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Smoke Detection and Recognition Based on Flame Feature Extraction

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Abstract. The sensor-based fire monitoring scheme requires the installation of temperature and smoke detectors near the monitoring target. Meanwhile, the pictorial fire detection technology is capable of capturing the location and development degree of the fire instantly, enabling rapid detection. Aiming at the issue that the traditional fire monitoring system is prone to failure in large-space indoor and open outdoor environments, a digital image fire monitoring algorithm based on the characteristics of fire flames and smoke is proposed. In the early stage of a fire, smoke is frequently accompanied by its generation and can spread over a large area in the space and is not easily blocked. Therefore, the detection of smoke can realize the early warning of fires and conduct fire rescue work in a targeted manner. In this paper, the background subtraction method is initially employed to extract the moving object, and then the required flame model features are extracted through image preprocessing, and the fire image is identified through multi-feature fusion. The experiment indicates that the flame identification method proposed in this paper can accurately identify the flame under various circumstances and provides a favorable judgment basis for fire alarms.

Keywords: Flame identification, Feature extraction, Object detection.

1. Introduction

Fire is a serious threat to people's production and life safety, at the same time in order to deal with the fire, the input of the fire force is also huge, in recent years, there are many fire rescue operations in the fire sacrifice incident, so improve the existing fire monitoring force, the fire stifle in the cradle, to minimize the fire risk is the current urgent problem.

In order to monitor fire in fire-prone areas, many fire detection techniques have been explored. At present, relatively mature fire detection methods have been found in some places, such as gas-sensitive, temperature-sensitive, smoke-sensitive detectors, in addition to compound detectors, although the physical quantity of detection is increased and the overall performance of the detector is improved, but it cannot effectively eliminate drawbacks. This detection technology has many shortcomings, such as long response time, high equipment cost and single alarm information [1], and there are still technical defects for fire detection in outdoor and large space buildings, and it is difficult to play its due role. For example, these detectors will only issue an alarm when the smoke temperature or gas concentration reaches a certain degree, so the alarm must have a certain delay, which is not conducive to the early rescue of the fire [2].

The image fire detection technology can make up for the shortcomings of these methods, effectively eliminate the influence of interference factors, and is superior to the traditional fire detection technology in the accuracy and reliability of large space fire detection. Image fire detection technology, early mainly focused on the characteristics of flame color identification, such methods cannot distinguish the real flame from similar flame color objects. The fire detection technology based on video image has a unique advantage in quickly and accurately identifying the early flame. Therefore, the fire detection technology of video image has been deeply studied at home and abroad, and more features of flame have been explored and utilized. Li Juhu [3] et al. used the texture features of flame for flame identification, but the texture features of flame are actually unstable, and the extraction and matching of texture features require a lot of calculation work, which is very resource-consuming. Jin [4] et al. used the frame difference method to extract the moving region between two consecutive frames as the suspected flame region. This method can quickly extract some moving objects including flames, but the detected moving objects are not complete. Jin Huabiao [5] determines whether a fire has occurred according to the changes in the area and similarity when the flame spreads. However, to find out the applicable and practical characteristics of the flame image for fire detection, further in-depth research and tests are needed. In addition, for the fire alarm system, various factors should be comprehensively considered, and the speed and accuracy of the fire detector needs to be strengthened. Toreyin [6] et al. used time-domain wavelet change and spatial-domain wavelet change to analyze the flicker of the flame and the color change inside the flame, reducing the probability of false positives. However, since the features of the distant flame may be blocked or weakened, it is impossible to effectively identify the distant flame. This method also easily misidentifies sunlight or other light sources as flames. Mei Jianjun [7] et al. used a more concise visual background extractor algorithm to extract moving objects in images, and segmented moving objects as suspected flame regions, which could realize flame detection in a variety of complex environments. However, direct identification of moving objects as suspected flame regions could not filter out non-flame moving objects, and the recognition accuracy still needed to be improved. These methods can usually detect the flame in most cases, but they are also prone to misjudgment.

The traditional image fire detection method only considers some characteristics of the flame, but does not comprehensively consider these characteristics from the whole point of view, which makes it easy to produce missing or false detection, and the detection speed is relatively slow. In view of this, this paper takes advantage of the changing shape and area of the flame in the early stage of the fire, uses the method of moving target detection to extract the suspected area of the flame, and then extracts the characteristic value of the flame according to the color distribution of the flame, the gradual expansion of the area and the constant change of the edge, and then makes a comprehensive discrimination.

