A Survey on Video Smoke Detection

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Abstract Fire destroys human lives and property. Therefore, there is a huge need for a reliable and probable fire detection technique. This paper provides a review on various methods developed to detect smoke through videos. The study basically categorizes techniques of smoke detection on the basis of feature extraction method (static/dynamic characteristics), locating region of interest (ROI), etc. It also discusses the nature of camera, color model used for detection and so on. A basic method of smoke detection is described stepwise with different types of algorithms used in each step. The pros and cons of each method are also discussed briefly in this paper.

Keywords Smoke · Detection · Image · Processing · Video

1 Introduction

Smoke is considered as a signal of fire. Fire can result in a damage of crucial property. Therefore, we need to have an early solution of fire detection, so that it can cause hazardous to a minimum. In recent years, computer vision technology has come into existence to overcome the drawbacks that we faced in sensor-based smoke detectors. It makes it possible in field of surveillance to keep a constant eye on every camera. Installing cameras to capture video and then using computer vision technology to detect smoke has made it all easy to do the surveillance job. Entire process has the advantage of being automated, and it also has negligible transportation delay, which was a great disadvantage of sensor-based fire alarm.

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To avoid huge fire and its consequent damage, video processing technique for smoke detection and analysis of fire are being performed. As soon as smoke occurs in any one of the camera installed, it detects immediately and notifies the user. In this article, a revised review of smoke detection is presented. The basic difference in methods of detection is in feature extraction method, whether to use wavelet transform or ROI or clustering or color-based feature extraction, etc.

Generally, we see the first step in whole process of smoke detection involves detection of moving regions in the video. This is performed traditionally by background subtraction algorithm, in which the current video frame is subtracted from the background frame to get the moving areas. Whether it may be Gaussian mixture model, frame difference method, or optical flow method, all these algorithms are used as a first step to find the moving regions in the frame. This step often involves high computational cost and is also sensitive to noise. Next, after background subtraction, it is needed to distinguish smoke from other objects detected in first step. For that, features of smoke are studied and are extracted. Therefore, feature extraction is the soul of the whole smoke detection process. Some algorithms involve use of static characteristics of smoke such as color, texture, and contrast, while others use dynamic characteristics of smoke such as area of smoke, its direction, and growth of region and shape. Some use LBP (local binary pattern) to learn features of smoke. But this method has a drawback of LBP being sensitive to changes in the background or foreground.

After the feature is extracted in each block of image, positive samples and negative samples are used for training the classifier that classifies the given block contains smoke or not.

Camera for recording the smoke video can be still where the background subtraction method is involved and can be moving in other cases. Each algorithm takes image in different color model. The three basic models in which smoke images are taken are YUV, RGB, HSI.

Recent methods of smoke detection basically vary in the technique they use for feature extraction and classification of smoke. A number of smoke detection methods have been come into existence. Not only smoke, but flame is also used for fire detection. Firstly, taking smoke into account, we have huge algorithms. Using motion as a key for identifying smoke areas, background subtraction has been continuously in trend. Gaussian mixture model was used for preprocessing purpose very commonly in [1, 2]. Then in contrast, optical flow was used for detection of movement of smoke [3]. In [4], Kalman filtering for motion detection provided an efficient way of background estimation considering its nonlinear property, while [5] used combination of Kalman filter with MHI (motion history image) for extracting motion regions from image.

Some algorithms used static characteristics of smoke in feature extraction phase. Ma et al. and Xiong et al. [5, 6] use color information for identifying smoke in given video sequence. Another smoke detection is performed by making color

Fig. 1 Basic steps for video-based smoke detection

histogram for measuring color similarity features with reference to histograms of sampled smoke templates [7]. For dynamic features of smoke, [7–9] consider shape irregularity of smoke, [10] use texture information, [11, 12] use temporal wavelet transformation and discrete wavelet transformation, respectively. An approach that performs detection of region of interest (ROI) using stationary wavelet transform (SWT) is made in [13]. A four-stage algorithm for smoke detection that involves fuzzy c-means clustering to cluster candidate smoke regions is given in [14]. Another research was identifying ROI by connected component analysis and calculating area of ROI by convex hull algorithm after detecting area of change was proposed in [15]. These are some recent contributions made in the area of smoke detection (Fig. 1).

