Abstract

Current techniques used to detect forest fires involve the use of thermal/infrared sensors. This technique can be improved upon by taking advantage of a unique characteristic of forest fires. Strong, narrow band, potassium emission lines can clearly be distinguished in a fire of this type.

We have constructed a multispectral imaging system to compare these two techniques for fire detection. Our system captures images from the visual, thermal/IR, and from two narrow bands near the potassium emission region of the spectrum (766.8 and 780 nm). Data collected using this system on actual fires has allowed us to show that detection in the potassium region of the spectrum can be used to more accurately detect the presence and location of a fire.

Introduction

Forest fires cause severe damage to the natural environment as well as to personal and public property. They are a destructive and unpredictable problem throughout the world. As a result of the severe damage associated with forest fires, techniques to prevent, detect, and control forest fires are continuously being researched. Satellite remote sensing systems are one possible way to detect forest fires.
The Forest Fire Imaging Experimental System (FIRES) team at the Rochester Institute of Technology (RIT) is currently working on remote sensing techniques for the detection and monitoring of forest fires. Their goal is to investigate the fundamental science behind wildland fires and establish the feasibility of observing fires from remote platforms.

As part of this project, research is being done on the feasibility of using potassium emission lines to detect forest fires with greater accuracy. This is being accomplished by obtaining and analyzing image data of fires from both conventional thermal/IR and potassium emission detection systems.

Background

Previous remote sensing techniques for the detection of forest fires used thermal/infrared sensors to detect the heat signature of a fire. This process is fairly well understood and research has proceeded further into other aspects of fire. One such aspect of fire is a unique potassium (K) emission spectrum. This emission occurs in two narrow bands peaking at 766.5 and 769.9 nm (Figures 1 and 2).

![Figure 1: Spectral fire response (0-2500 nm)](image)

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This emission feature is very strong because of the low ionization potential and relatively high abundance of potassium in plant life. Plant life consists mostly of carbon, hydrogen, oxygen, and nitrogen but also contains small amounts of other elements. Among these other elements, potassium has the highest abundance, up to 7% dry weight. One final aspect of potassium emission that lends itself well to remote fire detection is the fact that the potassium emission lines are transmitted through the atmosphere with relatively little attenuation (Figure 3). This fact increases the likelihood of potassium emission being a viable option for the remote detection of fires from satellites.
**Method**

**Optical Setup**

This project required the construction of an imaging system that would enable the capture of four separate images of a fire. The images captured are each in a different region of the spectrum. These regions are the visual, thermal/IR, and two band specific regions (766.8 and 780 nm). The device had to be constructed in a manner that would allow for the capture of these images at a safe enough distance away from the fire. It was also necessary for each image to be of the exact same scene of the fire. This was relatively easily accomplished for three of the images as a result of our final optical design.

The final optical design consisted of three grayscale CCD cameras in addition to the thermal/IR camera used in conjunction with beamsplitters, lenses, and filters (Figure 4). All optical equipment except the thermal/IR camera was contained on a specially constructed plate. This optical setup allowed for each CCD camera to image the exact same scene of the image.

A –200 mm lens was used in combination with 50 mm focal length C-mount lenses on each CCD camera to provide both the proper magnification and eliminate stray light from striking the CCD array. This also allowed for a safe stand off distance of about 3 feet for the optical system. The first beamsplitter sends 30% of the image to the first camera, which records the visual image. The remaining 70% of the image is split by the second beamsplitter. This sends 35% of the original image towards each of the remaining two cameras. One camera has a 766.8 nm filter (passing the potassium line) in front of it while the other has a 780 nm filter in front of it. Both filters have a bandwidth of 10 nm. The image through the 766.8 nm filter is the potassium emission image. The other image is an off-potassium emission image; the image is from a region of the spectrum slightly above the potassium region. In order to eliminate "ghost images" in the visual and...
off-potassium images, a black surface was placed on the edge of the plate behind the filters. Since each of the three cameras looks down the same optical path, each of these images is of exactly the same part of the fire.

The final image was obtained using the thermal/IR camera. This was set up in front of the optical plate setup in a position that did not interfere with the capture of the other three images. The position of this camera was adjusted in order to image approximately the same scene of the fire as the other three images.

**Image Capture Setup**

Optimally, the images from all four cameras should be recorded at the same instant in time. This is essential if we are to compare the images later on. It was determined that a commercially available 'quad processor' would be ideal for this task. This device allowed all four images to be captured as one image while ensuring that the images are synchronized. The use of a quad processor did have the unfortunate effect of reducing the size of each image from 640 x 480 to 320 x 240 (after separating the four images). It was determined however, that this resolution was sufficient and the task could still be accomplished adequately using smaller images.

The output from each of the four cameras was therefore sent to the quad-processor. Its output was split between a monitor and digital video recorder. This split allowed for continuous video feed capture while still maintaining our ability to view the experiment in real time on the monitor. Individual frames were then selected from the captured video to be used for analysis.

**Image Registration**

The next aspect of the setup was to more accurately register the individual images spatially. It was decided that this could best be accomplished by placing locators in the original scene that could be captured in all four images. Four small white lamps accomplished this task and were mounted in a dark frame, which was placed in front of the fire scene. These four points were then captured in each image and provided fixed points with which to register the four images.

