Near Remote Sensing for Tactical Earth Protection

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Abstract – In this paper we present how to use an Unmanned Aerial System in remote sensing. The system is specifically designed for forest fire management, as a support tool for the Fire Services to improve their tactical decisions. The system payload includes two cameras: a thermal camera and a visual camera. A simple image processing algorithm is applied to the thermal images in order to detect hot areas. In case of detecting a hot spot, it raises an event and notifies the geographical position of the spot, so that the firemen manager can know the hot spot position as soon as possible. On demand, the system also provides the visual image of the area with the shape of the detected hot spot marked on it. The visual images of the surroundings of the fire can help experts to discard false positives and to make faster and more accurate decisions.

Keywords: Unmanned Aerial Vehicles, Unmanned Aerial Systems, Airborne Remote Sensing, Image Processing, Forest Fire Management.

1. INTRODUCTION

Wild fires are a devastating catastrophe for forest, especially in Mediterranean countries. More than 50,000 fires are detected in South Europe each year which burnt from 200,000Ha in the 'good' years to more than 750,000Ha in the worst recent year (2003). Much effort is done today in prevention, detection and extinction tasks. In terms of costs, extinction represents the 70% of the total budget of the firemen. Supporting the decision making process might improve the effectiveness of the dedicated resources.

Remote Sensing is the process of acquiring, processing and interpreting the electromagnetic waves of an area from an aerial mean (Sabins, 2007). Traditionally, satellites have been the main source of Remote Sensing data. Increasing number of constellations and better precision had driven many qualified studies, mainly for scientific use. In the case of wild fires, studies on the behavior of past fire fronts made possible the simulation on new fires, thus the anticipation of fire fronts movement. Another approach for Remote Sensing is the use of aircrafts. Aircrafts are used today to obtain more precise data of a given region. Also their flexibility allows to have Remote Sensing at the exact moment it is needed, without having to wait for the satellite to fly over the interest area and then to reach a data download station. A wild fire data has much more interest for the firemen on command of ground squads if it is real time data.

In this paper we focus on a special type of aircraft, the Unmanned Aerial Systems (UAS), which are showing up as a valid future alternative for real time Remote Sensing (Everaerts, 2008). UAS have the flexibility of an aircraft for working as fast Remote Sensing decision tool. Moreover, UAS have two added advantages: cost and safety. The cost of operating UAS, once the legal aspects are defined, will be on a tenth of operating an aircraft. And more important, for dangerous scenarios like a wild fire, the absence of a pilot on board is absolutely safer than traditional aircrafts for obtaining real time Remote Sensing data.

The paper is organized as follows: Section 2 presents the global picture of the UAS usage and its payload for our target hot spot mission. Section 3 provides the details of the framing systems used for the Remote Sensing, as well as the image fusion algorithm used. In Section 4 results come out. Finally in Section 5 conclusions and future work are given.

2. UNMANNED AERIAL SYSTEM

For the proposed task, we consider a UAS composed by the following elements (see Figure 1):

- The Unmanned Aerial Vehicle (UAV), including the airframe and all the devices on-board that compose the payload.
- The Ground Control Station (GCS), which is used to control the UAV flight and the mission from the ground.
- A Communication Channel (CC) between the UAV and the GCS. This channel is also used to distribute the acquired data in real time.
- Squad Information Terminals (SIT) for the ground crew. These are very light and personal devices to receive information of the current fire state.

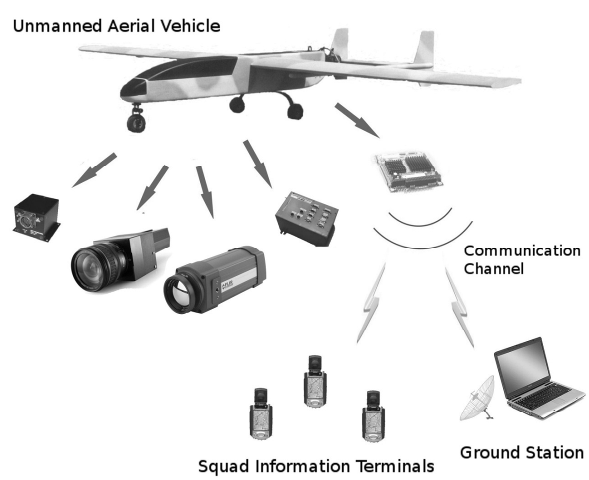


Figure 1. UAS components

The system operates as follows: The UAV flights over the area of interest taking thermal and visual pictures. The thermal images are processed in real time. If a hot spot is detected, a notification including the geographical position is sent to the GCS. The person in charge can then ask for the fusion of thermal and visual information, which can be sent directly to the SIT. Next, we describe the related payload in more detail.

