Computer vision techniques for fire monitoring using aerial images

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Abstract— **The paper presents an approach to the use of aerial images for fire monitoring. It shows techniques to segment the fire on visual images and to geo-locate the fire front. Color processing is used for fire segmentation. To geo-locate the fire base, a planar surface is assumed. The homography between the image plane and the real plane can be computed from several points correspondences. This homography is later used to geo-locate the fire base. Several artificial landmarks are used to obtain an initial relation. The homography is updated as the camera moves by tracking several points over the sequence of images. The points are tracked by using a feature matching algorithm. The explained procedure has been applied to visual images of controlled field fires taken by a camera placed on a helicopter.**

I. Introduction

Forest fires have become an important problem, leading to the destruction of wide areas every year.

During the last 10 years, several research projects and systems related to fire-fighting have been developed, mainly for fire detection [2] [5]. Furthermore, satellite-based systems have been proposed for forest fire monitoring [5] [11]. However, the time scale and resolution of these systems is still very low for the requirements of forest-fire fighting in many cases. In [1], an intelligent system for forest fire detection is presented. This system combines infrared and visual image processing with a neural network classifier and a fuzzy rule based technique to detect forest fires by discriminating false alarms.

In the last years, the European Commission has funded several projects dealing with the characterization, detection and monitoring of fires, among them the INFLAME and SPREAD projects [13]. In the framework of those projects, a new system for fire monitoring has been presented [10]. The system uses still cameras placed on the ground to obtain measures such as the fire front, flames height, flame inclination angle, fire-front width, by means of image processing. The system is very useful for the monitoring and measurement of experimental fires where the location of the cameras can be previously selected to provide appropriated views. However, its use in operational fire-fighting conditions is constrained because the difficulties to obtain these views.

A more realistic situation is the deploying of cameras on board of helicopters or other aerial means. This situation is a key issue in a new European project dealing with *Unmanned Aerial Vehicles* (UAV): the COMETS Project. The paper shows the use of aerial imaging to obtain measures from a forest fire. Color image processing is used to obtain fire features on the image. A planar surface is assumed, so the relation between geographical coordinates and image coordinates is a homography. This homography is used to geo-locate the fire front. Point correspondences are used to obtain and update that relation. A feature matching method has been adopted to track the points along the sequence of images.

Experiments of real field fires have been carried out during the last years in Gestosa, Portugal, in the framework of the above mentioned projects. The paper shows several results related to those experiments.

The paper is organized as follows. Sections II and III talk about the image processing techniques employed for fire monitoring using aerial images. Section IV resumes some implementation aspects. Section V shows some results. Section VI summarizes conclusions.

II. Fire segmentation using aerial color images

This section presents a technique to separate the fire from the background using color images. The fire contour on the image plane is one important feature for fire monitoring. The fire contour will allow us to estimate the fire front position, fire front height and other characteristics of the fire.

If RGB color images are used, a simple approach to segment the fire from the background consists on a thresholding technique over the red component, based on the hypothesis that the fire gives a high magnitude on the red component. This technique has been used in the system described in [10], and it is useful in many cases. However, other objects in the image plane can give also high response in the red component (such as white objects,among them the smoke generated).

A more robust technique considers the other color components. For fire images, the pixels belonging to fire should have a red component bigger than the other components.

Let $r(u,v)$, $g(u,v)$ and $b(u,v)$ be the RGB components for pixel (u,v). Then, first a region of the RGB space is selected, delimited by the planes

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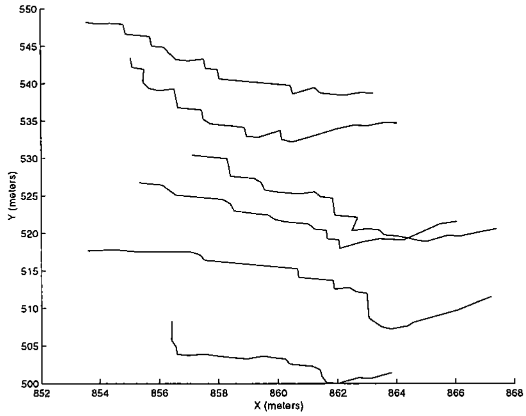

Fig. 8. Fire front

VI. Conclusion

The use of aerial images will be usually the only feasible mean for fire monitoring. In a real scenario, helicopters will be a realistic place to deploy cameras and sensors.

