TELKOMNIKA, Vol. 11, No. 10, October 2013, pp. 5563 ~ 5570
ISSN: 2302-4046

Video Fire Detection Algorithm using Multi-Feature Fusion

Mengxin LI, Weijing XU*, Ke XU, Jingjing FAN, Dingding HOU
School of Information and Control Engineering, Shenyang Jianzhu University
Shenyang 110168, China,024--24692899
*Corresponding author, e-mail: 357557997@qq.com

Abstract

At present, the moving target detection and flame characteristics extraction almost become the most important parts in majority of video fire detection systems. Through the above two-part study, a new fire features detection method is presented in precise moving target area. That is, using the improved background difference method and flame features (such as the color and uniformity, Wavelet energy, stroboscopic and contour features) to detect fire. Experiments show that this method can improve the accuracy and anti-interference ability of fire detection.

Keywords*: video image; moving target detection; flame Multi-Feature; color feature; stroboscopic feature*

1. Introduction

With the rapid development of social economy and urbanization, the fire situation in China, especially in the urban construction, fire is becoming more and more serious. How to effectively reduce the incidence rate and the loss caused by fire is a significant research.

Currently, some places have adopted some mature fire detection methods, such as smoke, temperature and other fire detectors. however, in the various groups of the tall building spaces or outdoor areas, the detection signal will be weak and difficult to play an effective role in early warning as the distance becomes larger. And these methods are easily affected by environmental factors. Therefore, digital image processing techniques can be used to overcome the shortcomings of high false alarm rate, poor real-time performance and strong dependence on environment.

At present, many scholars have carried out a lot of researches on fire detection by using the digital image processing techniques. SunJae Ham et al. [1] proposed a fire-flame detection method using probabilistic membership function of visual features and Fuzzy Finite Automata (FFA). Peixun Liu et al. [2] put forward the algorithm that extracts the suspected flame region through the conditions of three visible lights. In order to further improve the accuracy of fire detection, a fire detection algorithm by using an accurate moving target and flame multi-feature fusion has been proposed in this paper.

2. Moving Region Detection

2.1. Background Difference Method

Because of the extraction of moving target region can affect detection results seriously [3], the extraction of dubious moving target region become one of the most important parts. Background difference method is a widely used for detecting moving objects. It not only can detect a complete moving target with fast calculation, but also can filter out the non-moving subject with slight movement in a certain extent.

The idea of background difference method is getting the difference image from the difference between the current frame and background frame, and then binarizing the obtained difference image by selecting an appropriate threshold value. So the moving object can be divided. This is one of the most simple and effective methods to detect moving target. The formula is as follows:

Received April 15, 2013; Revised June 21, 2013; Accepted July 10, 2013

$$D(x,y)=\begin{cases}255 & if\ d=|I(x,y)-B(x,y)|\geq T\\ 0 & if\ d=|I(x,y)-B(x,y)|<T\end{cases} \quad (1)$$

Where $D(x,y)$ is difference image, $I(x,y)$ is current frame, $B(x,y)$ is background frame, and T is the threshold to divide moving object from background image.

The constant change of the background makes the acquisition and updating of background model become the key part. So the background image must be updated before each calculation of the difference image. The current background image is obtained from the previous background image and the current image. And the first frame of the original image sequence is set to be the first frame background image. The update formula is as follows:

$$B_{n+1}(x,y)=\begin{cases}aB_n(x,y)+(1-a)I_{n+1}(x,y) & (x,y)\text{stationary}\\ B_n(x,y) & (x,y)\text{motive}\end{cases} \quad (2)$$

Where $B_{n+1}(x,y)$ and $B_n(x,y)$ represent the gray values of two neighboring background images at a same (x,y) pixel location; $I_{n+1}(x,y)$ is said to be the intensity value at pixel position (x,y) in the current image. If the values of $B_n(x,y)$ and $I_{n+1}(x,y)$ are different, we can say that the pixel (x,y) is motive, otherwise is stationary.

