REAL TIME IDENTIFICATION AND LOCATION OF FOREST FIRE HOTSPOTS FROM GEO-REFERENCED THERMAL IMAGES

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KEY WORDS: Digital, Remote Sensing, Detection, Forest Fire, GPS/IMU, Geo-referencing, Aerial, Thermal

ABSTRACT:

More than forty percent of Canada's land area is covered by forest, of which fifty-six percent is commercially productive. However, this forest resource is constantly at risk of destruction by wild-land fire. Fire annually burns 433,000 hectares of commercial forest, and it enlarges Canada's forest management budget. This paper briefly explains the application requirements and system components used to develop a system to potentially improve the response time of the forestry department in the identification of newly ignited forest fires. This project is currently under development by the mobile multi-sensor research group at the University of Calgary. The objective of this research is to develop a real-time Forest Fire Detection (F^2D) system for identifying and locating forest fire hotspots automatically using geo-referenced thermal images, and contribute to reducing the impact of forest fires through earlier detection. The system consists of an integrated WADGPS/INS unit for direct georeferencing purposes, and a thermal imager to detect potential forest fire hot spots. In this paper, the process to properly identify forest fires from thermal images is briefly explained, followed by the corresponding georeferencing results from using this process.

1. INTRODUCTION

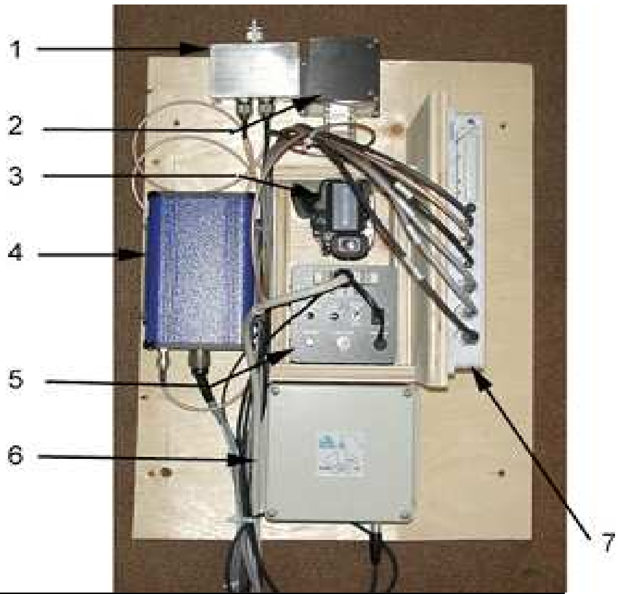
Canada has totally 997 million hectare of land area, and 42% of the land, 418 million hectare, is covered by forest. The Canadian forest industry is very strong: it accounts for 16% of world pulp production and almost a third of the total production of newsprint. Canada is the main exporter of manufactured forest products, with a 20% share in the market. The forest in Canada is not only a source of economic well-being, but also a home for wildlife and a filter of air and water. The greatest threat to the forest resource is wild fires. If one looks back over about 30 years, 8767 forest fires have burned out over 2,130,000 hectare annually throughout Canada, with property losses up to 4.67 billion dollars per year.

With the recent cost and size reductions in long wave infrared (LWIR) cameras, and the readily available processing capacity of modern PC's, it has become very economical and practical to equip an aircraft with the appropriate technology to rapidly survey a potential fire zone for any new forest fire ignitions. LWIR cameras have already been installed into fire bombers for accurate fire retardant application through smoke, and also in surveillance aircraft to video tape the current situation for manual review, with GPS information overlaid on to the video. This has provided accurate and valuable fire control planning information within hours of the survey.

Our goal is to provide this information within minutes, instead of hours, by automating the identification of forest fire hotspots through custom video processing, integrating these results with real time navigation technologies (Wide Area Differential GPS "WADGPS" and low cost Inertial Navigation System "INS") to photogrammetrically determine an accurate fire size and position. This information can then be transmitted to the fire control officers for integration into the Fire Control GIS system. The use of LWIR cameras, which sense the heat emitted in the form of infrared radiation, will enable early detection and location of forest fires in reduced visibility due to haze, smoke or darkness. Figure 1 shows the components of the F^2D prototype system.