The paper has presented computer vision techniques for fire monitoring using aerial images. Two main issues are described: techniques for fire segmentation and techniques for fire geo-location. A feature matching method is used to track the points employed in the georeferencing step.

Further research should be done in the geo-location procedure, in order to deal with more complex surface models. The use of GIS systems let us to access to digital terrain models of high precision. Also, sensors as GPS can provide dynamically information about the camera position. However, to geo-locate fire features, a very accurate camera position estimation is need. Therefore, image processing techniques can be used besides GPS to help to the geo-location of the features.

Also, further research on color processing is being carried out, in order to improve the robustness of the fire features extraction methods.

The paper also includes the results of field forest fire experiments carried out in Gestosa (near Coimbra, Portugal). These tests demonstrated the interest of the presented perception system.

On the other hand, new research and development activities have been planned for the operational use of the system in the INFOCA forest fire-fighting plan of the Regional Government of Andalucía (Spain).

Acknowledgments

The work described in this paper has been developed in the project in the project SPREAD (European Commission, 5th Framework Programme, EVG1-CT-2001-00043) and in the project COMETS (European Comission, 5th Framework Programme, IST-2001-34304) . The authors thank the help of Begoña Arrúe, Francisco Gómez, Fernando Prado, Carmen Rosa, Juan José Giraldo, Francisco Ortiz and Antonio Luis Flores in the development of the work. The authors thank the profitable help of Prof. Viegas and ADAI team from the University of Coimbra (Portugal). The authors acknowledge Francisco Salas and Francisco Rodriguez y Silva of the Forest Fire Prevention and Restoration Service of the Regional Environment Service of Andalucía for his support to the SPREAD and COMETS projects.

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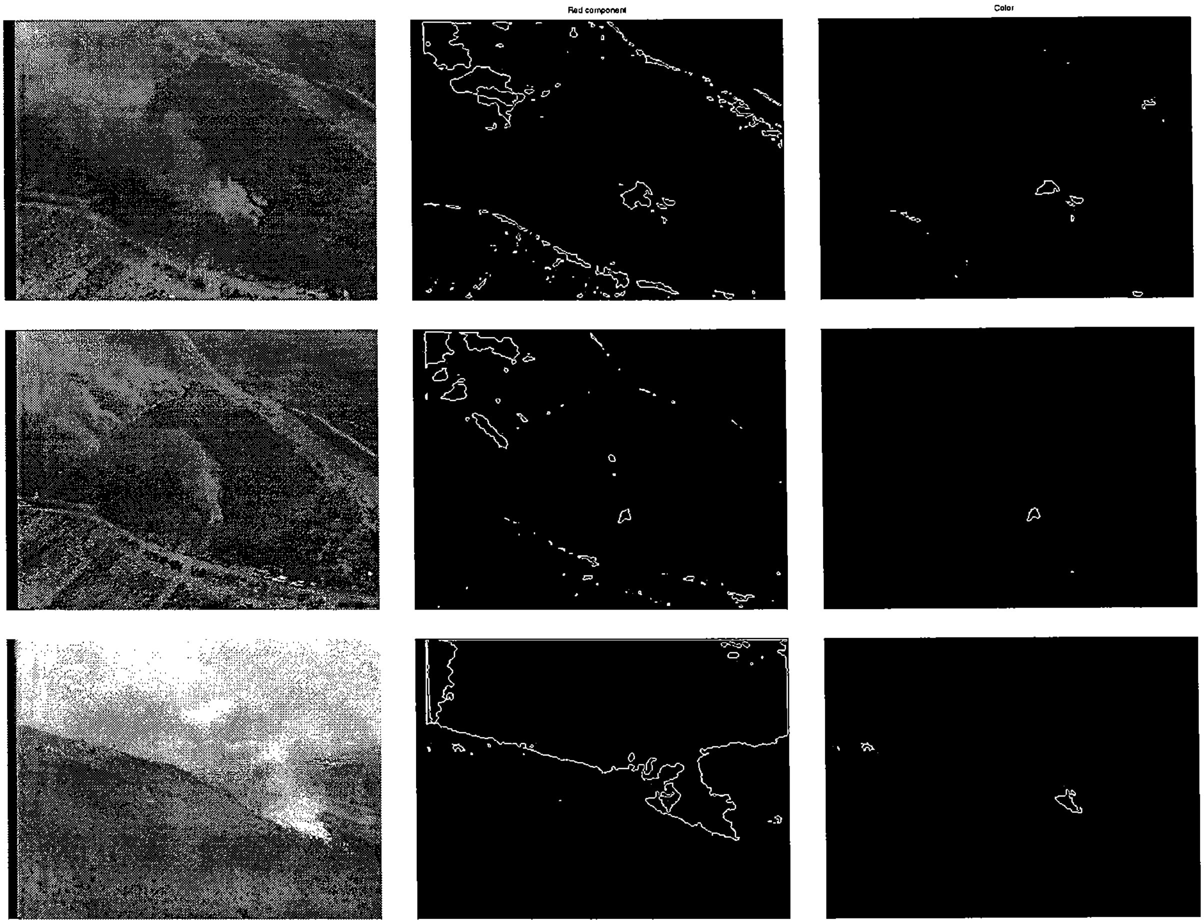