2 Overview of Visual Smoke Detection

There are many techniques for detecting smoke in the field of computer vision. And most of the techniques even use combination of several approaches to improve performance and reliability. Some of the steps are common in most smoke detection systems; they are motion detection, region analysis, dynamic analysis, and lastly smoke classification stages. The difference lies in algorithms used in these separate stages. Next, we will discuss each algorithm, its benefits, and drawbacks, so that one can choose the optimal algorithm for fire detection in future to improve the system performance.

2.1 Smoke Detection Based on Color

Mainly, RGB, HIS, or YUV model is used for color-based smoke detection. Nearly, all visible range cameras have sensors which detect video in RGB format. Although using RGB indicates very low computational complexity but in smoke pixels, RGB values are very close to each other. HIS is often adapted, because of its suitability of providing more people-oriented way of describing the colors [25].

YUV on the other hand describes luminance and chrominance values of a particular pixel.

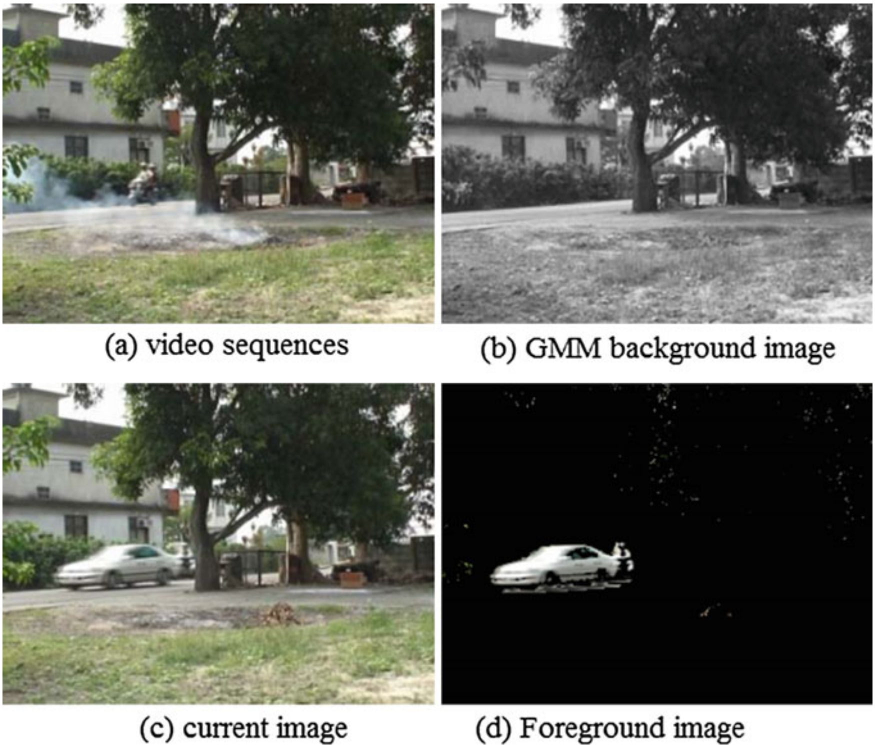

Fig. 2 Foreground segmentation using background subtraction (GMM) [26]

2.2 Moving Region Extraction Method

Well-known moving region algorithms are background subtraction, temporal differencing, optical flow analysis, and Gaussian mixture model. Background subtraction is easy to understand but is very sensitive to noise, lightning, etc. Optical flow technique uses motion field but is computationally complex [26].

Temporal differencing has advantage of quick adaption of change in environment but has disadvantage of being incapable of extracting complete contours [27] (Fig. 2).