To determine 3-D coordinates of the fire from the images, the position vector (3 parameters per image) and direction/orientation (3 parameters per image) of the camera at exposure times are needed for a pair of images. These parameters will be obtained from the WAGPS and INS data. After the georeferencing process, the images can be used for feature extraction using photogrammetric intersection techniques. As a first step, image processing techniques will be applied to the LWIR images. The purpose of the image processing is to identify, isolate, and track the hotspots and fires in real-time. Different filtering techniques; such as thresholding, morphological, texture and variance filtering are used for identifying and isolating hotspots and fires from the rest of the image. Once the hotspots and fires are identified within the video sequence, they must be tracked from frame to frame to accurately position them. The goal is to track the hotspot across as many frames as possible and as long as possible to give the space intersection calculation as wide an angle as possible. Following the 3D coordinate computation of the hotspots and fires, this information will be sent to the web server using one of the satellite communication techniques.

The paper also addresses the specific issues related to the identification, extraction, and tracking of forest fire hot spots from the georeferenced LWIR images. The implementation of geo-referencing and its need in this system as well as some of the issues encountered while implementing the real time direct geo-referencing of the video is discussed. Finally a preliminary evaluation of the system's accuracy in real time through field test results is presented.



1. Signal Synchronization Board
2. AHRS – Attitude and Heading Reference System
3. Video Camera
4. WADGPS Receiver
5. Thermal Camera
6. Inertial System
7. Data Logger

Figure 1- Hardware of the F^3 System

2. EXTRACTION, IDENTIFICATION AND LOCATION OF FOREST FIRE HOTSPOTS FROM THERMAL IMAGES

A forest fire hot spot is hotter than its general surroundings. Radiated heating takes a lot more time than convection and conductive heating, and is dependent on several factors, including the absorption rate, the heat capacity of the object, the distance between the objects among others. For detecting fire, thermal imaging detects fire by the radiated energy. With a small forest fire at the base of trees, and surrounded by several trees, the radiation is absorbed by these surrounding trees and not transmitted through. This leads to the fire "hot spots" being obscured occasionally by the surrounding forest.

Also note there is a blooming effect around the fires. This occurs from the immediately surrounding air being heated. What this can cause is an incorrect determination of the hotspot center within the image when combined with the actual hot spot being obscured. Figure 2 is used to help explain these two characteristics.

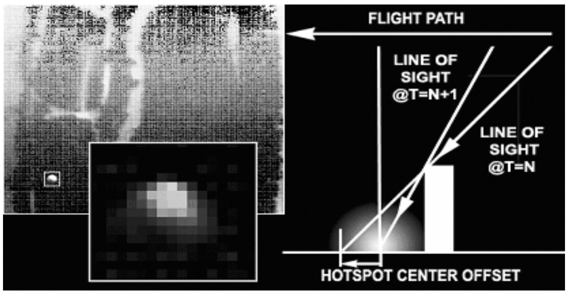


Figure 2: Hot Spot Characteristic Diagram

The inset image is an enlargement of the hotspot from the background image. The background has been enhanced for clarity while the inset is the actual pixel values. At the flying altitude that this image was taken from, the fire pit imaged here would only be 1 pixel in size, but the hotspot from the fire in that pit is several pixels in size, because of the blooming effect stated previously. The right side of Figure 2 shows the effect of the hot spot being obscured. The imager can see some of the heated air around the fire, but not the exact centre of the un-obscured hot spot. As a clearer path to the hot spot occurs, a brighter hot spot is imaged. This will cause some error in the actual centre for the hot spot. By monitoring the location of the brightest pixel within the identified hot spot, it may be possible to weight the 3D intersection process, and also to potentially separate actual hot spots from strong reflections and low level thermal sources such as roads or rock.

The effect of an obscured hot spot is shown in the following excerpt from a video sequence, as depicted in Figure 3. Note that these are inverted images, such that hotspots are black. To properly identify and locate small forest fire hot spots from thermal imagery, a three-step process has been defined, as explained next.

