Experimental Discussion on Fire Image Recognition Based on Feature Extraction

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Abstract. Video image-based fire detection technology can overcome some shortcomings of traditional fire detection, and has a good development prospect. This paper summarizes the basic principles of image-based fire detection, and analyzes the main features of fire combustion images. According to these features, firstly, the inter-frame difference method and the watershed algorithm are used to extract the suspected fire image area which may occur. Then, the features of flame image in early fire stage, such as increasing flame area, fluttering edge, irregular shape and flame color, are used as fire recognition criteria. Meanwhile, various image processing technologies and algorithms are used to extract the four main features of the fire, so as to eliminate various sources of interference and further determine whether a fire has occurred. Finally, a variety of different fuels were selected under indoor conditions to simulate fire experiments under different conditions, and the video was recorded. Fire recognition experiments were carried out using experimental videos and some videos found on the Internet. The experimental results show that the extraction and further recognition of suspected fire areas are both effective. However, the experimental simulation environment is relatively simple, and many theoretical and practical problems need to be further studied and solved.

Keywords: Feature Extraction, Region Segmentation, Fire Recognition, Image Processing, Fire Flame

1. Introduction
When a fire occurs, if the fire can be detected in time and emergency measures can be taken in the early stage, the loss can be reduced to the greatest extent. Traditional fire detectors mainly judge whether a fire has occurred through signal processing and comparison of parameters such as temperature, flame and combustion gas. Different types of fire detectors are suitable for different occasions and naturally have their own limitations, they are inevitably restricted by the working environment, and are prone to false alarms and under-reports, and it is difficult to accurately detect and warn the fire in time. In order to solve these problems, relevant institutions and researchers at home and abroad have carried out various exploration and research work, and made a lot of achievements. In recent years, fire image detection technology has been widely concerned by the fire science and engineering circles at home and abroad and developed very rapidly [1]. Video image-
based fire detection technology is a new technology, which shows advantages in many aspects. The richness and intuitiveness of image information can not be provided by any other fire detector. Through image processing, we can observe the occurrence of fire in time. Abundant image information has laid a solid foundation for identifying and judging the occurrence of fire, which can not be achieved by other fire detection technologies. At present, there are two main categories of image-based fire detection methods: fire detection based on traditional image processing and fire detection based on deep learning. The former mainly combines image processing and pattern recognition technology, firstly, the suspected flame area is segmented, and then features are extracted from the area, finally, the pattern recognition technology is used to classify and identify these features to complete the fire detection work. Meanwhile, the latter is to send the original image data to the network model for training, and use the trained model to identify the measured data. All roads lead to Rome, but the latter simplifies the feature extraction work of the former. In this paper, we adopt the feature extraction method for fire image recognition. That is, a video camera is used to monitor the target area, and the suspected fire images are extracted from the surveillance video and analyzed. By extracting multiple feature parameters of the suspected area and comparing them with the set feature threshold value, when a fire occurs, it can be comprehensively judged according to the multiple features of it. Based on this understanding, this paper divides the fire detection process into two steps: target segmentation and extraction, and target recognition.

2. Feature Analysis of Fire Image
Fire is a burning phenomenon, and corresponding physical phenomena will occur during the burning process. For example, it emits light, generates heat, and produces a lot of smoke, and the basic shape and outline of the flame can be seen visually [2]. The fire image recognition is based on the optical features of the flame. But not all burning phenomena is a fire. For example, the burning of candles and lighters is a burning phenomenon that people can control, not a fire. Only the burning phenomenon out of control is the fire we need to identify (as a fire). Generally, the features of fire on the image are mainly as follows:

2.1. The Color Feature of the Flame
The flame consists of three parts: outer flame, inner flame and flame core. During a fire, the flame has distinctive color feature. The flame can show different color features during the development and change of the fire [3]. Flames vary in color from the core to the outer flame, generally from bright white to dark red gradually. In general burning scenes, the light of the background object is mainly reflected diffusively, and its brightness is difficult to reach the brightness of the flame burning. The color of the flame is bright compared with most backgrounds, and the color of the flame is brighter and the brightness value is higher [4]. Using this feature, if a continuous image frame is extracted from the surveillance video and a certain area shows high brightness, it can be judged as a suspected flame area. However, due to the complex surrounding environment during the fire, such as wind, burning material, burning adequacy, light and sunlight, etc, all these have certain influences on the color and brightness of the image frame. Based on this alone, it is difficult to determine whether a fire has occurred. In order to accurately determine whether a fire has occurred, further judgments should be made in combination with other features of the fire.

