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Fire Detection using Stereoscopic Imaging and Image Processing Techniques

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Abstract- **This paper presents a stereoscopic imaging technique for fire detection. A low-cost binocular CCD camera is used to acquire the stereoscopic images of a controlled gas fire. Computer algorithms are developed to segment the fire zone in the HSV (Hue, Saturation, Value) color space and to determine the correspondence points of image pairs. The location, size and propagation of the fire are then determined from the perspective relationship between the fire and the camera. Experimental results under laboratory conditions show the effectiveness of the proposed approach for fire detection.**

Keywords—Fire detection, Stereoscopic imaging, Image processing,

I. INTRODUCTION

Conventional fire detection devices are mainly based on particle and temperature sampling, and air transparency testing [1]. They are regarded as 'point sensors' where an alarm cannot be triggered till smoke particles or heat reach to the sensor, resulting in a substantial delay in the fire detection. In addition, those sensors cannot be used in open and large volume spaces (such as tunnels, warehouses, forest, etc) [1, 2]. Furthermore, they cannot give the quantitative information of the fire such as location, size and propagation without background models. With advent of image sensing and image processing techniques, vision-based fire detection techniques have received a great attention in recent years. They are regarded as volume monitoring and have much higher probability of successful early detection of fire without space constraints.

There have been some studies on vision-based techniques for fire detection, particularly for forest fire detection. Santana et al [3] described a video-based system for fire detection in which techniques such as model-based false alarms rejection, color-based fire's appearance model, wavelet-based model of fire's frequency signature and the camera-world mapping were employed for the identification of the fire from video images. Töreyin et al [4] proposed an image processing technique for fire and flame detection where a wavelet transform was used to determine the color variations in flame regions. Çelik et al [5] presented an algorithm which combines fire color information with an adaptive background model of the scene for detection of forest fire. Vipin [6] also reported an image processing technique for forest fire detection where rule based color model spaces (RGB and YCbCr) were used for fire pixel classification. An image processing technique was also introduced for automatic real time fire detection in video images where the temporal variation of fire intensity captured by a CCTV (Closed Circuit Television) camera were extracted and used for determining the presence of fire [7]. Although those algorithms can efficiently be used in fire detection with reduced false alarms, they are based on a monoscopic vision setup (i.e., using one camera with a single lens), and are generally unable to give the exact location and propagation of the fire without registered background of senses.

Stereoscopic imaging is based on triangulation of rays from multiple viewpoints (similar to human vision) and can provide a 3-D (three-dimensional) measurement in a dynamic environment [8] through the perspective relationship between the measured object and the imaging system. Previous attempts have been made to use stereoscopic imaging techniques for fire measurement. Ng and Zhang [9] used a single camera with a stereo adapter to performing flame stereoscopic imaging and reconstructed successfully the 3-D surface of an impinging diffusion flame. Rossi et al [10] proposed a real-time stereovision system for the 3-D modeling of outdoor fires where the dynamic characteristics of fire such as position, orientation and dimension can be determined. They also conducted field experiments on the stereoscopic measurement of the geometric characteristics of a fire front [11]. Although various progresses have been made, fire detection still faces significant challenges for reducing false alarms, increasing sensitivity and dynamic response in open and large volume spaces.

The present study aims to develop a stereoscopic imaging and image processing technique for fire detection. A low-cost binocular CCD camera is used to acquire stereoscopic image pairs of a fire. Algorithms are developed for computing the disparity of the image pairs and so the depth of the fire is determined based the stereoscopic principle. Fire information,

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such as location, area and propagation can then be obtained. Preliminary experimental results are presented and discussed.

II. Methodolgy

Binocular stereoscopic imaging uses two offset imaging sensors to generate pairs of stereo images, i.e., left and right images for creating the 3-D visual effect of an imaged object. Fig. 1 illustrates the schematic diagram of the stereoscopic imaging principle for fire detection. Two imaging sensors observe simultaneously an object (fire, in the case of study) from two slightly differed points of view. Two parallel optical axes represent the optical paths of the sensors. The focal length of the camera lens is *f*. *b* is the distance between the two optical axes. C_l and C_r represent the optical centers of the left and right sensors, respectively. O_l and O_r are the principle points of the left and right optical planes, respectively. $P(X_o, Y_o, Z_o)$ represents a point on the object with the distance to the optical plane, *z*. $p_l(x_l, y_l)$ and $p_r(x_r, y_r)$ are the projections of *P* on the left and right image planes, respectively (so called correspondence points).