2.3 Feature Extraction Method

Every other smoke detection system mainly differs by the algorithm used for feature extraction method of smoke. Some of the methods are listed below

1. **Using Static Characteristics**: Static characteristics of smoke refers to some component which has some fixed value, for example, color, intensity, etc.

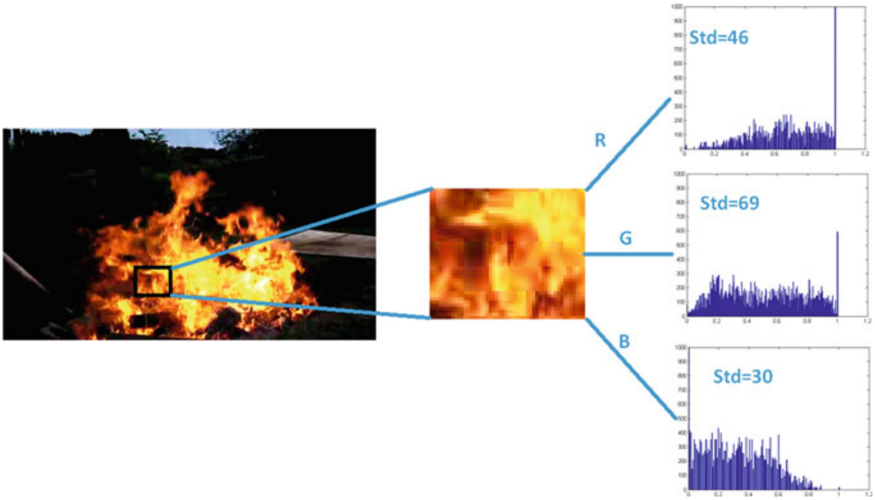

Fig. 3 Spatial difference analysis: in case of flames, the standard deviation σ *G* of the *green* color band of the flame region exceeds $\sigma = 50$ (Borges [30])

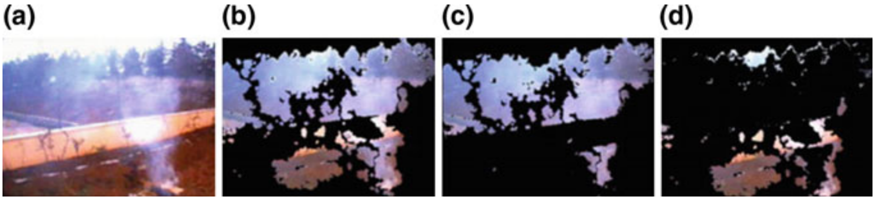

Fig. 4 Segmentation of smoke color using the fuzzy c-means algorithm: **a** original image, **b** moving regions, **c** smoke regions and **d** non-smoke regions [14]

2. **Using Dynamic Characteristics**: Refers to some uncertain characteristics or in which value is uncertain such as smoke area, moving direction, shape, and growth of region [15].
3. **Spatial and Temporal Analysis (Flicker Analysis)**: Since smoke is semi-transparent, therefore, the edges can lose their sharpness; this can lead to a decrease in high-frequency content of an image. This decrease in high frequency energy was used in spatial wavelet transform.

Also, it is very important to distinguish between fire smoke and other fire smoke-colored object. The key to do this is to observe their motion. To study such characteristic of smoke which changes with time refers to temporal analysis. One of the most common is flicker analysis that says that at any time in any pixel, fire flames may be present for a fraction of time. The candidate regions are checked for the presence of flickers (Fig. 3).