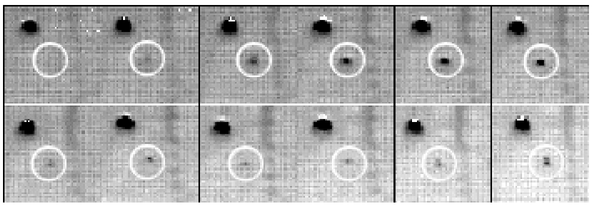


Figure 3: Extracted Sub Image Highlighting Effect of Obstruction on Hot Spots
(Note that Figure 3 is an inverted image for clarity)

2.1 Initial Feature Extraction from Thermal Images

The first step of the process is to extract any features that are hotter than the general background. Figure 4 outlines this step. A low-level threshold is set to identify any pixels and object that are of above average temperature from the background correct image at the top left of Figure 3 creating a feature mask.

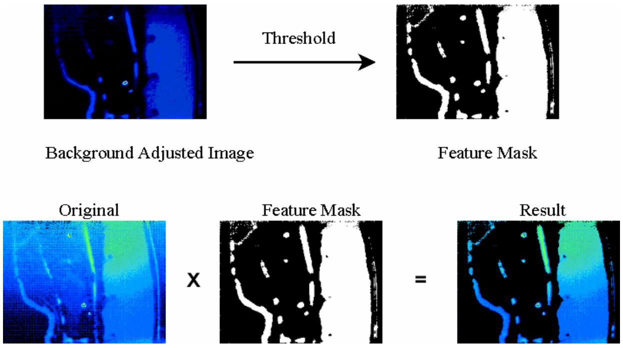


Figure 4: Image Processing for Feature Identification

The feature mask is used to select isolate particular features from the original image. The background adjustment process (not described here), reduces noise to simplify the feature extraction process, but tends to eliminate the small hot spot peak temperature characteristic, so the original image is used for peak pixel intensity determination. The desired features are extracted from this final resulting image. Several characteristics of the features are extracted, including the center of gravity, area, maximum intensity pixel, and the corresponding coordinate of the maximum intensity pixel. These feature characteristics are required for the second step of the process, outlined next.

2.2 Hot Spot Feature Track Identification

By using a low threshold in the previous step to isolate any features of above average temperature, several undesired features are also extracted with the hot spots. So instead we turn to the temporal aspect of the image and feature sequence.

Fire is extremely obvious, by the very high pixel intensity, when the thermal imager directly views it. As stated previously, the direct viewing path may be obstructed, such that a hot spot may only show up in one or two few images at a time. For various reasons, a longer feature track is desirable for accurately identifying, tracking and locating any hot spots. Only the basics required to specifically identify a hot spot are presented here.

Every feature previously extracted is cross-referenced or tracked from frame to frame, creating a feature track. The maximum observed pixel intensity is updated for that feature track until no more features are added to that track for several frames. Once the feature track is considered complete, the maximum pixel intensity is evaluated as to whether that track was ever hot enough to be considered a fire or not.

Figure 5 is an actual intensity profile observed during testing. For a majority of the feature track, the pixel intensity stays fairly low, and varies quite substantially. It peaks above 250 for one pixel towards the end of the feature track. This peak value of the track, and in some respects the range of values, are what identify this feature track as the track of a hot spot.