2.2. The Morphological Feature of the Fire
The early stage of a fire is a stage where the fire continues to develop and spread, and the image features of the flame are more prominent. At this stage, the shape, area, color, temperature and other features of the flame are changing at different times [5]. With the expand of burning, the dynamic features of the flame itself are the important basis for accurate fire judgment [6]. The main features of early fire flames are the increasing flame area and irregular changes in the number of sharp corners. The relative instability of flame burning makes the similarity between fire image frames low and the color distribution of flame image changes. Through the processing of continuous multi-frame images,
the connection and difference between the multi-frame images of the suspected fire area in the image are analyzed according to the corresponding algorithm to further determine whether a fire occurs.

3. Suspected Fire Image Area Extraction

This paper needs to recognize the fire in the video surveillance image, so it needs to use the image segmentation technology to get the suspicious area in the image first. Then use various algorithms to analyze the suspicious area in the image to determine whether there is a fire. Due to the diversity of fire environment, burning materials and interference in the background, there is no universal fire image segmentation method suitable for various scenes at present. The segmentation of the flame area is the premise of fire feature extraction, and whether the segmentation is reasonable has a greater impact on the accuracy of fire recognition. This paper uses the inter-frame difference method and the watershed segmentation algorithm to extract the fire area in an image.

3.1. Inter-frame Difference Method

When a fire occurs, the flame burns in a gradual changing process, the flame has a moving features, and most other objects are in a static state. The characteristic of the video image is that a new target appears in the original background image. Therefore, by comparing the video image sequence, we can judge whether there is a suspected flame target in the background. The video sequence captured by the camera has the characteristic of continuity. If there is no moving target in the scene, the change of consecutive frames will be very weak. If there is a moving target, there will be obvious changes between consecutive frames. The Temporal Difference method (Temporal Difference) is to carry out a difference operation on two or more frames of images that are continuous in time, subtracting the pixel points corresponding to different frames to determine the absolute value of gray difference, when the absolute value exceeds a certain threshold, it can be judged as a moving target, thus realizing the detection function of the target [7]. According to the specific implementation, the algorithm can be further divided into two-frame method or three-frame method. The two-frame method is to do the difference operation on two adjacent or separated frames of images, and judge whether there is a moving target according to the absolute value of the difference. The three-frame method is using the AND operation based on the two-frame method. Suppose there are three frames of A, B, and C. AB does the difference operation, BC does the difference operation, and then the two difference operations do the AND operation.

Use the inter-frame difference method to carry out the moving target extraction experiment on the fire video image, as shown in Figure 1.

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| Original image | After frame difference method | Convert to binary graph |
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**Figure 1.** Effect of the three-frame method

When using the inter-frame difference method, the flame area in the two adjacent frames is partially overlapped, so the difference obtained after the difference method is not the complete part of the flame area, but only the relative change part of the flame. However, this step is only the extraction of the suspected fire area, and will not affect the subsequent feature extraction. And in addition to this, this method can detect all moving targets, such as people walking. Return to the subject, whether there is a fire requires further judgment.
3.2. Watershed Segmentation Algorithm

Using image segmentation technology, the image can be divided into several parts according to the features of color, edge, gray and so on, and the target area can be extracted. The watershed segmentation algorithm combines the advantages of edge detection and region growth, and essentially uses the regional characteristics of the image to segment the image. During segmentation, according to the similarity between adjacent pixels, the pixels with similar spatial positions and similar gray values (to calculate gradient) are connected to each other to form a closed contour [8].