Table 1 A tabular comparison of different methods of smoke detection in recent years

Paper	Technology	Moving region extraction	Background noise removal	Details	Color model used	Blob analysis	Camera
Liu YunChang, Yu ChunYu, Zhang YongMing [16], 2010	CCD infrared video image	Background Subtraction	Necessary	Uses segment length value of first frame as background for next and so on. And MCR (mean crossing rate) is calculated from length values	Gray scale image	No	Static CCD
Yuan De-fei, Hu ying, Bi feng-long [17], 2015	Semitransparent properties-based algorithm for detection of smoke in video	Background and current frame are recognized using optical model used in haze image restoration	Not necessary	Semitransparent properties identified by matching current and background frame, then ROI is obtained using region growing method and at last fuzzy clustering is done to reduce false alarms	RGB	No	fixed
Li Ma, Kaihua Wu, L. Zhu [5], 2010	Kalman filter (moving history image), MHI analysis, and Gaussian mixture color model	Kalman filter and MHI to extract moving regions	Necessary	After moving region extraction, trained Gaussian mixture model is compared online with smoke color model and dissimilar objects are removed	RGB	No	Pre-recorded video sequence
H Kim, D. Ryu, J. Park [18], 2014	Gaussian mixture model, and Adaboost algorithm	GMM is used as background estimation	Necessary	Following moving region extracted by GMM, differential image is calculated. Then candidate area is determined using morphological operations. Finally using Adaboost algorithm, it is determined whether the area has smoke or not		Yes	Pre- recorded video sequences

(continued)

Table 1 (continued)

Paper	Technology	Moving region extraction	Background noise removal	Details	Color model used	Blob analysis	Camera
D. Kim, Y Wang [19], 2014	Block–based approach is used for detection of ROI, and K-temporal information is used for smoke classification of each blob	Block-based background subtraction	Not necessary	First is to ensure whether the camera is moving or not. Then, ROI is extracted and final step is to classify each blob as smoky/non smoky using temporal information of color and shape	YUV	Yes	moving
G. Lee, I Ince, G Kim J Park [20]	Histogram technique for varying shape of smoke	Frame difference method	Necessary	Chrominance/Luminance intercorrelation of video is examined periodically. High luminous and less chromatic pixels are used as features of smoke	L * a * b	Yes	stationary
A Benazza, N hamouda, F Tilli, S Ouerghi [21]	DCT(discrete cosine transformation) coefficients	Image difference using Hurst exponent	Not necessary	This paper calculates DCT coefficients at each coordinate pixel. Next, the smoke blocks are supposed to have roughness characterized by a specific range of values of Hurst exponent, which is different of that of non-smoke blocks	RGB	No	Compressed videos
J Li, W Yuan, Y Zeng, Y Zhang [22], 2013	DWT(Discrete wavelet transform)	Improved Gaussian mixture model	Needed	After background subtraction, extraction of smoke fuzzy characteristics based on wavelet analysis is done and finally mobility characteristics are selected for detection criterion of smoke	RGB	No	fixed

(continued)

Table 1 (continued)

Paper	Technology	Moving region extraction	Background noise removal	Details	Color model used	Blob analysis	Camera
T Tung, J Kim [14], 2011	Fuzzy c-means for clustering, SVM(support vector machine) to classify smoke and non-smoke region	Approximate median method	Not necessary	Moving region is segmented using median method, FCM clustering is performed to identify candidate region, then it utilizes combination of color and dynamic features of smoke and an SVM	L * a * b color space	No	static
B Toreyin, Y Dedeoglu, A Cetin [23], 2006	Hidden Markov model (HMM), temporal and spatial wavelet analysis of object contours	Recursive threshold estimation	Not necessary	Decrease in high frequencies is considered as edges using spatial wavelet transform. Decrease in U, V channels is identified, and flicker analysis is carried out by HMM. Finally, wavelet analysis of object contours is carried out	YUV	No	stationary
H Tian, W Li, P Ogunbona, D Nguyen, C Zhan [24], 2011	Local binary pattern (LBP), non-redundant local binary pattern (NRLBP), non-redundant local motion binary pattern (NRLMBP)	Adaptive Gaussian Mixture Model including block-based processing	Not necessary	LBP captures local appearance information based on texture, but is also sensitive to changes in background and foreground. Thus, NRLBP was introduced to reflect contrast between background and foreground and do the job of LBP. Further for temporal texture descriptor NRLMBP was introduced	RGB	No	stationary