The α in equation (2) is the update parameter. It can reflect the influence degree that the original background image and the current image have made to the current background image. If the value of α is too small, the non-moving subject with slight movement is more likely to be separated from the background. But if the value is too large, it is not sensitive to the moving subject with slight movement with the algorithm.

2.2. Improved Background Difference Method

In order to avoid the non-moving subject with slight movement separated from the background as the motive target, we usually set a large value of α in background updating. But in the early stages of the fire, it is difficult to detect the flame with weak and slow changes. According to the above problem, an improved background difference method is put forward.

Firstly, the first frame in video image sequence is introduced to the process of background updating. That is, a background reference in a long time interval is added to the background updating. So the flame with weak and slow changes won't be filtered out as a background image [3].

Secondly, as the background is updated continually, in order to get more accurate moving subject, the threshold is updated with the updating of background. The improved background difference method can be expressed as:

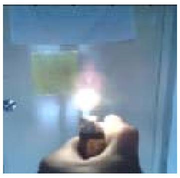
$$B_{n+1}(x,y)=\begin{cases}aB_n(x,y)+bI_{n+1}(x,y)+(1-a-b)B_1(x,y) & (x,y)\,stationary\\ B_n(x,y) & (x,y)\,motive\end{cases} \quad (3)$$

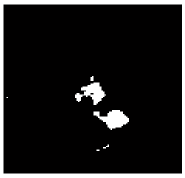
$$T_{n+1}(x,y)=\begin{cases}aT_n(x,y)+(1-a)(5\times|I_{n+1}(x,y)-B_n(x,y)|) & (x,y)\,stationary\\ T_n(x,y) & (x,y)\,motive\end{cases} \quad (4)$$

where $B_n(x,y)$ is the previous estimate of the background intensity value at the same pixel position; $B_1(x,y)$ is set to the first image frame; $T_n(x,y)$ represents the previous threshold before updating and $T_{n+1}(x,y)$ is the current threshold after updating. The sum of the update parameters α and b is a positive real number close to one.

The moving target detection results obtained with the improved background difference and the original background difference methods are listed as:


(a) Original image


(b) Current image


(c) Foreground before improving


(d) Foreground after improving

Figure 1. Detection results of foreground object

Experiments show that the proposed improved background difference method can extract moving subject more accurately and meticulously than the original background difference method.

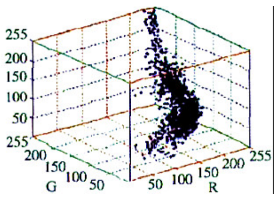
The moving subject extracted by using the improved background difference method includes not only the flame, but also some other moving objects. So how to detect whether the foreground object is flame or not is an important part.

3. Extraction and Detection of the Fire Features

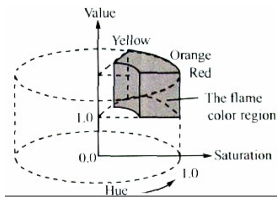
Flame has many significant features different from other objects, such as the color, energy, stroboscopic, and contour features [4]. So these integrated features can be used to detect fires.

3.1. Extracting the Color of Fire Flame

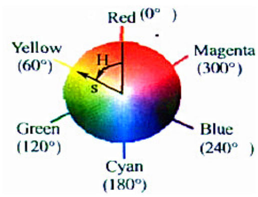
The color information is an important static feature of the flame [5]. A large number of experiments on fire-colored pixels have shown that the hue of fire-colored pixels is in the range of 0^o and 60^o [6] [7] as follows:



(a)RGB cube of fire-colored pixels



(b) HIS cylinder of fire-colored pixels



(c) Hue of fire-colored pixels

Figure 2. Fire-like color models in different color spaces

Since fire is a light source its pixel values must be larger than some threshold. The RGB domain equivalent of this condition [8] is

$$R(i,j) > G(i,j) > B(i,j) \quad (5)$$

$$R(i,j) > R_t \quad (6)$$

Where R_t is the threshold of the red channel.