Any grayscale image can be regarded as an uneven terrain surface. The grayscale value of each pixel represents the altitude of the point. The area with the largest grayscale value in the image is regarded as a mountain peak, and the area with the smallest grayscale value is regarded as a valley. The concept and formation of the watershed can be illustrated by simulating the immersion process: at each local minimum surface, pierce a small hole, and then slowly immerse the entire model in water. As water is injected through this small hole, the water surface of different areas will continue to rise and converge. In order to prevent the mixing of water in different areas, a dam needs to be built, this dam is the watershed line, which corresponds to the dividing line of the original image.

Use the watershed segmentation algorithm to perform image segmentation experiments on fire video images, as shown in Figure 2.

![Original image and Segmented image](image)

**Figure 2.** Effect of watershed segmentation algorithm

4. Fire Image Recognition

After the extraction of the suspected fire image area is completed, only part of the features of a fire can be determined in this area. In fact, lights, flashlights, burning candles, and even moving objects can all be extracted according to the methods described above. In order to eliminate these interferences and improve the accuracy of the algorithm for fire recognition, it is necessary to select typical features that can completely characterize the fire information as the basis of fire recognition. In the process of fire burning, the area, shape, position, color of the flame and so on of the flame are constantly changing. The criteria of fire image mainly includes color feature, texture feature, geometric feature and so on. This paper, the following four features are extracted as the basis for fire recognition.

4.1. Area Growth Rate

In the early stage of a fire, the flames keep beating and spreading, and the fire area will continue to spread and expand, and the area of the fire flame will show a continuous and expansive growth trend. The area of the corresponding camera and the detected target will gradually increase. As a result, the image shows a continuous increase in high-brightness areas, which also reflect changes in the spatial distribution of the flame [9]. Thus, a method for recognize whether there is a flame could be, by calculating the ratio of the flame area of several consecutive frames of images over a period of time. Since the video shot by a general camera is usually 30 frames per second, and the target area changes very little in a short period of time, so this paper selects 5 frames of images with a time interval of 6
seconds. Since we only need to judge the size relationship of the flame area in consecutive frames of images, it can be achieved by calculating the number of all pixels, rather than calculating the exact size of the area. In image processing, the image is denoised and filtered first, and the target is extracted after threshold segmentation, and finally the flame area is determined by calculating the number of bright spots in the binary image. Figure 3 is the original image, median filtered image and binary image at a certain moment respectively.

![Original image, Median filtered image and Binary image](image)

**Figure 3.** Original image, Median filtered image and Binary image

4.2. The Circularity of the Flame

The regularity of an object’s shape can be measured by the degree of circularity. When a fire occurs, the shape of the flame is extremely irregular, while most of the interference sources (such as incandescent lamps, candle flames, etc.) have a high degree of regularity. Therefore, the circularity of the flame can be used as a criterion for fire recognition. Most stationary interference sources (such as incandescent lamps) have regular contours. Generally, the square of the area and the perimeter is used as the definition of circularity.

In this paper, formula (1) is used to calculate the circularity of the target image.

\[ C_k = \frac{4\pi A_k}{P_k^2} \quad \text{where} \quad k = 1, 2, \ldots, n \]  

(1)

In this formula, \( C_k \) is the circularity of the \( k \)-th target image, \( P_k \) is the perimeter of the \( k \)-th target image, \( A_k \) is the area of the \( k \)-th target image, and \( n \) is the number of target images. Obviously, the closer the shape of an object is to a circle, the larger \( C_k \) is, on the contrary, the more complex the shape is, the smaller the it is. Setting a standard value, when the circularity is greater than this value, the contour of the primitive is considered to be relatively regular and the flame is excluded; otherwise, the contour of the primitive is considered to be irregular and meets the flame profile features.