2. Research method

2.1. Extraction of suspected fire areas and contours

The extraction of suspected fire areas and contours is the basis of flame feature extraction and recognition. The quality of flame target extraction plays an important role in improving the recognition accuracy and detection speed of the system. In traditional fire monitoring methods, the target area of the flame is mostly segmented based on the gray value threshold. Although this method can extract the target effectively, it also brings a lot of noise, and increases the calculation workload for the removal of these noises, and also increases the probability of misjudgment. In view of this, this paper uses background subtraction method to initially locate suspected areas in the fire image according to the characteristics of the flame growing from nothing and having movement changes in the initial stage of the fire, and then extracts suspicious areas and contours in the fire image through the area threshold method based on the connected area. This method is fast and can effectively filter out some noise and some static objects with flame color characteristics.

The core of the background subtraction method is to approximate the pixel value of the background image by establishing the parameter model of the background, and then compare the image of the current frame with the background by using the differential comparison method, so as to identify the moving

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region, in which the pixel region with large difference is the moving region, and the pixel region with small difference is the background region [8]. The formula is as follows:

$$diff_{BS} = |f_t - b_t| \tag{1}$$

$$F_{diff_{BS}} = \begin{cases} 1 & if\ diff_{BS} \geq ForeObjThreshold_{BS} \\ 0 & otherwise \end{cases} \tag{2}$$

In the formula:

$diff_{BS}$ is the absolute value of the difference between image and background at time t;

f_t is the pixel value of the image at time t;

b_t is the pixel value of the background at time t;

$F_{diff_{BS}}$ is a binary image with background difference;

$ForeObjThreshold_{BS}$ is the default threshold.

2.2. Feature extraction of flame color

During the combustion process, the color characteristics of the flame are more obvious, and there are more colors in the range of yellow to red. When a fire occurs, there is a distinct visual disparity between the flame area and the background area. The flame luminescence phenomenon is manifested as a red color in the image, and its brightness value is conspicuously higher than that of other surrounding pixels. Therefore, this paper will employ the color characteristics of the flame for the research on fire identification. When extracting flame image features, the collected flame model is stored in the computer by RGB model, which is very beneficial to the extraction of flame features. The 16 images containing flame were analyzed. These images contained about 2.548 million pixels, of which about 824,000 were flame pixels. There are also 8 images that do not contain flames, and these images contain about 1.156 million pixels.

The RGB color model is also referred to as the additive color mixing model. In accordance with the principle of three primary colors, the quantity of light is represented by the primary color light unit. In the RGB color model, any color light F can be obtained through the addition of different components of R, G, and B, and the expression is F = r [R] + g [G] + b [B]. When the three primary color components are 0, F is black light; when all the three primary color components are 1, F is white light. The RGB color model encompasses almost all the colors that human vision can perceive. F is a point in the coordinates of the cube, representing any color, and adjusting the value of any of the coefficients r, g, or b alters the coordinate value of F, thereby modifying its color value. The RGB color space can be depicted by the cube shown in Figure 1.

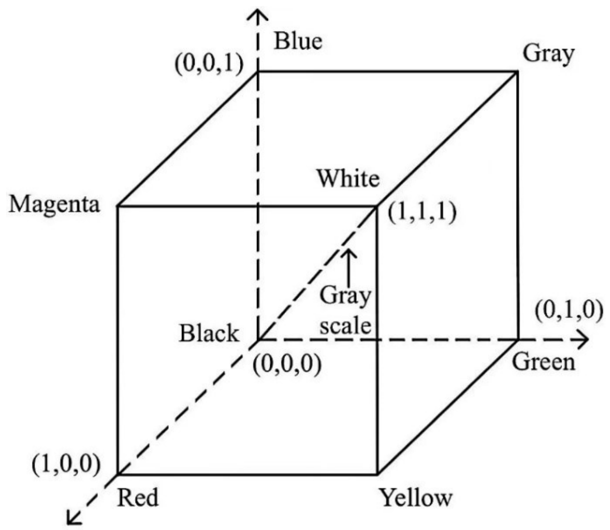

Figure 1. RGB color space.