The last rule is about saturation:

$$S > (255 - R) \bullet S_t / R_t \quad (7)$$

Where S is the saturation value of a pixel and S_t is the saturation value of this pixel when R is R_t .

As there are many objects with flame color, the calculation of color uniformity in suspicious area is added to further eliminate interference objects that have flame color. This can narrow the scope of testing and improve the real-time of detection system.

In flame images, the value of R channel in the RGB has the very high saturation, so the value of G or B can be selected to determine uniformity. Take the G color channel as an example, the specific color uniformity is calculated as follows:

- Filtering the matrix B with a 3 × 3 matrix to obtain the difference between the maximum and minimum $(\max G - \min G)$ in eight neighborhoods.
- Calculating the threshold Th by using Otsu method.

$$Th = \arg \max_{0 \le q \le L-1} [\omega_0(q)(\mu_0(q) - \mu)^2 + \omega_1(q)(\mu_1(q) - \mu)^2] \quad (8)$$

Then

$$TH = Th * (\max G - \min G) + \min G \quad (9)$$

- Calculating uniformity ratio

$$Rate = \frac{sum(\mathrm{Re}\,gion)}{sum(region)} \quad (10)$$

Where Region is the total area of *G* value which is greater than *TH.* And those non-flame objects with flame color will be excluded according to the rate of uniformity.

3.2. Extracting the Energy of Fire Flame

The real fire, whose internal pixel values have great changes, which can be described by the edge energy of spatial wavelet. So analyzing the changes of internal pixel values through the space wavelet energy to detect the fire is also one of the flame detection methods.

The idea can be described as follows: first, get the detail components on the horizontal direction (H), vertical direction (V), and diagonal direction (D) through the original image wavelet transform. Then the spatial wavelet energy will be calculated by the formula (11):

$$E = \frac{1}{M \times N} \sum_{[i,j] \in (M,N)} \left|P_H[i,j]\right|^2 + \left|P_V[i,j]\right|^2 + \left|P_D[i,j]\right|^2 \quad (11)$$

Where E is the energy of space wavelet, $P_H[i,j]$, $P_V[i,j]$, and $P_D[i,j]$ are the sub maps on horizontal, vertical, and diagonal direction. (M,N) is the suspicious movement area with flame color. And $M \times N$ is the number of pixels. There is a threshold E_0 to detect the flame area. When $E \ge E_0$, this area can be thought as a flame area.

3.3. Extracting The Stroboscopic Feature of Fire Flame

As other objects with the above features may also be detected as flame, the flame stroboscopic feature caused by a strong infrared radiation is adopted. From the long-term experiments on flame flickering phenomenon, it is carried out that the fire flicker frequency can be set from 10 HZ to 20 HZ in a low frequency area [9]. There must be some height changes in the front and rear frame images because of the flame flickering and jumping. So the changes of flame height can be thought as a condition of calculating the flame flicker frequency. The steps about this determination method are as follows:

Firstly, Mark a collection of heights in suspicious areas, then describe elements in the collection, finally work out a characteristic function about altitude changes to reflect the component within the spectrum [10].

$$h_q^p = H(G_q^p) \quad (12)$$

Where, there are p different height values in first q frame.

Secondly, get each height element through the Discrete Fourier Transform. And the elements within the collection can be described as:

$$t_q^p = d(H) = \frac{1}{k}\sum_{q=1}^{k} h_q^p e^{-j2\pi iqlk} \quad (13)$$

Finally, obtain a characteristic function about altitude changes by using the integration operation.

$$f_d(T^p) = \sum_{q=2}^{l/2} \frac{t_i^p t_i^{p'}}{l/2-1} \quad (14)$$

Where l is the length of the Fourier transform, T^p represents a collection of Fourier transform coefficients. Therefore, the height changes in a specific time period can be expressed from the above formula. And whether there is a flame in the suspicious area can be determined successfully.