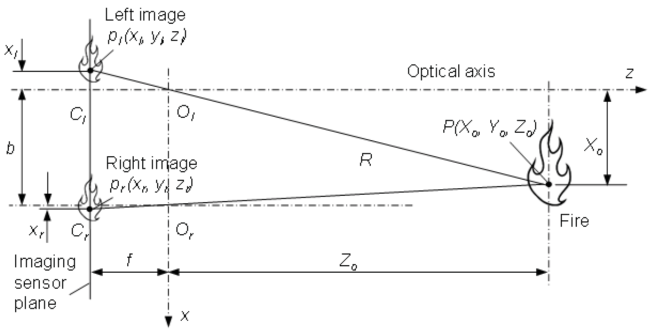


Fig. 1. Schematic diagram of stereoscopic imaging for fire detection.

According to the principle of similar triangles, we get,

$$x_l = -X_o \frac{f}{Z_o}, \tag{1}$$

$$x_r = (b - X_o)\frac{f}{Z_o}, \tag{2}$$

and,

$$y_l = y_r = Y_o \frac{f}{Z_o}, \tag{3}$$

where X_o, Y_o and Z_o are the coordinates of point *P* in the x_l-O_l-z coordinate system. x_l, is the x-coordinate of p_l in the x_l-O_l-z coordinate system and x_r is x-coordinate of p_r in the x_r-O_r-z coordinate system. Rearranging equations (1) and (2) yields,

$$Z_o = \frac{bf}{x_r - x_l}. \tag{4}$$

Let,

$$d = x_r - x_l, \tag{5}$$

we get,

$$Z_o = \frac{bf}{d}, \tag{6}$$

where *d* is called disparity. Equation (6) illustrates that, when *b* and *f* are fixed, coordinate Z_o is inversely proportional to the disparity *d*. The distance from the origin (O_l) to the point *P*, *R*, is then given by,

$$R = \frac{b\sqrt{f^2 + x_l^2 + y_l^2}}{d}. \tag{7}$$

Equation (7) is called the true range equation and can be worked out from corresponding pixel coordinates in the left and right images. The disparity *d* is generally very small compared to *R*, and so a small error in determining disparity in the two images can result in a large error in the measurement. A careful camera calibration is therefore required to ensure an accurate image acquisition and processing.

III. Experimental results and discussion

A. Camera and experimental setup

A binocular CCD camera (Fuji FinePix Real 3-D W3) was employed in this study to acquire fire images. The technical specifications of the camera are summarized in Table 1. The camera has two identical lenses and CCD sensors which ensure images of the fire can be simultaneously.

Table 1. Technical specifications of the binocular CCD camera [12].

Parameter	Specification
CCD sensor	1/2.3-inch CCD×2
Focal length (mm)	f=6.3-18.9
Lens	Fujinon 3×optical zoom lens, F3.7 (Wide)-F4.2 (Telephoto)
Shutter speed (sec)	1/4-1/1000
Aperture	Wide: F3.7-F8.0, Telephoto: F4.2-F9.0
Shooting mode	SP mode, ADV 3D, ADV 2D

Fig. 2 shows the experimental setup where a gas camping burner was used to generate a fire flame in a large engineering laboratory with a complex background. In the test, the camera was fixed and the burner was moved along a sliding rail for different locations. Pairs of stereo images of fire flame were captured and transferred to a PC. Fig. 3 shows a pair of stereo images of the fire in the experiments.

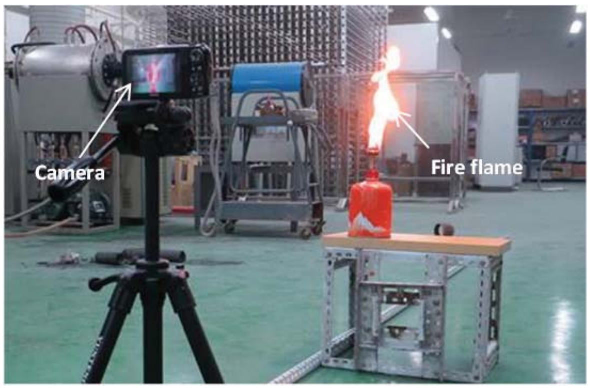


Fig. 2. Experimental setup.

(a) Left (b) Right

Fig.3. A pair of stereo images of fire flame.

B. *Camera calibration*

The camera has to be calibrated in order to determine the parameters of transformation between an object in the real world and its images taken by the camera. The algorithm proposed in [13] was employed for the calibration of the camera in this study. The transformation parameters calibrated include: a) extrinsic (external) parameters which are orientation (rotation) and location (translation) of the camera *(R, t)* relating the world coordinate system to the camera coordinate system; and b) intrinsic (internal) parameters which are the characteristics of the camera such as the coordinates of the principal point $O_l(u_o, v_o)$, scale factors in image axes (α, β) and the skewness of the two image axes (γ). The full description of the calibration algorithm can be found in [13]. In comparison to classical techniques such as photogrammetric calibrations and self-calibration, this algorithm is simple, flexible and robust. The calibration procedure can be summarised as follows,

a) Print a planar template;
b) Take the images of template under different orientations by moving either the template or the camera;
c) Determine feature points in the images;
d) Estimate the intrinsic and extrinsic parameters using the closed-form solution;
e) Estimate the coefficients of the radial distortion by solving the linear least-squares;
f) Refine all parameters by minimizing.

