and turned off. Figure 6 shows three images taken at exactly the same time by three different cameras with three different filters. The images visually show differences in which camera/filter picked up different components of the fire. However, to be able to confidently and clearly see trends in which filters result in which intensities, it was necessary to perform analytical work to obtain qualitative data. After calclations were performed using the Mathcad code, plots were made displaying mean gray value for each image in a trial. Below is one figure made displaying the mean gray values of each image from 1-100 for different trials with different filters, but on the same camera. The trendline for each series is made using a sixth degree polynomial as a way to roughly visualize the behavior of filters.

Camera 1 – 780nm   Camera 2 – 800nm   Camera 3 – 760nm

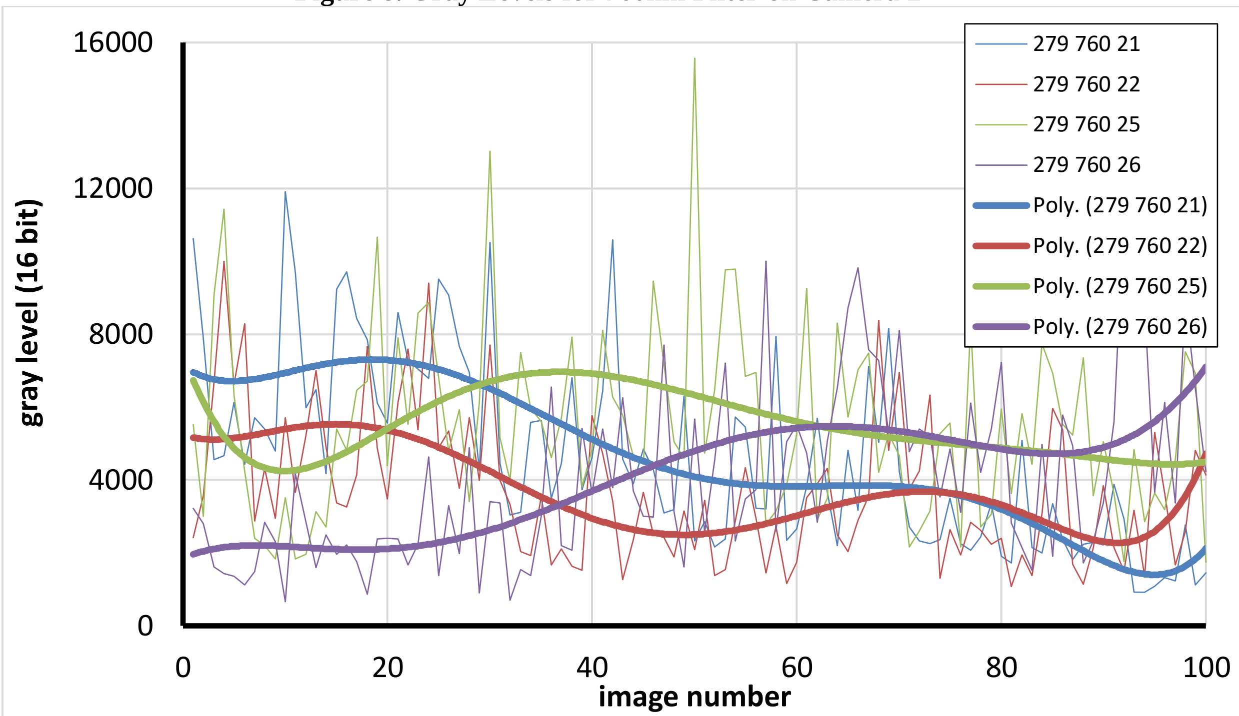
Figure 6. Trial 26 Image 94 for Respective Cameras and Filters

Figure 7. Gray Levels for Camera 2 (Serial No. 279) with Various Filters



For further understanding of the behavior of the cameras and filters in terms of intensity values, plots were made to show the trend corresponding to one filter's intensity value on different cameras from different trials.

Figure 8. Gray Levels for 760nm Filter on Camera 2



As can be seen by the plots, it is difficult to determine any significance of the relationship between filter bandwidth and image intensity. The lack of clear results could be due to numerous factors such as being too close to the fire, the cameras not being calibrated, or the fires differing too much in emission production. Furthermore, the fact that the results were conducted using a mean grayscale value of the entire image may have also impacted the data. From the results acquired and behavior of the filters, a conclusion about the validity of this type of imaging can not be drawn with the current information.

A. Future Steps

In future experiments, calibration of the cameras would be necessary to decrease the uncertainty in the obtained data. It may be necessary to use different imagers altogether, or to change the experimental process altogether. Changing the distance from the cameras to the fire may be a required change, in addition to changing current equipment. The current image-processing technique may need to be expanded or altered to only include the highest intensity pixels in the plots and analysis as opposed to a mean of the pixel values with various intensities.

B. Applications

Once there is a more clear understanding of the behavior of the filters on smaller images, larger-scale experiments could be performed in an effort to move towards aerospace applications. Analyzing how the distance the camera is from the fire, as well as the size of the fire impacts the resulting data would be a step towards determining if this imaging technique could be utilized for observation via an aerospace system. Small imagers could be placed on a drone, balloonsat, or plane and flown over a controlled fire of a larger area.

IV. Conclusion

This experiment aimed to determine the possibility of using small imagers to detect the potassium emission resulting in combusting pine needles, and the data obtained and analyzed did not provide clear answers to whether or not this imaging technique is valid. However, the project did provide significant steps toward testing small imagers to analyze controlled fires. Ideas of how to set up and perform the experiments and analyze the data are now present, opening the door for more developed testing tecniques and more advanced testing equipment to take place. The overall conclusion from this project is encouraging in the sense that the answer to this imaging technique being possible for implementation was not “no”. Future experiments are being planned for in the hopes of more clearly determining whether or not small imagers can accurately be used for early forest fire detection.

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