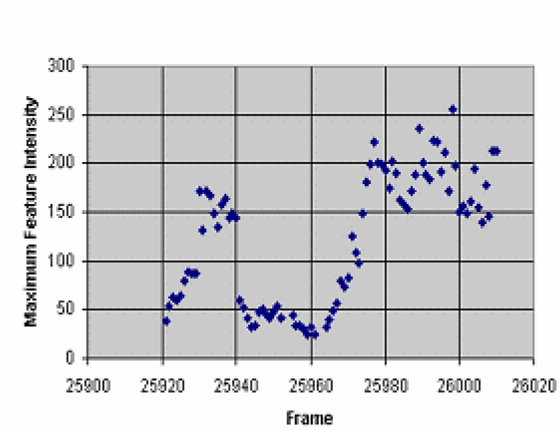


Figure 5: Example Hot Spot Feature Track Intensity Profile

Once the hot spot feature track is identified, then the motion of the hot spot is tracked over different images. Motion estimation is the determination of spatial change over temporal changes. The first step in tracking the hot spots from frame to frame is to develop an estimate of the potential or effective pixel motion that could occur. This involves both the camera characteristics and also the overall motion and flight characteristics. These include the effective flying height, flight speed, crab angle, and attitude variation of the system, as well as the effective field of view of the camera. On a frame by frame basis, there is a direct correspondence between the change in roll and change in image x coordinate (dx), as there is with the change in pitch and change in image y coordinate (dy). The crab angle, or difference between actual motion vector and the body orientation will have a slight affect on both x and y, adding additional variation to both dx and dy. The majority of the image flow will occur from the position changes of the aircraft instead of the attitude. The change in image y coordinate (dy) is related to the forward motion of the aircraft, and dx is related to any side to side motion. Finally, the actual pixel motion due to attitude variations is independent and unrelated to height, but pixel motion due to speed is directly related to the height, due to the change in scale with height.

In a remote sensing application, the attitude of the aircraft is generally controlled very tightly such that the variations are minimal, although a range will be considered here. Table 1 lists the pixel motion range estimates due to attitude variations, and Figure 5 shows the pixel motion range estimates due to height and flight speed. Figure 6 shows an example of an entire hot spot feature track, as it would be seen moving across the image. Once a hot spot is tracked through the image sequence, its location can be determined, as explained in the following section.

Angle Type	Degrees	X Pixel Variation	Y Pixel Variation
Roll:	0.5	2.61	0.00
Pitch:	0.5	0.00	2.61
Azimuth:	0.5	1.38	1.38
Total Pixels:		3.99	3.99

Table 1: Pixel Motion Estimate Due to Attitude Variations

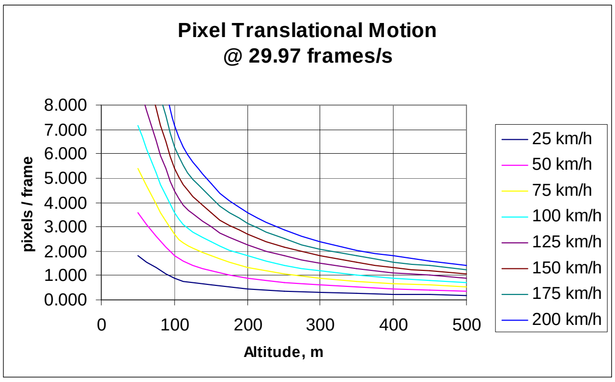


Figure 5: Pixel Motion Estimate Due to Speed and Flying Height

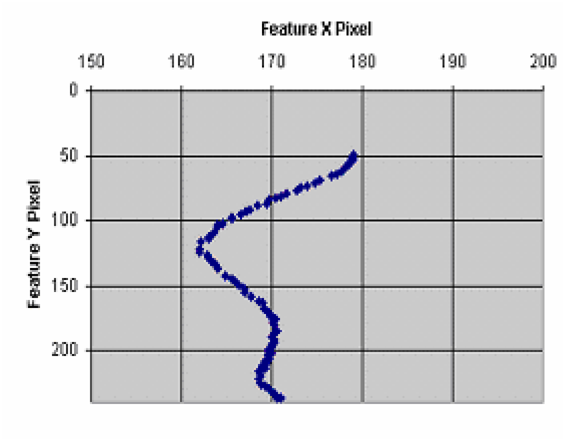


Figure 6: Example Hot Spot Feature Track

2.3 Real-time georeferencing

Real-time georeferencing is accomplished by using the WADGPS/INS information to georeference the LWIR images. The physical relationship between the GPS antenna, the INS, the camera and the ground target is shown in Figure 7.

