A stereovision system for fire characteristics estimation

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ABSTRACT

This paper presents a stereovision system for the measurement of forest fire spread characteristics. Images of the scene are captured by a pre-calibrated stereo camera. A new approach is introduced in order to capture a three dimensional flame structure and to estimate important characteristics of this phenomenon like position and rate of spread of the fire front, height, length, inclination and geometry of the flame surface. Results from indoor and outdoor experiments are presented. The obtained results are promising and show the potential of using the proposed system as a metrological tool for modeling and monitoring real-life fires.

Keywords: Stereovision, segmentation, features detection and analysis, 3D modeling.

1. INTRODUCTION

Each year, devastating forest fires damage large forest areas over the world. For efficient fire fighting, the personnel in the ground need tools permitting the prediction of fire front propagation. For almost sixty years scientists have strived to understand the behavior of fire spread. Their work led to various propagation models [1], [2], [3], [4]. The experimental data of fire spread and related phenomena are necessary to produce fire models hypothesis or to validate existing ones. Information about the position of the flame front, its rate of spread (ROS), its inclination and its height partly describe the fire propagation phenomenon and are important to monitor fire propagation over time. The flame geometry is also an important characteristic in the heat transfer phenomenon. Thus it is important to evaluate this characteristic.

For more than two decades, visual and infrared cameras have been used as complementary metrological instruments in fire and flame experiments [5, 6, 7, 8, 9]. Vision systems are now capable of reconstructing a 3D turbulent flame and its front structure when the flame is the only density field in images [10, 11, 12]. Image processing methods are also applied to monitor forest fire properties like the rate of spread of flame fronts, fire base contour, flame orientation and maximum flame height [13, 14, 15, 16, 17]. These techniques extract information from a scene using multiple viewpoints (in general, frontal and lateral views) and synthesize the data in subsequent steps.

These types of processing are not suitable to obtain the height of flames belonging to a curved fire front and their inclination. Such information is fundamental in studying the spread of forest fires.

Rossi *et al.* [18] show the potential of the use of stereovision in the visible spectrum in order to obtain a fire 3D form. The authors present the algorithms used for segmenting fire areas in images captured in an outdoor complex environment. The resulting 3D model of a fire front matches closely the form of the real world fire.

This paper presents the use of a stereovision framework as a metrological system in order to estimate fire characteristics like the position, the ROS of a fire front, the flame height, its inclination and the volume of the fire. Results for indoor and outdoor experiments using the same vision system are presented.

The main contributions of this paper are a new 3D vision system for indoor and outdoor fire study including new algorithms for estimating fire characteristics: 3D position, rate of spread and height of linear and non linear fire fronts.

2. STEREOVISION SYSTEM

In this work, a Point Grey pre-calibrated Bumblebee XB3 camera was used. This camera is a trinocular multi-baseline stereo camera with an extended baseline of 24 cm. It has a focal length of 3.8 mm with 66° HFOV. The image sensor is a 1/3" Sony ICX445AQ CCD. This system is pre-calibrated for stereo processing. The image resolution is 1280x960 with a frame rate of 16 FPS. Image acquisition was developed using C++ with Point Grey Triclops SDK. This system permits the simultaneous acquisition of a pair of images of the scene. The captured images are stored for further processing using algorithms developed in Matlab®.

3. COMPUTATION OF 3D FIRE POINTS

The three-dimensional points of fire are obtained from stereoscopic images. The steps involved in the proposed approach are [8]:
Segmentation of fire images in order to extract fire regions;

- Features detection algorithm for extracting salient points from the segmented regions;
- Best features selection using a correlation based matching strategy. This step permits the refinement and selection of salient points and the construction of a set of corresponding points;
- Computation of three-dimensional fire points using stereo correspondence;

Fig. 1 shows a typical curved fire front obtained during the spread of a fire front in a laboratory inclined plan. The stereovision system was placed in the back position from the fire.

Fig. 1. Curved fire front

Figure 2 shows the 3D flame points corresponding to the above flame front. In this example, 147 points are computed. The X-axis corresponds to the width of the front flame; the Y-axis corresponds to its height, and the Z-axis to its depth. The reference frame has its origin in the left image center point of the XB3 camera.