3.4. Extracting the Contour Feature of Fire Flame

As the lights and other luminous objects are very similar to the flame features, the contour feature of fire flame can be used to distinguish such interference. Generally, the contour feature can be described as the circularity feature [11]:

$$C_i = \frac{4\pi S_i}{P_i^2}, i = 1,2,...,k \quad (15)$$

Where C_i, S_i and P_i are circularity, area, and perimeter of the first I object. K is the number of objects. The four-domain edge detecting algorithm is used to calculate the flame edge contour. The specific method is as follows:

First, open up a memory area to store the temporary image. The width and height of the processed image plus two are set to the width and height of the temporary image. And all the bytes in memory area should be cleared.

Second, copy the processed image to the center of temporary memory area.

Third, check each pixel of the temporary image in order. If the value is 255 (white), then check the four adjacent pixels of its top, bottom, left and right. If all the four values are 255(white), then the current pixel value in the processed image will be set to 0(black). So the edge contour of the processed image can be obtained and then the perimeter P_i will be calculated.

At last, calculate the circularity with the area and perimeter. There is a certain threshold value C_0 in this paper, the area is not flame area while $C_i \geq C_0$, and it is flame area while $C_i < C_0$.

4. Experiments

Since the flames in different environments have different characteristics, a variety of video images in different scenes are used in the following experiments.

For color feature detection: In Figure 3, (a) is original image; (b) is binarized image of moving object. The moving object includes flame and lighter shell. However, the lighter shell is filtered out successfully through the detection of color feature as Figure 3(c). Figure 4 is also listed to show the uniformity of flame region and yellow clothes region. It is obvious to see that the uniformity of the flame region is much lower than the uniformity of yellow clothes.

(a) Original image (b) Moving object (c) Moving object with flame color

Figure 3. Extraction of moving object with flame color

(e) Uniformity of flame region (f) Uniformity of yellow clothes region

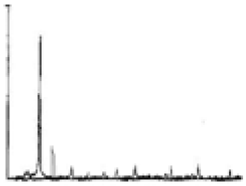
Figure 4. Uniformity of flame region and yellow clothes region

For spatial wavelet energy detection: In Figure 5, (a) is original image; (b), (c), (d) and (e) are sub-band images of low frequency, horizontal, vertical and diagonal direction. It's clear that the spatial wavelet energy of flame area is much larger than the rest area. The spatial wavelet energy E can be calculated as 1.027×10^{6} according to the formula (8), which is bigger than the threshold E_0 (According to related information and experiments, the threshold E_0 can be 1×10^{5}).

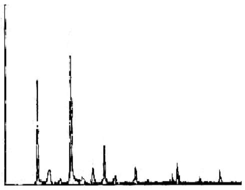
(a) Original image (b) Low frequency image (c) Horizontal image (d) Vertical image (e) Diagonal image

Figure 5. The result of Wavelet transform

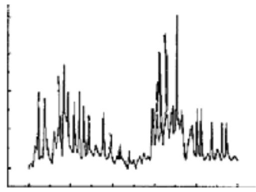
For stroboscopic feature detection: In Figure 6, (a), (b) and (c) are the spectrum changes of street light and headlight and flame. From the three images, it's easy to see that the spectrum changes of flame are much more frequent than those changes of street light and headlight. Therefore, the flame with much spectrum changes can be found out easily.



(a)Spectrum changes of street light



(b) Spectrum changes of headlight



(c) Spectrum changes of flame

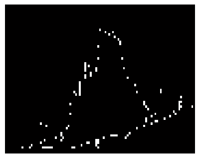
Figure 6. Figure of spectrum changes

For contour feature detection: In Figure 7, the circularity of flame area calculated from four-domain is 0.2043, and calculated from sobel is 0.3182, so they are both smaller than the threshold of 0.5. It is considered as a flame area. The circularity of light area calculated from four-domain is 0.9864, and calculated from sobel is 0.9734. It's obvious that the two values are much bigger than the threshold of 0.5. So the possibility of fire signal is excluded successfully.