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2.3. Feature extraction of flame model

The flame model feature extraction algorithm eliminates the influence of strong light or the change of external light intensity on the flame according to the characteristics of the ratio of the three color components of the RGB color model in the flame image. The flow chart of the algorithm is shown in Figure 2:

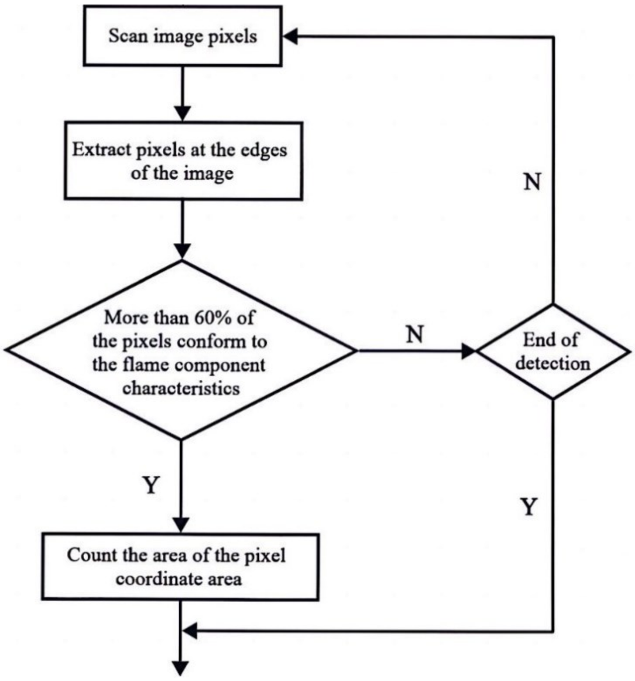

Figure 2. Flow chart of flame model feature extraction algorithm.

As shown in Figure 2, the pixels of the connected area are taken from the top left of the image to the right in turn. If there are no pixels on the right side (that is, the disconnected area on the right side), they are taken down, and all pixels on the image are extracted in this order. If more than 60% of the pixels meet the following characteristics, such a connected region is considered to be a flame region, and the red component value of the peripheral region of the flame will become smaller, that is, if the RGB color component meets the following two conditions, it is considered to be the feature image to be extracted: $R(x, y) > G(x, y) > B(x, y)$ and $R(x, y) > 200$ $G(x, y) < 200$, $B(x, y) < 100$.

2.4. Feature extraction of smoke model

The reference point x is selected by scanning the pixels of the color image and taking the components of the three primary colors of the RGB color model and the H component of the hue of the HSI color model. When the hue of a pixel is in the range of $175° \leqslant H \leqslant 185°$, the parameter α is calculated, and the pixel with the value range of α in $\alpha \in [0,20]$ is selected as the reference point. For pixels whose spatial distance is less than 0.2 (parameter $\alpha \in [0,20]$) and similar to the reference point, the pixels whose spatial distance is >0.2 are reserved as noise cancellation, that is, they are set to white. The algorithm flow chart is shown in Figure 3:

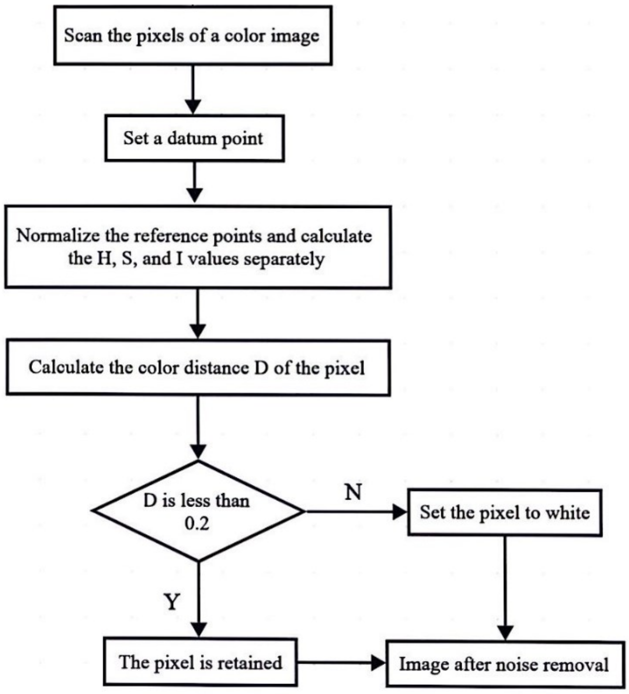

Figure 3. Flow chart of smoke color extraction algorithm.