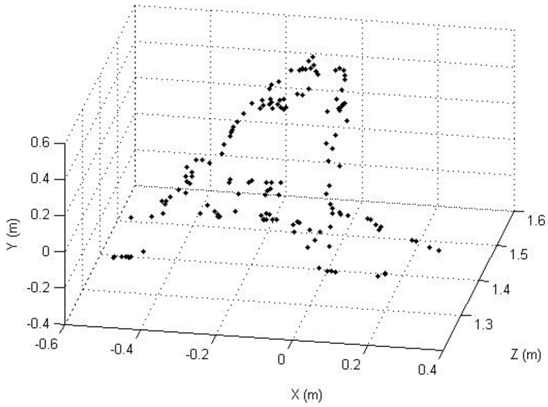

Fig. 2. Estimated 3D fire points

4. ESTIMATION OF FIRE CHARACTERISTICS

Fire characteristics are estimated using 3D points computed from fire stereo images as described in section 3.

Estimation of the rate of spread
In order to obtain information like the position, the rate of spread and the height, for complex fire situations, processing is conducted using the estimated 3D fire points.

Selection of 3D back points
Generally, the 3D flame points are irregularly distributed in space. To select the points that are in the back part of the front, the following steps are performed. The 3D points are divided into several sets along the X-axis. For each set of points, the minimum width $(Z_{\min})$ and the maximum width $(Z_{\max})$ are estimated and a limit (limitZ) is computed as follows:

$$\Delta_Z = Z_{\max} - Z_{\min} \text{ and } \quad \text{limitZ} = Z_{\min} + \Delta_Z / 2 \qquad (1)$$

The points having $Z < \text{limitZ}$ are selected and their minimum height $(Y_{\min})$ and maximum height $(Y_{\max})$ are estimated. A limit (limitY) is computed as follows:

$$\Delta_Y = Y_{\max} - Y_{\min} \text{ and limitY } = Y_{\max} - \Delta_Y / 2 \qquad (2)$$

For each set of points, we choose the points having $Y <$ limitY. These points are considered as part of the back front.

Estimation of a base plane

This procedure is conducted using 3D points belonging to the flame fronts at two successive times. The 3D selected points are used to compute a base plane with a least square method. With this procedure, ROS estimation can be applied even if the spreading area is inclined.

Estimation of the back front line

Each set of 3D back points is projected on the base plane and two 2D back front lines are computed using Bezier interpolation (Fig. 3). These 2D front lines show the position of the back part of the flame front at two successive times.

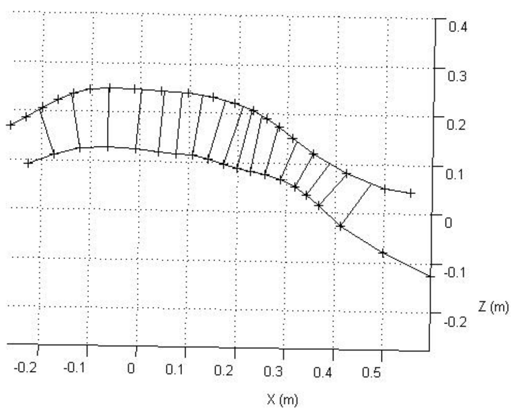

Fig. 3. Position of back front lines of two successive fire fronts.

Estimation of the rate of spread

The ROS is estimated for a set of equidistant points of the first line. For each point, the normal to the tangent vector of the line is computed and the distance between its position and the position of the point obtained by the intersection of the normal and the second front line is computed. Each point of the first line has a corresponding point in the second line and the ROS of this point is computed as the quotient of the distance between these points on the laps of time between two image acquisitions. Fig. 4 shows the corresponding points of a front line for two views with a time gap of 10 s.

Estimation of the height of the front

To estimate the height of the front, a similar method is applied. The 3D points of each flame front are divided into several sets along the X-axis. For each set of points, all the points are used to compute the minimum height $(Y_{\min})$ and the maximum height $(Y_{\max})$. A limit (limitY) is computed as follows:

$$\Delta_Y = Y_{\max} - Y_{\min} \text{ and limitY} = Y_{\max} - \Delta_Y / 2 \qquad (3)$$

The points having $Y >$ limitY are selected and a B-Spline interpolation of these points is used. The remaining points are used to estimate the average height of this part of the flame front.

Fig. 4 shows a model of a curved flame front where each subpart of the front is shown with its average height.