Fig. 1. Fire segmentation. Left, original images. Middle, contours obtained by using only the red component. Right, contours obtained by using also other components

$$\left.\begin{array}{l} r(u,v) - k \cdot g(u,v) \geq 0 \\ r(u,v) - k \cdot b(u,v) \geq 0 \end{array}\right\} . \tag{1}$$

Only image pixels belonging to this region will be considered as candidates of fire. k is a parameter that tunes the importance of the red component. A value of 1.1 and 1.2 leads to good results.

Finally, a threshold is computed over the red component for the regions selected. The threshold value is computed using a well-known iterative technique [12]. After applying this threshold value, the resulting binary image is filtered to eliminate spurious pixels and too small objects. Finally, the contours of the different blobs are computed, and stored in a list.

Fig. 1 shows the results for several color fire images. Left column shows the original images. The middle column shows the result of the thresholding technique over the red component alone (only the contour of the objects is shown). The right column shows the results considering also other color components.

The computed contours carry information about the fire front and the fire height.

III. Fire front geo-location using aerial images

To geo-locate the fire front once it has been located on the image plane, it is necessary to relate the pixels coordinates to geographical ones. Assuming a planar surface, the relation between pixel positions and their geographical position is a simple homography. Let $\mathbf{x}_i = (x_i, y_i)^T$ be the geographical position of a point of the planar surface, and $\mathbf{p}_i = (u_i, v_i)^T$ its corresponding pixel coordinates. Considering homogeneous coordinates, the relation can be expressed as:

$$\begin{pmatrix} x_{\lambda,i} \\ y_{\lambda,i} \\ \lambda \end{pmatrix} = \underbrace{\begin{pmatrix} a & b & c \\ d & e & f \\ g & h & 1 \end{pmatrix}}_{\mathbf{H}} \begin{pmatrix} u_i \\ v_i \\ 1 \end{pmatrix} \tag{2}$$

$$\begin{pmatrix} x_i \\ y_i \end{pmatrix} = \frac{1}{\lambda} \begin{pmatrix} x_{\lambda,i} \\ y_{\lambda,i} \end{pmatrix} . \tag{3}$$

Notice that one element of $\mathbf{H}$ can be chosen arbitrary as 1. Then, only four correspondences are needed to compute this relation. However, more points will be used, computing the parameters of the matrix by using least squares.

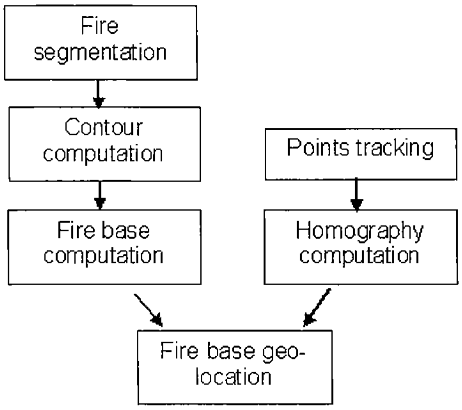

Fig. 5. Image processing scheme for aerial images

The information about the evolution of the fire front location is dynamically transmitted to a *Geographical Information System* (GIS). Then, this information can be stored for future use, or combined with other type of information, such as slope maps, fuel maps and so on.

The tool has been implemented C++, over Windows NT. The visual dialogs has been implemented by using the Microsoft Fundation Classes. The hardware used has been a Pentium III at 450 MHz, with a frame grabber μTech MV-1000.

It could be also possible to implement the system by means of parallel processors. Real-time efficient parallel DSP implementations of feature matching algorithms have been described in the literature [3].

V. Results

As it has been said, in the framework of the INFLAME and SPREAD projects, experiments of real fire have been carried out. These experiments consists of the burn of plots delimited by firewalls.