The spatial distance between the scanned pixels and the reference points is calculated to determine the similarity of HSI colors. Suppose pixel y, its hue, saturation and brightness are h, s, i, x and y respectively, and the space distance between the two points is D, then the space distance D is calculated as follows:

$$D = \sqrt{(V1 + V2 + V3)} \tag{3}$$

In the formula:

$$V1 = (I - i)^2$$

$$V2 = S \times \cos H - s \times cosh \times (S \times cosH - s \times cosh) \tag{4}$$
$$S \times \cos H - s \times sinh \times (S \times sinH - s \times sinh)$$

3. Research result

MATLAB is a simulation calculation software, which is widely used in scientific calculation. It has powerful functions such as calculating numerical values and symbols, language programming and simulation drawing. The process of image processing requires a large number of matrix operations, while MATLAB has a strong matrix operation capability, and a large number of functions provided are easier to implement mathematical operations [9]. The proposed algorithm is simulated by MATLAB in the experimental environment of R2016a(9.0.0.341360) and 64-bit(win64). The results are as follows:

3.1. Picture recognition

Import a picture and get the number of closed images, whether there is flame, flame roundness and five types of recognition results of this picture, as shown in Figure 4:

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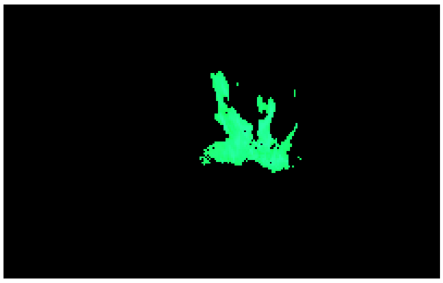
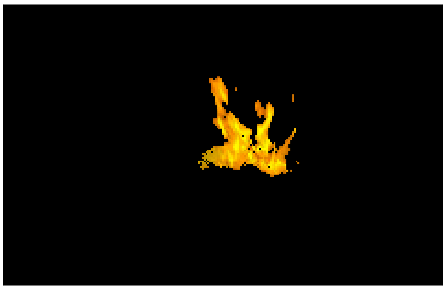
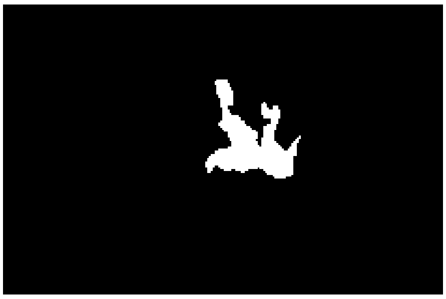
(a) Detection of a picture



(b) HIS conversion diagram



(c) Color segmentation diagram



(d) Binary conversion diagram

(e) Median filter processing diagram

(f) Closed figure diagram

Figure 4. Recognition of an image and five types of graphical results.

3.2. Video recognition

Import a video, select the start frame and end frame to be recognized, and get the number of closed shapes of these selected frames, whether there is a flame, the roundness of the flame and the following five types of recognition results (Figure 5):