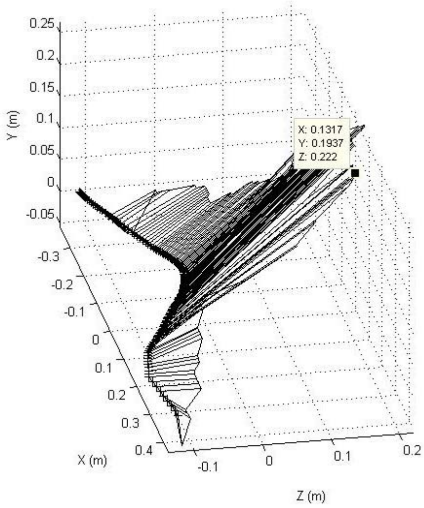

Fig. 4. Height of a fire front.

Estimation of the front inclination

The inclination of the fire front is estimated by:

$$\text{Angle } \alpha = \text{atan}(\Delta z/h) \qquad (4)$$

With Δz the difference of the z position between the bottom and the top of the flame and h its height.

Figure 5 shows the estimated inclination for the fire front presented in Fig. 1.

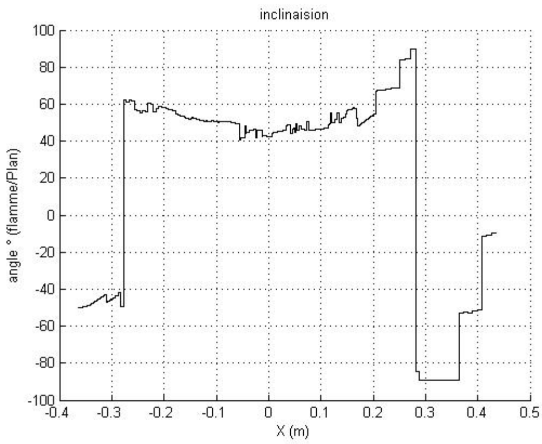

Fig. 5. Inclination of the front

Three dimensional surface rendering and volume estimation

In order to illustrate the computation of the volume of a fire, an example of outdoor experiments is considered here (Fig. 6). To perform the three-dimensional surface of this fire front, we perform the Crust algorithm in the set of obtained 3D points [19]. This algorithm works with unorganized points and it is based on the three dimensional Voronoi diagram and Delaunay triangulation. It produces a set of triangles called the crust of the sample points. All vertices of crust triangles are sample points. Fig. 7 shows the results of the Crust algorithm. In this figure, we obtain a global form of the flame front in relation with the one appearing in the Fig. 6.

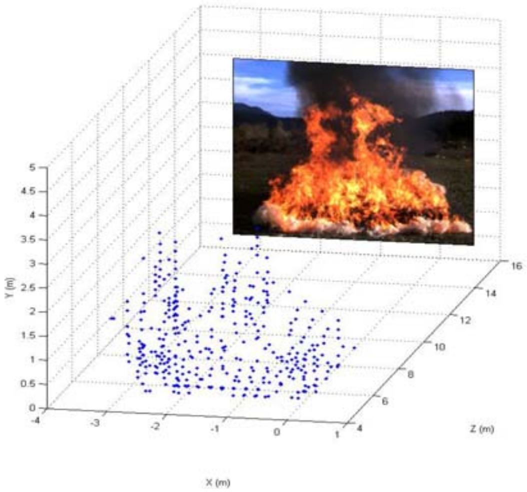

Fig. 6. Estimated 3D fire points

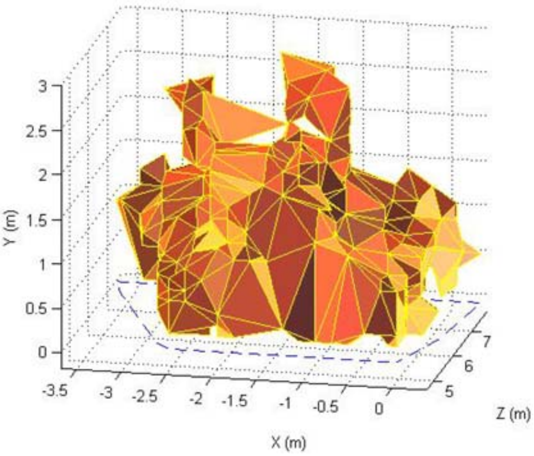

Fig. 7. 3D model approximating a fire front volume

From the 3D points, a convex hull algorithm [20] is used to compute the volume of the reconstructed shape. The stereo system was positioned at approximately 6 *m* from the fire front. The height of the fire was approximately 2.5 *m*. Figure 7 shows that the reconstruction results are in concordance with these data. The data estimated by computation are equal to 4.1 *m* for the maximum width, 2.5 *m* for the depth, 15 m^3 for the volume.