Fig. 6 shows one of the plots burned. Several beacons can be observed in this figure (little white squares). Also, the GPS position of the contours of the firewalls are stored in a map.

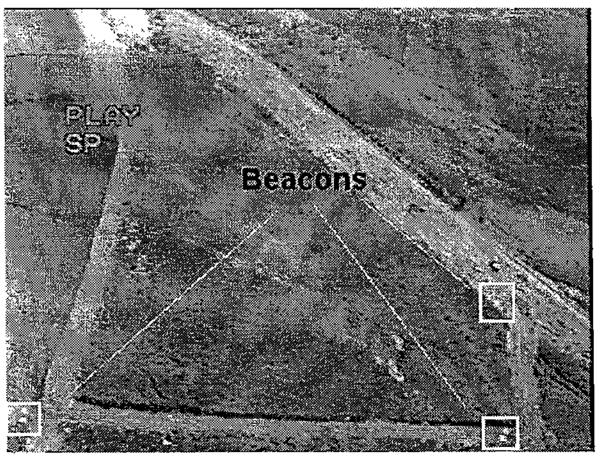

Fig. 6. Plot burned during the experiments carried out in Gestosa

The procedure explained has been applied to several of the cited experiments. Fig. 7 is related to one of these experiments. The top figure shows some of the points used to compute **H** (marked as $\times$). Also the corresponding regions on the image plane are shown in the middle image (the view of the scene is taken from a position near the upper right corner in the top figure). Notice that one region belongs to a smoke plume. This region will be identified by the outlier rejection step. The lower figure shows the computed fire front location.

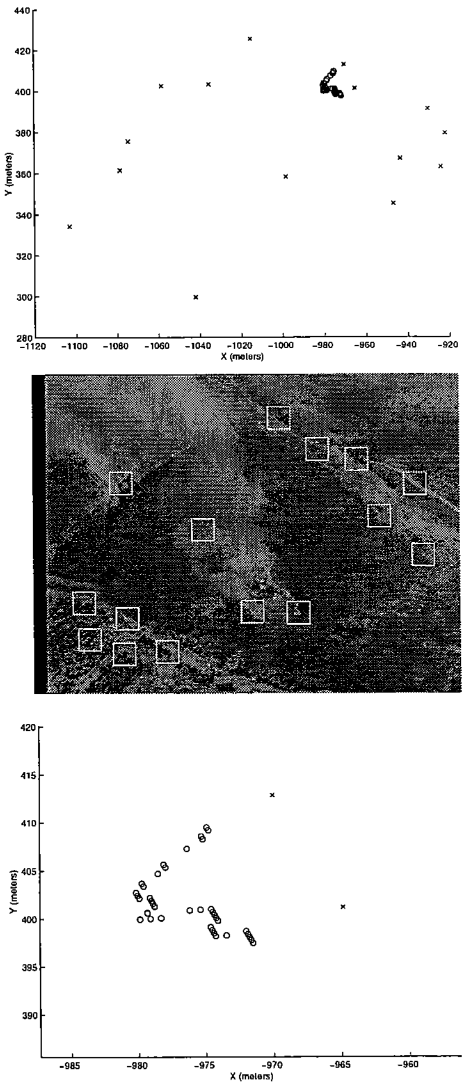

Fig. 7. Top: Points used to compute the homography ($\times$) and fire front ($\circ$). Middle: Image regions corresponding to the points. Down: Close view of the fire front geo-located ($\circ$).

In fig. 8, the fire front each 20 seconds for one of the experiments is shown (the coordinates are related to real UTM ones by a translation).