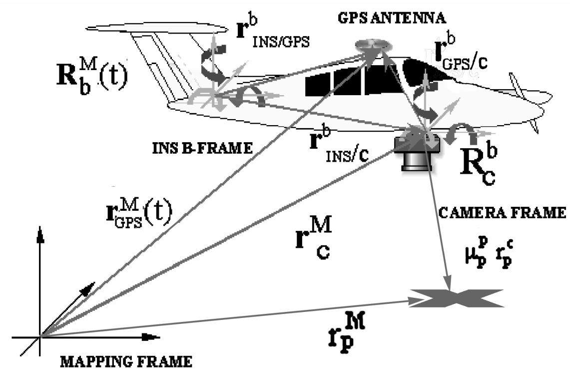


Figure 7: General Geo-Referencing Diagram

In Figure 7, $\boldsymbol{r}_P^M$ indicates the position vector of the hot spot with respect to the mapping coordinate system. This position vector can be obtained mathematically as below.

$$\mathbf{r}_P^M = \mathbf{r}_{GPS}^M(t) - \mathbf{R}_b^M(t)\mathbf{R}_c^b\left(\mathbf{r}_{GPS/c}^b - \mu_p^P \mathbf{r}_P^c\right) \quad (1)$$

Where:

$\mathbf{r}_P^M$ Is the X, Y, Z position vector of the feature point in mapping frame

$\mathbf{r}_{GPS}^M(t)$ Is the real time GPS position vector in mapping frame

$\mathbf{R}_b^M(t)$ Is the attitude matrix between the body frame and mapping frame

$\mathbf{R}_c^b$ Is the rotation matrix between the camera frame and body frame

$\mathbf{r}_{GPS/c}^b$ Is the GPS to Camera lever arm vector

μ_p^P Is the Image point scale factor

$\mathbf{r}_P^c$ Is the image point

t Is the time of exposure

For each image, $\mathbf{r}_{GPS}^M(t)$ and $\mathbf{R}_b^M(t)$ are obtained from the direct georeferencing system and any $\mathbf{r}_P^c$ for hot spots are determined from the feature track extraction process in as explained in Section 2.2. $\mathbf{R}_c^b$ and $\mathbf{r}_{GPS/c}^b$ are fixed values that are obtained through calibration. $\mathbf{r}_P^M$ and μ_p^P are obtained through performing a 3D space intersection.

3. RESULTS

To test the overall accuracy of the F^2D system, an airborne test flight took place over controlled fire pits in Calgary in July 30, 2002. The controlled and monitored fires were set in fire pits at the Bowness Park picnic area. The F^2D system was mounted in a remote sensing aircraft (aircraft and flight services provided by Geodesy Remote Sensing, Calgary). Two multi pass test flights at varying aircraft altitude took place over the test filed to allow for collection of data under both day and night conditions. Figure 8 shows a sample of the fires that were used as targets, and the corresponding forest coverage of that target. Any where that the blue sky is observed in the right hand image is where the thermal imager could potentially see the fire.

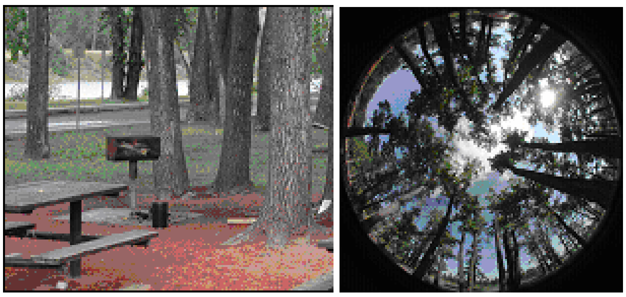


Figure 7: Sample Target Hot Spot and Forest Canopy Coverage

Table 2 lists the positional accuracy of the aircraft derived position from the WAAS and the OmniStar real-time systems during the two test flights. The reference trajectory for these results is the post processed double Differenced GPS (DGPS) solution (accurate to 10 cm). The DGPS solution was derived from the University of Calgary KINGSPAD™ software (http://www.kingpads.com/), El-Sheimy and Schwarz 1998). The table clearly indicate that positional accuracy of the aircraft is in the 1-2 level for both the WAAS and OmniStar systems.