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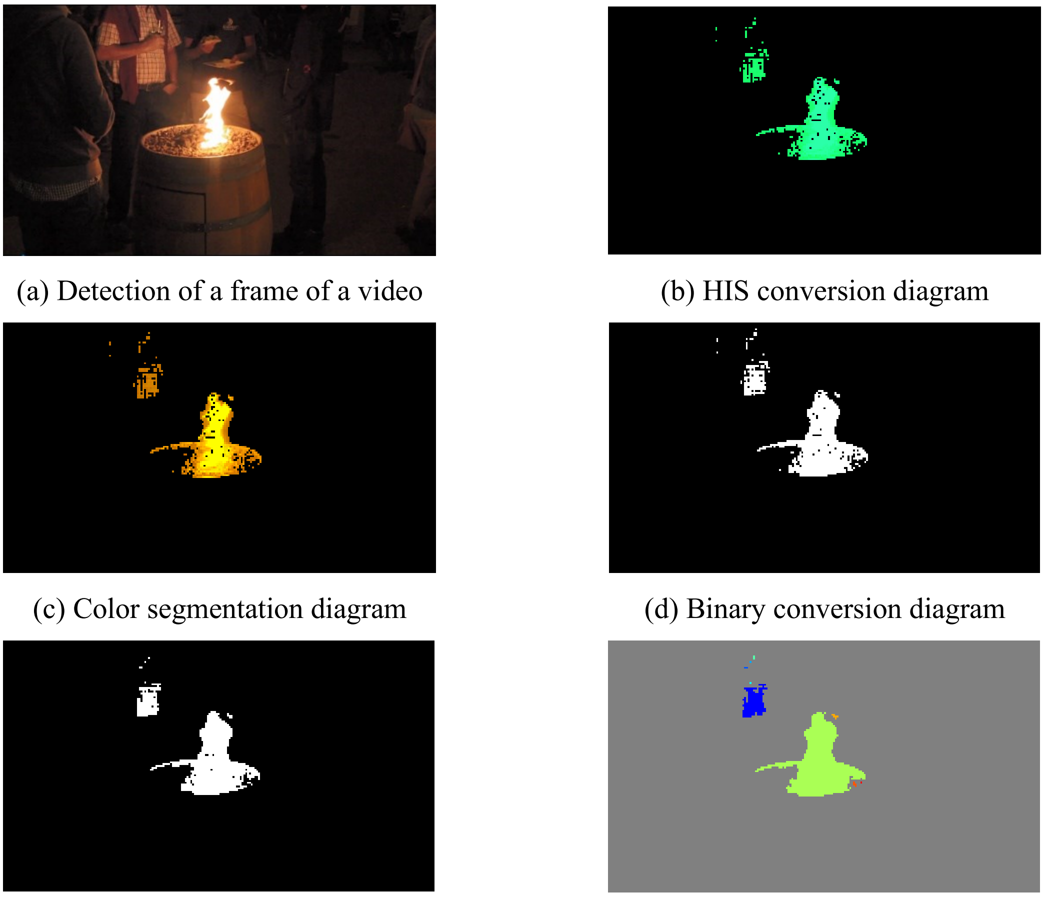

(a) Detection of a frame of a video (b) HIS conversion diagram

(c) Color segmentation diagram (d) Binary conversion diagram

(e) Median filter processing diagram (f) Closed figure diagram

Figure 5. Recognition of a frame of a video and five types of graphical results.

As depicted in Figures 4 and 5, the background subtraction technique is capable of detecting objects with relatively intact contours and ample fine details. The algorithm boasts low computational complexity and facilitates ease of implementation, thereby satisfying the requirements for real-time video surveillance. In Figure 4, the static background devoid of noise and other interfering factors allows for optimal detection performance. Conversely, Figure 5 presents a challenge due to the figure's coat color closely matching that of the flame, thereby precluding distinct flame identification. Moreover, the recognition outcomes preserve the shadow cast by the moving target, potentially introducing a margin of error in subsequent target tracking processes.

4. Conclusion

The flame color feature is predicated on the triad of primary colorants, i.e., red (R), green (G), and blue (B), within the RGB color model, and the interplay among these components to ascertain the presence of a flame. The smoke model feature is derived from the HIS (Hue, Intensity, Saturation) color space model subsequent to image gray level preprocessing. The Euclidean distance, D, is computed between pixels and reference pixels to diagnose the existence of a fire. The experimental outcomes indicate that the flame and smoke feature extraction algorithm introduced in this paper demonstrates enhanced performance and superior timeliness. It facilitates rapid and efficient monitoring, effectively addressing the challenging task of fire detection within expansive areas. When employing the background subtraction technique for smoke detection, critical considerations include the choice of feature types and sizes. The feature size selections encompass pixel-level, block-level, and cluster-level dimensions, while feature types encompass color features, frame features, texture features, and others. The utilization of the standard RGB color feature is susceptible to alterations caused by external environmental factors such as varying light conditions. Consequently, when employing color features to detect moving targets, significant discrepancies may arise in the detection outcomes if there are changes in external lighting. However, the identification robustness of smoke can be significantly improved and the false positive rate diminished by integrating spatio-temporal information, for instance, the inter-frame relationships within a video sequence. Deep learning models, such as the Convolutional Neural Network (CNN) and the Recurrent Neural Network (RNN), are capable of learning intricate feature representations, thereby enhancing the accuracy of smoke recognition. This technology is capable of timely identification of flames and smoke in buildings, forests, and other areas. It monitors the location and scope of fires, offering guidance for firefighting and rescue operations, thereby enhancing the efficiency of fire management. Additionally, it can be employed to detect atmospheric smoke, aiding in the monitoring of air quality and enabling prompt action to mitigate pollution. In the context of surveillance cameras, the technology can identify potential fires or other emergencies, thereby enhancing the efficacy of the security system. In conclusion, this technology, through ongoing research and technological advancement, possesses significant practical utility and broad prospects for application.

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