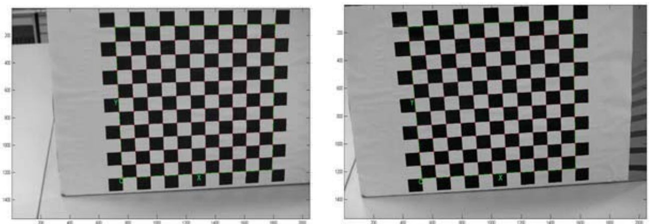
In this study, the determination of the principal points, i.e., origins of the left and right optical plane $O_l(u_{ol}, v_{ol})$ and $O_r(u_{or}, v_{or})$ is crucial. Once they are determined through the calibration, equations (6) and (7) can be rewritten as,

$$Z_o = \frac{bf}{[(u_{0r} - X_r) - (u_{0l} - X_l)]dx}, \tag{8}$$

$$R = \frac{b\sqrt{f^2 + (u_{0l} - X_l)^2 d_x^2 + y_l^2}}{[(u_{0r} - X_l) - (u_{0r} - X_r)]dx}, \tag{9}$$

where X_l and X_r are the x-coordinates (in pixel) of projection points p_l and p_r in the image plane. dx is the pixel size in mm/pixel.

The Matlab camera calibration toolbox [14] was used to perform the camera calibration. Fig. 4 shows example images of the template plane taken by the camera during the calibration. The images were taken at 24 different angles of view. The corner points were detected as the intersection of straight lines fitted to each square (22mmx22mm). Once the coordinates of the origin is selected, the coordinates of each corner point can be computed (as marked in Fig. 4). They were then used to calculate the camera parameters.



(a) Left (b) Right

Fig. 4. Images of the template planes.

Table 2 shows the extrinsic and intrinsic parameters of the camera obtained through the calibration. The results show that the two optical axes of the imaging sensors are not ideally parallel to each other. In this study, however, the effect due to this minor difference on the measurement results is considered to be insignificant.

Table 2. Extrinsic and intrinsic parameters of the camera.

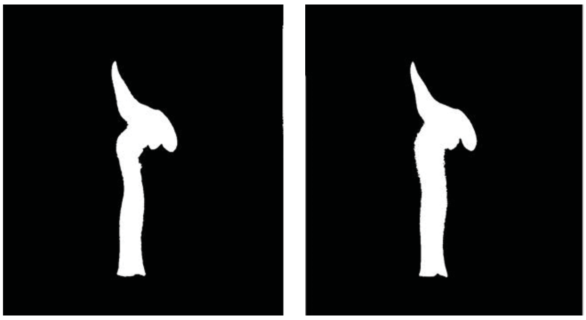
Parameter	**Value**	
	Righ camera	Left camera
Focal length (pixel)	2413	2463
Coordinates of principal points O_l, and O_r (pixel)	(1023, 786)	(992, 795)
Skewness of two image axes *(γ)*.	90°	90°
Rotation vector *(R, radian)*	[0.00558, -02388, 01474]	
Translation vector *(t, mm)*	[75.8, 0.14, -0.44]	

C. *Image segmentation and matching*

In order to determine the location of the fire using the stereo spectroscopic algorithm, pairs of characteristic points in the fire images have to be identified. Image segmentation and matching were then performed. These were done by transforming RGB images into a statistical HSV (Hue, Saturation, Value) color space where fire color information can be used for the quick extraction of fire zone [15]. A mathematical morphology technique was then applied to segment the fire zone. The technique is based on the field of set theory which can effectively eliminate small holes and smooth the edge over the images [16]. Fig.4 shows the segmented images of the original fire images in Fig. 3. As can be seen, the proposed algorithm can effectively extract the fire zone from a noisy background.

A Scale Invariable Feature Transformation (SIFT) matching algorithm [17] was used to locate the correspondence points in each pair of the stereo images. In points matching, for a feature point in the left (or right) image, the Euclidean distances of all the feature points in the right (or left) image were calculated. The ratio of the minimum distance (d_{min}) and the second-closest distance (d_{sec}), i.e., *distance ratio*=d_{nim}/d_{sec}, was used to identify whether the key points are correctly matched [17], i.e.,

If *distance ratio≤0.8*, it was regarded to be correctly matched; and If *distance ratio>0.8*, not matched. The threshold 0.8 was chosen based on a large database of feature points from images. Fig. 5 shows the matching results of a pair of segmented images where 10 feature points were given.