2.1 Payload

The equipment required for the tactical support of hot spots missions is composed of an altimeter, a GPS, a clock, a high resolution visual camera and a thermal camera. The temperature maps provided by the thermal camera are crucial to detect the hot spots and to select the most significant ones. Visual images are very sensitive to changes in illumination, the weather conditions, or the presence of other external factors such as smoke; but they are needed to discard false alarms caused by other hot objects, such as vehicles, or solar reflections, such as water. Nowadays, there exist infrared cameras that include a visual camera and a fusion function to overlay the thermal image directly over the corresponding visible image. Nevertheless, the visual resolution (1.3 Megapixels) is still far from the system requirements, and the processing of the fused image would be more complex too. Note that the aim of the visual image in the proposed system is only to provide additional information to the ground crew. Furthermore, current fusion camera models do not seem suitable to be boarded on the UAV. On the other hand, hyper-spectral cameras or scanners are not needed in the system because the altitude is low enough to obtain good images with COTS cameras (Dunagan, 2005).

The GPS position of the UAV, the altitude and the camera angles can be used to determine the ground GPS location of the hot spots detected in the images (Barber, 2006). Nevertheless, people working on that kind of missions agree that visual information is often more useful than GPS coordinates. Finally, for a rapid data acquisition and distribution we require network connections for the cameras (such as a local Ethernet) and a radio modem to connect the UAV with the GCS and SIT.

3. IMAGE PROCESSING

This section describes the camera model used to map the thermal and visual images and the algorithm used to detect the hot spots and mark them in the visual image.

3.1 Mapping Thermal and Visual Images

For each camera, we consider a simple projection model with the coordinate system centered in the focus lens (see Figure 2). A 3D point *P* in the object space (*X, Y, Z*) is projected in the image plane (*x*, *y*) inverted and scaled in a factor that depends on the focal length (*f*) and on the focus distance (*Z*). The focal length and the sensor size (*w* x *h*) determine the field of view (FOV) of the camera, which is the area observed by the camera at the focus distance.

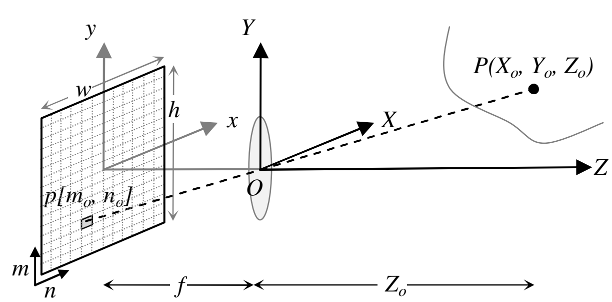


Figure 2. Camera model

In our system, the thermal and the visual cameras are tied together in an upright position. The focus distance (in our case the flight altitude) is large enough to assume that both cameras are positioned at the same point. As each camera has its own FOV (α_t and α_v), the captured areas (W_t x H_t and W_v x H_v) are different in size. In general, the thermal image will be a lower resolution subimage of the visual one, and one pixel in the thermal image will probably match more than one in the visual one. Figure 3 shows the *Y* axis view of the resultant projection model. Subindex *t* is used for the thermal camera parameters and subindex *v* for the visual ones.

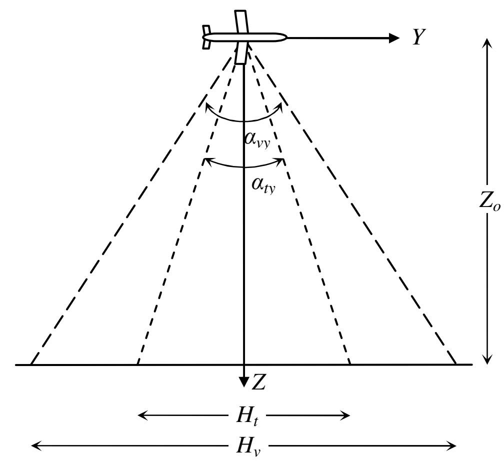


Figure 3. Thermal (*t*) and visual (*v*) cameras model

Taking into account the resolution of each camera (M_t x N_t and M_v x N_v pixels), the pixel coordinates of the point *P(X, Y, Z)* on each image ($[m_t, n_t]$ and $[m_v, n_v]$) can be expressed as follows:

$$m_t = \left\lfloor -X\frac{M_t}{H_t} + \frac{M_t}{2} \right\rfloor \quad ; \quad n_t = \left\lfloor -Y\frac{N_t}{W_t} + \frac{N_t}{2} \right\rfloor$$
$$m_v = \left\lfloor -X\frac{M_v}{H_v} + \frac{W_v}{2} \right\rfloor \quad ; \quad n_v = \left\lfloor -Y\frac{N_v}{W_v} + \frac{N_v}{2} \right\rfloor \qquad (1)$$

Where

$$H_t = 2 \cdot Z \cdot \tan(\alpha_{ty}/2) \quad ; \quad W_t = 2 \cdot Z \cdot \tan(\alpha_{tx}/2)$$
$$H_v = 2 \cdot Z \cdot \tan(\alpha_{vy}/2) \quad ; \quad W_v = 2 \cdot Z \cdot \tan(\alpha_{vx}/2) \qquad (2)$$

As said above, one thermal pixel could be mapped to a small submatrix of visual pixel:

$$p_t[m_t, n_t] \leftrightarrow \begin{pmatrix} p_{v_{11}}[m_{v_1}, n_{v_1}] & \cdots & p_{v_{1L}}[m_{v_1}, n_{v_L}] \\ \vdots & \ddots & \vdots \\ p_{v_{K1}}[m_{v_K}, n_{v_1}] & \cdots & p_{v_{KL}}[m_{v_K}, n_{v_L}] \end{pmatrix} \qquad (3)$$

From (1) we can infer the relation between those thermal and visual coordinates:

$$
\begin{aligned}
m_{v1} &= \lfloor (m_t - T_{tm}) \cdot S_m \rfloor + T_{vm} \\
n_{v1} &= \lfloor (n_t - T_{tn}) \cdot S_n \rfloor + T_{vn} \\
m_{vK} &= \lfloor (m_t + 1 - T_{tm}) \cdot S_m \rfloor + T_{vm} - 1 \\
n_{vL} &= \lfloor (n_t + 1 - T_{tn}) \cdot S_n \rfloor + T_{vn} - 1
\end{aligned} \tag{4}
$$

Where

$$
\begin{aligned}
&T_{tm} = \frac{M_t}{2}\ ;\ \ T_{tn} = \frac{N_t}{2}\ ;\ \ T_{vm} = \frac{M_v}{2}\ ;\ \ T_{vn} = \frac{N_v}{2} \\
&S_m = \frac{H_t}{M_t} \cdot \frac{M_v}{H_v} = \frac{M_v}{M_t} \cdot \frac{\tan(\alpha_{ty}/2)}{\tan(\alpha_{vy}/2)} \\
&S_n = \frac{W_t}{N_t} \cdot \frac{N_v}{W_v} = \frac{N_v}{N_t} \cdot \frac{\tan(\alpha_{tx}/2)}{\tan(\alpha_{vx}/2)}
\end{aligned} \tag{5}
$$

Usually both cameras have square pixels, and the scale factors S_m and S_n are the same value. Note that the mapping of the images depends only on the field of view and the resolution of the cameras, but not on the geographical relieve, the flight altitude or the cameras pitch, which are relevant factors for other applications such as geo-location or image correction.

3.2 Hot Spots Visualization

The thermal image is processed in three steps. First, a median filter is applied for noise reduction. This kind of filter is suitable to remove impulsive noise while still preserving the image detail (Pitas, 1990). Second, it is converted to 8-bit gray scale, so that the highest gray value (255) corresponds to the maximum temperature in the image. Finally, equations (4) are used to fuse the thermal and the visual images.

To detect the hot spots we apply a simple threshold mechanism. All pixels p_t with temperature value over the threshold temperature are considered hot spots. To mark them in the visual image with a red shade, the red channel $p_v(r)$ is enhanced and made proportional to the pixel temperature, the green component $p_v(g)$ is removed, and the blue channel $p_v(b)$ is softened:

$$
\begin{aligned}
p_v(r) &= 127 + 0.5 \cdot p_t \\
p_v(g) &= 0 \\
p_v(b) &= 0.5 \cdot p_v(b)
\end{aligned} \tag{6}
$$

The rest of the thermal image is marked in green (by softening the blue and red components) to contrast with the hot spot pixels, as well as indicating the area covered by the thermal image:

$$
\begin{aligned}
p_v(r) &= 0.5 \cdot p_v(r) \\
p_v(b) &= 0.5 \cdot p_v(b)
\end{aligned} \tag{7}
$$

In the last step, a black rectangle enclosing the hot spots is drawn to mark the hot area and facilitate its visual detection. Additionally, location, surface, average and peak temperature data could be provided to help in selecting the most relevant hot spots.