4.3. Flame Sharp Corners

When the fire is burning, the flame edge has the characteristics of intense jitter, the specific performance in the image is the number of sharp corners of the flame showing irregular jump, we can use this feature to determine whether a fire has occurred. The number of sharp corners of the fire flame changes irregularly with time, so it is hard to determine whether a fire has occurred according to the number of sharp corners of a single frame of image. Generally speaking, the number of sharp corners of fire flames changes irregularly over time, and the number is relatively large. In contrast, incandescent lamps, cigarette butts, and flashlights have the number of sharp corners basically remain unchanged, and the number is relatively small. The situation of the candle is more complicated, when it is slowly moved closer, its flame is stable, and the number of sharp corners is basically unchanged; when the wind blows, the number of sharp corners fluctuates but is very small. In this paper, we selects the number of sharp corners of the aforementioned 5 consecutive images to take the average value and set a threshold value. When the average value is greater than this fixed value, we consider it
to have the edge features of a fire flame, otherwise, we consider that it does not have the edge features of a fire flame.

4.4 Color Features
Colors in nature can be regarded as different combinations of three basic colors (red, green, and blue). These three colors are called three primary colors or three primary colors. According to the principle of three primary colors, any color can be obtained by mixing three colors (red, green, and blue) in different proportions:

\[ C = \alpha R + \beta G + \gamma B \]  

(2)

Where, \( C \) is the mixed color, \( R, G, \) and \( B \) are the three primary colors of red, green and blue, and, \( \alpha, \beta, \gamma \) are the mixing scale factors.

Smoke and flame are usually produced during a fire. The color features of the flame are obvious, generally ranging from bright red to bright yellow. Generally, the color of the flame should move from white to red from the core to the outer flame, on the whole, this process is gradual. The color of the whole flame is dominated by one or a few colors, sometimes with other colors. Fire pixels are usually bright yellow or red, so the color of each pixel is similar to some extent, statistics on a large number of flame pixels can obtain the distribution law of the \( R, G, \) and \( B \) values of each pixel [10]. According to the statistical analysis, the recognition criteria of the flame image in the RGB color space can be obtained as follows:

\[ R(x, y) > G(x, y) > B(x, y) \]  

(3)

\[ R(x, y) > R_{\text{mean}} \]  

(4)

\[ R_{\text{mean}} = \frac{1}{k} \sum_{i=1}^{k} R(x_i, y_i) \]  

(5)

In the formula above, \( R(x,y), G(x,y) \) and \( B(x,y) \) respectively represent the values of the red, green and blue components of the pixel at the position of the rectangular network \((x, y)\). That is, in a fire, the red component of the fire pixel is greater than the green component, the green component is greater than the blue component, and the red component value of the fire pixel is greater than all the mean value of the red component of each pixel in the whole image. Figure 4 is the original image and the statistical histograms of the three color channels of red, green and blue.

![Figure 4](image_url)

**Figure 4.** The original image and the statistical histogram of the three color channels of red, green and blue

5. Experiments and Conclusions
In this paper, fire recognition experiment was carried out under indoor conditions. The occurrence of real fires have the characteristics of complexity and diversity. There are many types of combustibles
and multiple fuels are often mixed and burned together. It is difficult for us to simulate the real fire environment. To be more representative, we chose various fuels to carry out fire simulation experiments under different conditions. The experimental results show that:

The inter-frame difference method and the watershed segmentation algorithm can effectively extract the suspected fire area. People and other activity targets can be easily identified by using other features of the flame, and features such as the increase in the area of stable burning of candles and the roundness of the flame are also easy to distinguish. Interference sources such as electric lights and flashlights cannot be distinguished by color characteristics, and other features can be distinguished. Under indoor conditions, fires such as diesel fuel, wood, paper, clothing and other fuels can be identified under different conditions. The recognition time is also relatively timely, and most experiments can be identified within 1-2 minutes after the fire. Paper type fire recognition time is longer, and two of them were recognized after 3 minutes and 30 seconds after the fire broke out. Of course, the number of our experiments is far from enough. In addition, the simulated fire environment is not as complicated as the real fire, and the quality of the fire video images collected is better either. In the future, various conditions should be changed to carry out simulation experiments, especially fire simulation experiments under severe environmental conditions, and the timeliness of fire recognition should also be improved. The fire image recognition technology is still in the development stage, and there are many theoretical and practical problems that we need to study and solve.

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