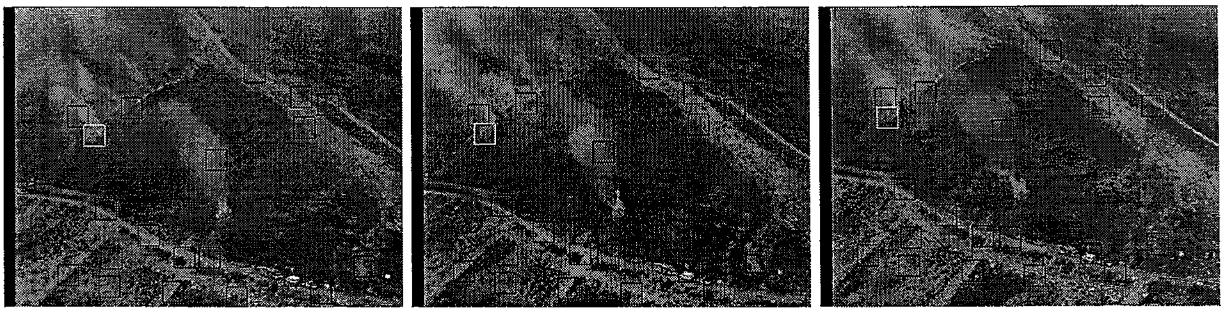

Fig. 2. Region tracking. Some of the tracked regions in 3 consecutive frames

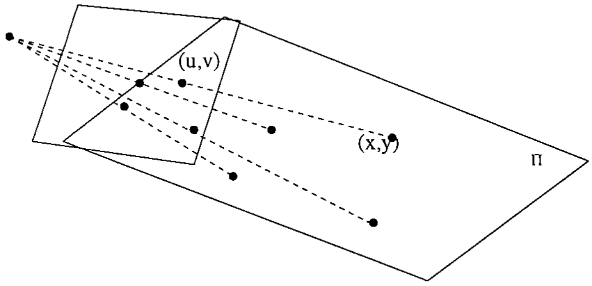

Fig. 3. Surface model employed

During the experiments considered, several artificial landmarks were placed (beacons). The positions of those beacons are known. The beacons are searched over the image plane. After that, an initial homography $\mathbf{H}_0$ is computed.

As the camera moves, the relation $\mathbf{H}$ has to be computed each time, and the corresponding points on the image plane tracked over the image sequence. The regions are tracked using a *Sum of Squared Differences* (SSD) based method. However, the artificial landmarks are only a few, and not the optimal features to be tracked (in the SSD sense). Thus, before the tracking procedure, new regions are selected. Suitable regions to track should have a good 2D structure. This can be measured by looking at the eigenvalues of tensors formed from quadrature responses of the image [6] [9], image derivative components [3][8] and others. Here the regions are selected by using the Harris measure [7]. Once the regions are selected, their geographical positions are computed by using the initial relation $\mathbf{H}_0$.

One advantage of a feature matching method is that it can deal with large displacements. Lost regions are replaced for new ones. However, if most of the regions tracked are lost, the artificial landmarks are looked again.

One important issue in the computation of $\mathbf{H}$ is to detect outliers. During the region selection step, pixels belonging to objects that moves independently could be selected. These regions would lead to wrong estimations of the homography. As in [4], each time the point with the maximum residual r_k (see (4), where $\hat{\mathbf{x}}_k$ is obtained according to (2) and (3)) in the least squares fitting of $\mathbf{H}$ is eliminated for the computation of it (if the residual is over a threshold). However, this way only one point can be eliminated each time (the other residuals are affected by the eliminated point).

$$r_k = \|\mathbf{x}_k - \hat{\mathbf{x}}_k\| \tag{4}$$

Fig. 2 shows three consecutive frames of a sequence of fire images. Also, some of the regions tracked are shown. In the images it can be noticed that one of the regions selected belongs to the smoke plume. The outlier rejection step detects that point and it will not be used during the computation of $\mathbf{H}$ (although it continues being tracked, because the region selection procedure would likely select it again if it was discarded).

The assumption of a (locally) planar surface holds for many of the experiments carried out in Gestosa (Portugal). However, if we deal with more complicated surfaces, a more complex model should be used. For instance, we could model the surface as piece-wise planar, and to compute an homography for each planar patch.

IV. Implementation

The use of aerial images has been included in a software application. In fig. 4 a screenshot of this tool can be seen:

The image processing scheme related to the aerial images is summarized in fig. 5. As a result of the processing stage, the fire front is located in geographical co-ordinates. These data can be further processed by the application to obtain another measures, such as the most advanced point from a reference, the velocity of spread, etc.

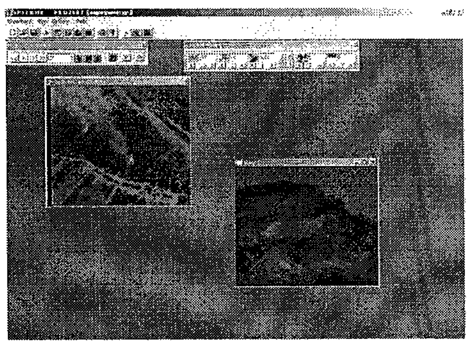

Fig. 4. View of the software application