4. RESULTS

For our experiments we filmed a bonfire with the thermal and visual cameras tied up together and focusing to the same point.

We used the FLIR A320 camera, a radiometric thermal camera working in the wavelength range from 7.5 to 13.0 µm and in the thermal range from 0 to 350ºC. It provides 320 x 240 pixel images of 32 bit floating point absolute temperature values. As visual camera, we used the Lumenera Le11059c 11 Megapixel network camera with Tamron A09 zoom lens. Table A summarizes the relevant specifications of the cameras. These characteristics imply that when flying at an AGL of 100 meters one thermal picture covers an area of 44 x 33 meters, which represents a precision of 0.02 m^2 per pixel. In our experiment, the focus distance was about 25 meters, thus meaning an area of 11 x 8 meters with 0.001 m^2 per pixel. Visual images were taken with the minimal magnification ration, which corresponds to a FOV of 65º x 46º. This implies a scale factor (S in equations (4)) of 4.3 in relation to the thermal images. The threshold temperature was set to 75ºC.

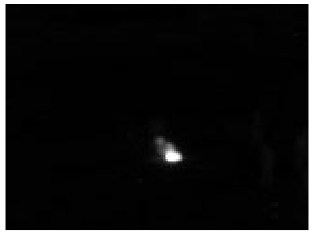
Table A.Specifications of the cameras

ThermoVision A320		
	Spectral range:	7.5 to 13 µm
	Temp. range:	0 to 350ºC (±2ºC)
	Field of view:	25.0º x 18.8º
	Focal length:	18 mm
	F-number:	1.3
	Resolution:	320 x 240 pixel
	Frame rate:	9 fps
Lumenera Le11059c + Tamron A09		
	Field of view:	75º-32º (diag)
	Focal length:	28-75 mm
	F-number:	1-2.8
	Resolution:	4000 x 2656 pixel
	Frame rate:	3 fps

Figure 4 shows one visual picture (a) and the corresponding thermal picture (b) taken during the active stage of the fire (only a subimage of the interesting region of each picture is included for clearness). The thermal image was saturated on 16 pixels, which means that the absolute temperature was over 350ºC for these pixels. The full output image generated by the application is shown in (c). The fire can be clearly detected in the thermal image, and it appears as a single mark over the output visual image.

The pictures in Figure 5 were taken 80 minutes later, when the fire was extinguished, but the ashes where still hot. From the thermal image (b) we can see that the hottest ashes are not in the center of the bonfire, but on the bottom-left side. The fused image (c) shows four hot spot marks enclosed by a rectangle. The maximum temperature in this image was 136ºC.

(a) Visual

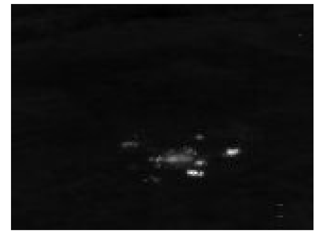


(b) Thermal

(c) Fusion

Figure 4. Active fire stage images

(b) Visual



(b) Thermal

(c) Fusion

Figure 5. Ash stage images

The complete application, programmed in C language, is executed in less than 2 seconds (less than 20ms of which are for the thermal processing) in a current PC under Linux operating system.

5. CONCLUSIONS

This paper presents the use of an Unmanned Aerial System for real time Remote Sensing in the particular scenario of hot spots detection. It provides significant advantages in front of current alternative systems in terms of flexibility, precision, cost, and safety. The system performs real time processing of pictures taken with a thermal camera and applies a simple threshold algorithm to detect hot spots. GPS and altitude information can be used to geo-referenciate the hot spots. On demand, the fusion of thermal and visual pictures is also processed and sent to the ground crew. It has been seen that the mapping of the images depends only on the FOV and resolution of the cameras. The approach has been successfully tested with pictures of a small bonfire. In the future we expect to fly over prescriptive fires and obtain more representative pictures, so that we can extract main trends and characteristics and improve the algorithm, which will be implemented more efficiently with programmable logic devices, such as FPGAs.

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