(a) Left (b) Right

Fig.4. Segmentation of flame images in Fig. 3.

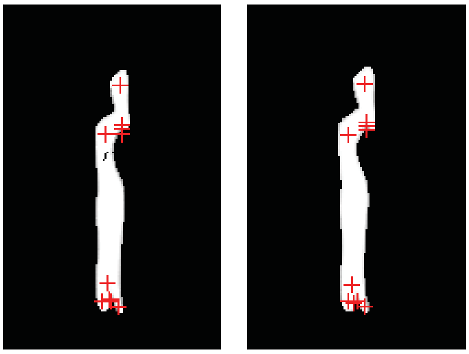


Fig. 5. Matching result of a pair of segmented images.

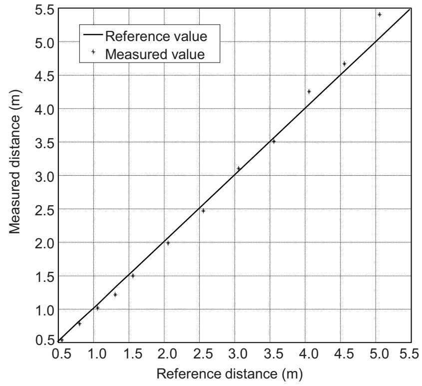
D. Determination of fire distance to the camera

The stereoscopic algorithm described in section II was implemented in Matlab program. The images of fire flame obtained at twelve different distances were processed. Disparities were then computed from feature points in the fire zone in each pair of stereo images. Fig 6 gives the measured distances from the fire flame to the camera and the relative errors of the measurement. It has been found that for the points detected the relative errors are no greater than 6.8% in comparison to the reference distance.

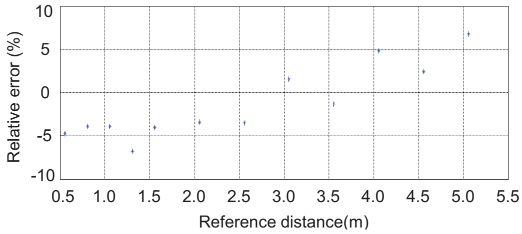
The area of a fire is also an important parameter which can be used to assess the propagation of the fire. Once the location of the fire is determined, its area can be computed by,

$$S = S'(\frac{z}{f})^2, \tag{10}$$

where S is the area of fire and S' is the image area of the fire. Fig. 7 shows the original images and segmented area of the fire flames taken for three different fuel flow rates (low, medium and high,) at the fixed distance (*z=655mm*), simulating the development of a fire. The calculated areas of fire are $S_{low}=1071.2mm^2$, $S_{med}=1966.9mm^2$, and $S_{high}=777.6mm^2$. In practice, once the time difference of two successive image frames is known, the propagation of the fire can easily be determined by computing the rate of change in its area.



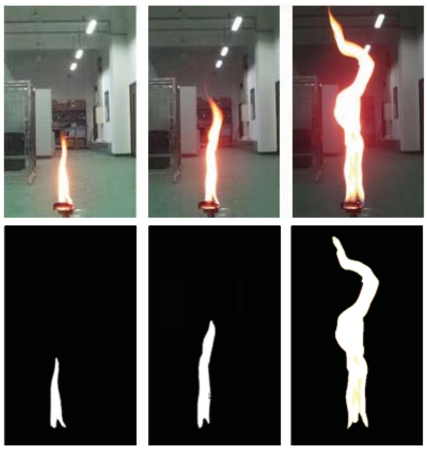
(a) Measured distance.



(b) Relative error.

Fig. 6. Measured distance from the fire to the camera.

It has been recognized that false alarms caused by moving bright objects (different velocities and sizes) and alternating light conditions (artificial lights) can be a problem in imaging based fire detection systems. This can be solved by integrating additional measurements in the image detection. For instance, the flicker frequency is considered to be one of important properties of fire which differs from that of other lighting sources [7]. The flicker frequency can be measured and used as a criterion to assess if the object detected is a fire or not.



(a) Low (b) Medium (c) High

Fig. 7. Original images and segmented areas of the fire for three different fuel flow rates.

IV. CONCLUSIONS

A stereoscopic imaging based technique for fire detection has been presented. A low cost binocular camera is used to acquire pairs of stereo images of fire flames. A morphology algorithm working in the HSV (Hue, Saturation, Value) color space has been performed for the quick extraction of fire area. SIFT (Scale Invariable Feature Transformation) algorithm has then been used to extract and match feature points in the fire zone. The location, size and propagation of the fire have then been determined based on the perspective relationship between the fire and the camera. Experiments carried out under different laboratory conditions have shown that the relative error for the distance detection is no greater than 6.8%. It has been evident that the technique proposed can provide quantitative measurement of fire flames.

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