In order to register the four images, they had to be separated from each other in the captured image (Figure 5). Sections of these original four images could then be sent through a star-finder program (from the NASA Goddard Space Flight Center IDLASTRO library) in our data processing code. This program finds the bright spots in an image and returns the location of the center of the bright spot. The lamp locations in each of the four images were obtained to sub-pixel accuracy using this routine.

A problem was noticed at this point in the process. It was impossible to record both the lamp locators and thermal/IR fire information without saturating the infrared camera data. Adjusting the temperature scale throughout the image capture process solved this problem. One scene image was captured with the locator
lamps present and then the scale was adjusted to contain the fire information. The lamp locations were found using the first image and the second image was cropped using these locations. The setup remained stable during this procedure.

Using the lamp locations, each image was cropped to contain the same scene. We were then able to compare image sizes and determine any magnification differences. It became evident that previous techniques to spatially register the images optically were sufficient as the image sizes never varied by more than two pixels. This is an acceptable amount of error for this experiment.

Figure 5: Captured image using quad processor (fire 2)

Upper left: potassium image
Upper right: off-potassium image
Lower left: visual image
Lower right: thermal/IR image
Analysis

The data analysis for this project contained some of the processes described previously including the image cropping section. In addition, the off-potassium and visual images had to be flipped, since the optical arrangement reversed one of the images left-to-right with respect to the other. This is a result of the beamsplitters used in the optical setup.

In comparing the images, we looked at only the potassium, off-potassium, and the thermal/IR image. The visual image did not provide any additional information to us at this time but could be used for alignment or another band at a later time.

![Figure 6: Captured image using quad processor (fire 1)](image)

- Upper left: potassium image
- Upper right: off-potassium image
- Lower left: visual image
- Lower right: thermal/IR image

From figure 6 it is evident that there is an error in the images captured for the first fire. The lines apparent in the thermal/IR image are most likely due to an improper connection in the thermal/IR camera. This error was not present in later fires and we are assuming that the problem was the result of this connection problem.
The image comparisons used consisted of calculating and examining the difference images between the three images. Figures 7-9 show difference images from our first experimental fire. Figures 10-12 show difference images from our second experimental fire.

Fire 1

![Figure 7: Potassium/IR difference](image1)

![Figure 8: Off-potassium/IR difference](image2)

![Figure 9: Off-potassium/potassium difference](image3)

Fire 2

![Figure 10: Potassium/IR difference](image4)

![Figure 11: Off-potassium/IR difference](image5)

![Figure 12: Off-potassium/potassium difference](image6)

Analysis of Figures 7 and 8 provides some interesting information despite the fact that the thermal data is saturated. It can clearly be seen that both the potassium and off-potassium emission occurs only in the
center of the flame. If we assume that this is the hottest part of the flame we can conclude that the emission occurs at the hottest part of the fire. Figure 9 reveals some data about the fire despite the intensity differences between the images. The off-potassium emission occurs in the center of the potassium emission.

Analysis of Figures 10, 11, and 12 reveal much of the same information. It appears once again that the thermal/IR image covers the greatest area. The potassium image is located at the heart of the thermal/IR image and the off-potassium image is located at the center of the potassium image.

Additionally, a hot soldering iron was placed in the scene during the first fire. The goal of this was to show that thermal emission data is not always accompanied by data in the off-potassium or potassium images. This accomplished its goal as shown in Figures 7 and 8. The soldering iron is imaged in the thermal/IR region but not the potassium or off-potassium region.

Lastly, temperature data from the IR image was analyzed. The temperature scale from the IR image was used to map temperature values onto the thermal/IR image. This resulted in an image consisting of temperature values instead of pixel values. From this data, the histogram, surface plot, and a contour plot of the flame temperature profile was obtained.

![Temperature data](image-url)
Conclusion

The results indicate that there is a distinct difference between the potassium emission region and infrared emission region. The potassium emission occurs in a region of the flame that is brightest in the infrared, indicating that this emission occurs only in the highest temperature portions of the flame. When a soldering
iron was placed in the scene, no image was obtained from the potassium camera. With this technique we can learn about the origins of the potassium emission signature from fire.

In the real time video, it was noted that the potassium emission occurs early on in the burn history of the fire, but rapidly decreased even though the IR emission from the fire is still quite intense. While the intense thermal emission existed throughout the duration of the fire, potassium emission occurred only in fuel that had recently began combustion. This emphasizes the point that the potassium emission can distinguish the active fire from the previously burned fuel and burn scar, which may still be hot.

Future Work

Thus far, our work has laid the foundation for future experiments, utilizing our equipment and techniques. Future work could include correlation of the temperature of the flames with the strength of the potassium emissions in an attempt to determine the precise temperature range in which potassium emission occurs. Furthermore, potassium emission could be examined versus time as a fire burns to determine when, during the life of a fire, this emission reaches its peak. This would also help us in tracking a fire’s movement. This knowledge is important if potassium emission could be used in the early detection of forest fires.

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