5. EXPERIMENTAL RESULTS

This section shows the results obtained with the stereovision framework presented in previous sections. Its efficiency to determine fire front position and height has been estimated by comparison with known objects positioned near the propagation zone. Human visual estimation has also been used for estimating the performance of fire segmentation and the obtained fire shape.

Figure 8 presents the temporal evolution of the fire front profile obtained during the propagation of the outdoor fire presented in Fig. 6. Conditions like wind or fuel density can modify the fire front profile during the propagation like we see in figure 9.

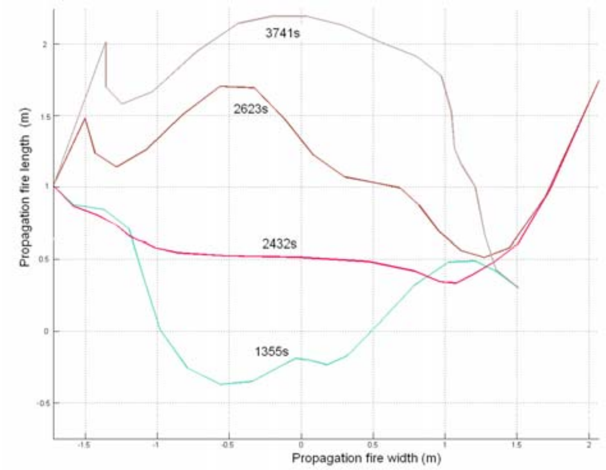

Fig. 8. Temporal evolution of the fire front profile of an outdoor propagation fire

Experiments were also conducted in order to estimate the ROS and the height of a wildland fire in Corsica (Fig. 9). The fire front was at approximately 80 m from the camera. The camera was placed in the back of the fire propagation area. The focal of the camera limits the 3D precision obtained for the most advanced points of the fire front. In our experiments, we used the obtained 3D positions of the nearest ones along with their heights for further processing (Fig. 10).

Fig. 9. Front view of the wildland fire

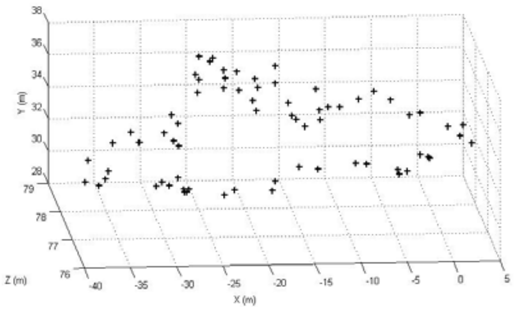

Fig. 10. Estimated 3D fire points from back view

A second camera was placed closest to the in a side-view, permitting the extraction of data from a lateral view (Fig. 11). The estimation of the 3D fire points is presented in Fig. 12.

From these points, the rate of spread of the fire and its length were estimated using the procedures described in section 4.

Fig. 10. Front view of the wildland fire

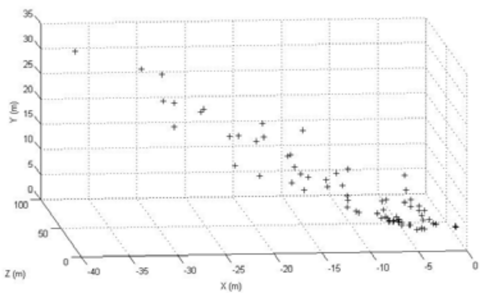

Fig. 11. Estimated 3D fire points from lateral view

6. CONCLUSION

This work proposes a promising stereovision system for the measurement of forest fire spread characteristics. The position, rate of spread, height and volume of a flame front can be estimated even in complex situations.

Future work will target the development of a fusion scheme for images obtained from multiple stereovision systems and its adaption for wildland fires.

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