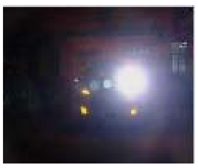
(a) Image of flame

(b) Mark of flame area

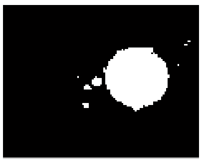
(c)Contour got from four-domain



(d) Contour got from sobel



(e) Image of non-flame



(f) Mark of non-flame area

(g)Contour got from four-domain

(h)Contour got from sobel

Figure 7. Calculating the contour of flame and non-flame

In this paper, 60 images of different scenes have been selected in the experiments, including the flame images indoor or outdoor, light images, cigarette butt images and non-flame images. From experimental result, the weak flame image in a strong wind is undetected in the outdoor flame images. And the image of red clothes moved by the wind is detected as fire incorrectly in the 15 non-flame images. There is not any false detection in the 15 indoor flame images and 15 light and cigarette butt images. The experimental results are shown in Table 1:

Table 1. Experimental result of the images in the different scenes

scene images	image frames	frames with the features of flame				frames detected as flame	accuracy of detection
		color and uniformity features	Wavelet energy feature	stroboscopic feature	contour feature		
outdoor flame	15	15	14	15	14	14	0.933
indoor flame	15	15	15	15	15	15	1
light and cigarette butt	15	5	6	4	2	0	1
non-flame	15	5	5	3	9	1	0.933

5. Conclusion

The improved background difference method is used to increase the accuracy of moving target detection. And the integrated features of flame (such as the color and uniformity, Wavelet energy, stroboscopic and contour features) are used for improving recognition accuracy of fire. This fire detection method with integrated features in an accurate moving target area can detect the fire signal in a variety of different scenes. It can be applied to both complex background and indoor or outdoor environments with lower error rate, higher recognition rate and certain anti-interference ability.

References

[1] Sun Jae Ham, Byoung Chul Ko, Jae Yeal Nam. “Fire-flame detection based on fuzzy finite automation”. *Pattern Recognition (ICPR), 2010 20th International Conference*. 2010; 3919 - 3922.

[2] Liu Peixun. “All-weather fire detection system based on video surveillance”. Master degree thesis. Jilin University. 2011.

[3] Rule HUANG. *Research on forest fire smoke recognition based on video images.* Beijing Forestry University. 2011.

[4] Zhiying ZHANG. *The research of fire detection technology in video monitoring system.* University of Electronic Science and Technology of China. 2010.

[5] Aijun XU, Luming FANG, Xiongwei LOU. Forest fire identification algorithm based on a visible light video. *Journal of Beijing Forestry University*. 2010; 32(2): 14-20.

[6] Lei SHENG, Kejun XU. Design and realization of real-time video-processing platform based on DSP and FPGA. *Journal of University of Science and Technology of China*. 2006; 36(3): 304-308.

[7] Yunyang YAN, Zhibo GUO, Hongyan WANG. Fire detection based on feature of flame color. *Pattern Recognition, 2009. CCPR 2009.* 2009; 4-6: 1-5.

[8] Shuen LU. *Research on fire detection rules based on flame recognition.* Chongqing University, 2009.

[9] Jinhua ZHANG, Jian ZHUANG. A Flame Detection Algorithm Based on Video Multi-feature Fusion. *Lecture Notes in Computer Science*. 2006; 38(2): 784-792.

[10] Sail Prabhakar. Fingerprint Classification and Matching Using a Filter Bank, A Dissertation for the degree of Doctor of Philosophy. *Michigan State University,* 2009.

[11] Wei HU, Huiqin WANG. Image fire detection technology based on DSP. *Modern Electronics Technique.* 2010; 17: 166-168.

[12] Celik T, Demirel H. Fire detection in video sequences using a generic color model. *Fire Safety Journal*. 2008; 2-11.

[13] Huijing LIU, Hui LIU, Hong LIN. Implementing fire detection based on machine vision and gaussian mixture model. *Process Automation Instrumentation.* 2012; 33(3): 60-62.

[14] Jing HOU, Mengxin LI, Languang ZHAO. A region-based image matching algorithm combining global and local features. *Journal of Shenyang Jianzhu University (Natural Science).* 2012; 28(2): 380-381.