(continued)

Table 1 (continued)

Paper	Technology	Moving region extraction	Background noise removal	Details	Color model used	Blob analysis	Camera
C Yu, Z Mei, X Zhang, [25]	Frame differential method for detecting smoke motion edges, while image block processing for flame motion features	Frame differential method	Necessary	Block image processing and optical flow technique are combined to extract smoke features, and backpropagation neural network for smoke classification	HIS for flame detection and RGB for smoke detection	No	Real time video sequence through static cameras

4. **Fuzzy Clustering Method**: It is a method of clustering of data sets. It is used additionally with some color or dynamic features of smoke with an SVM to further classify the clusters. The FCM algorithm is an iterative method of clustering that classifies each and every piece of data to belong to two or more clusters [14].

Support vector machines (SVMs) are a set of supervised learning techniques given by Vapnik, which analyzes data and recognize patterns [28, 29] (Fig. 4 and Table 1).

3 Tabular Comparison of Smoke Detection Methods

Analysis

Overall, the various techniques for video-based smoke detection fall under one or combination of one or more of the categories mentioned: (Fig. 5).

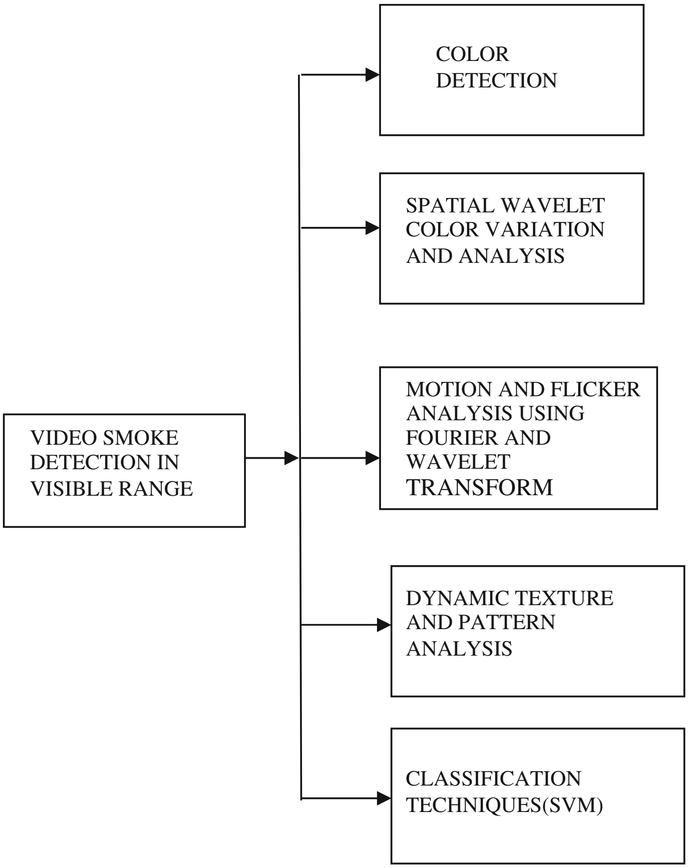

Fig. 5 Techniques of detecting smoke in visible range

4 Conclusion

In this paper, we tried to layout basic traditional methods of detecting smoke in video sequences in the field of computer vision. In spite of variation in smoke feature extraction, every algorithm has common steps as follows:

1. Foreground segmentation/moving region segmentation.
2. To analyze features of smoke and identify ROI.
3. Smoke/non-smoke classification of candidate regions.

Different features of smoke can also be integrated and used to detect fire smoke in a high accuracy. This paper reviewed smoke detection methods based on video images that are used in recent years. Algorithms can be opted for each part of detection in optimality, to improve the system performance.

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