	Night Flight		Day Flight	
	WAAS	OmniStar	WAAS	OmniStar
Mean	1.761	3.124	2.292	2.850
min	0.294	0.715	0.504	0.706
max	8.782	10.05	12.44	12.27
Std. Dev.	1.339	1.179	1.579	1.477

Table 2: 3D Error Statistics

Figure 8 show the real time attitude results for one of the test flights. The reference attitude for these figures is the post processed attitude derived from the University of Calgary KINGSPADTM software. The figure clearly indicates that the attitude accuracy is within 0.1 – 0.15 deg

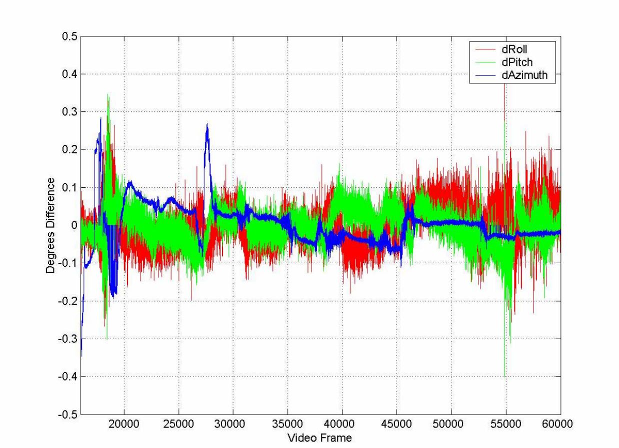


Figure 8: Night Flight Post Processed to Real Time Attitude Comparison

Utilizing the extraction and identification process outlined in Section 2, Table 3 and Table 4 lists the positional accuracy of the F^{2}D system in calculating the coordinates of 5 controlled fire pits. The results in Table 3 were calculated using post-processed georeferencing (position from DGPS) data, while the results in Table 4 were calculated using the real-time georeferencing (position from WADGPS) data.

	Average	Target				
	Altitude	1	2	3	4	5
Pass 1	404 m	2.4	8.1	2.1	4.6	1.8
Pass 2	359 m	7.3	8.4	5.0	1.8	6.0
Pass 3	942 m	6.5		8.7		
Pass 4	961 m	10.9		1.5		
Pass 5	364 m	11.2	11.6 m	7.5	8.2	8.6

Table 3: Post processed 2D Position Errors (meters)

	Average	Target				
	Altitude	1	2	3	4	5
Pass 1	404 m	2.3 m	7.7 m	2.8 m	5.4 m	2.9 m
Pass 2	359 m	6.3 m	6.9 m	3.9 m	1.1 m	5.0 m
Pass 3	942 m	5.3 m		7.3 m		
Pass 4	961 m	13.8 m		5.1 m		
Pass 5	364 m	11.3 m	11.7 m	8.0 m	11.7 m	9.0 m

Table 4: Real Time 2D Position Errors, meters

The results in Table 3 and 4 are extremely promising considering the altitude and the image sizes (image size is 320x240 pixels). The blank cells in the tables indicate that the target fire was not automatically detected. It is interesting to note that the results using post-processed data is not always better than the real time results for the same targets. The 2D errors are in a similar range for the particular target pass combination suggesting that there are some tracking errors still occurring. Some of the other possible error sources include redundant and multiple features being cross-referenced to the same feature track, differences between the feature centre of gravity co-ordinate and the maximum intensity co-ordinate, and incorrect geometric calibration of the non-metric thermal imager.

4. CONCLUSION

The F^{2}D system presented in this paper represents a substantial leap in the speed of reporting identified forest fire hot spots. In particular, by utilizing the latest in WADGPS/IMU system integrated with new computer technology and custom image processing algorithms, the georeferencing of small forest fire hot spots is definitely possible in real time. Preliminary results strongly suggest that small hot spots in a lightly forested area can be readily detected in real time to within a 2-10 m level of accuracy.

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