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Video fire detection – Review

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ABSTRACT

This is a review article describing the recent developments in Video based Fire Detection (VFD). Video surveillance cameras and computer vision methods are widely used in many security applications. It is also possible to use security cameras and special purpose infrared surveillance cameras for fire detection. This requires intelligent video processing techniques for detection and analysis of uncontrolled fire behavior. VFD may help reduce the detection time compared to the currently available sensors in both indoors and outdoors because cameras can monitor "volumes" and do not have transport delay that the traditional "point" sensors suffer from. It is possible to cover an area of 100 km^2 using a single pan-tilt-zoom camera placed on a hilltop for wildfire detection. Another benefit of the VFD systems is that they can provide crucial information about the size and growth of the fire, direction of smoke propagation.

1. Introduction

Video surveillance cameras are widely used in security applications. Millions of cameras are installed all over the world in recent years. But it is practically impossible for surveillance operators to keep a constant eye on every single camera. Identifying and distilling the relevant information is the greatest challenge currently facing the video security and monitoring system operators. To quote New Scientist magazine: "There are too many cameras and too few pairs of eyes to keep track of them" [1]. There is a real need for intelligent video content analysis to support the operators for undesired behavior and unusual activity detection before they occur. In spite of the significant amount of computer vision research commercial applications for real-time automated video analysis are limited to perimeter security systems, traffic applications and monitoring systems, people counting and moving object tracking systems. This is mainly due to the fact that it would be very difficult to replicate general human intelligence.

Fire is one of the leading hazards affecting everyday life around the world. Intelligent video processing techniques for the detection and analysis of fire are relatively new. To avoid large scale fire and smoke damage, timely and accurate fire detection is crucial. The sooner the fire is detected, the better the chances are for survival. Furthermore, it is also crucial to have a clear understanding of the fire development and the location. Initial fire location, size of the fire, the direction of smoke propagation, growth rate of the fire are important parameters which play a significant role in safety analysis and fire fighting/mitigation, and are essential in assessing the risk of escalation. Nevertheless, the majority of the detectors that are currently in use are "point detectors" and simply issue an alarm [2]. They are of very little use to estimate fire evolution and they do not provide any information about the fire circumstances.

In this article, a review of video flame and smoke detection research is presented. Recently proposed Video Fire Detection (VFD) techniques are viable alternatives or complements to the existing fire detection techniques and have shown to be useful to solve several problems related to the traditional sensors. Conventional sensors are generally limited to indoors and are not applicable in large open spaces such as shopping centers, airports, car parks and forests. They require a close proximity to the fire and most of them cannot provide additional information about fire location, dimension, etc. One of the main limitations of commercially available fire alarm systems is that it may take a long time for carbon particles and smoke to reach the "point" detector. This is called the transport delay. It is our belief that video analysis can be applied in conditions in which conventional methods fail. VFD has the potential to detect the fire from a distance in large open spaces, because cameras can monitor "volumes". As a result, VFD does not have the transport and threshold delay that the traditional "point" sensors suffer from. As soon as smoke or flames occur in one of the camera views, it is possible to detect fire immediately. We all know that human beings can detect an uncontrolled fire using their eyes and

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vision systems but as pointed out above it is not easy to replicate human intelligence.

The research in this domain was started in the late nineties. Most of the VFD articles available in the literature are influenced by the notion of 'weak' Artificial Intelligence (AI) framework which was first introduced by Hubert L. Dreyfus in his critique of the so-called 'generalized' AI [3,4]. Dreyfus presents solid philosophical and scientific arguments on why the search for 'generalized' AI is futile [5]. Therefore, each specific problem including VFD fire should be addressed as an individual engineering problem which has its own characteristics [6]. It is possible to approximately model the fire behavior in video using various signal and image processing methods and automatically detect fire based on the information extracted from video. However, the current systems suffer from false alarms because of modeling and training inaccuracies.

Currently available VFD algorithms mainly focus on the detection and analysis of smoke and flames in consecutive video images. In early articles, mainly flame detection was investigated. Recently, smoke detection problem is also considered. The reason for this can be found in the fact that smoke spreads faster and in most cases will occur much faster in the field of view of the cameras. In wildfire applications, it may not be even possible to observe flames for a long time. The majority of the state-of-the-art detection techniques focuses on the color and shape characteristics together with the temporal behavior of smoke and flames. However, due to the variability of shape, motion, transparency, colors, and patterns of smoke and flames, many of the existing VFD approaches are still vulnerable to false alarms. Due to noise, shadows, illumination changes and other visual artifacts in recorded video sequences, developing a reliable detection system is a challenge to the image processing and computer vision community.

With today's technology, it is not possible to have a fully reliable VFD system without a human operator. However, current systems are invaluable tools for surveillance operators. It is also our strong belief that combining multi-modal video information using both visible and infrared (IR) technology will lead to higher detection accuracy. Each sensor type has its own specific limitations, which can be compensated by other types of sensors. Although it would be desirable to develop a fire detection system which could operate on the existing closed circuit television (CCTV) equipment without introducing any additional cost. However, the cost of using multiple video sensors does not outweigh the benefit of multi-modal fire analysis. The fact that IR manufacturers also ensure a decrease in the sensor cost in the near future, fully opens the door to multi-modal video analysis. VFD cameras can also be used to extract useful related information, such as the presence of people caught in the fire, fire size, fire growth, smoke direction, etc.

Video fire detection systems can be classified into various sub-categories according to

(i) the spectral range of the camera used,
(ii) the purpose (flame or smoke detection),
(iii) the range of the system.

There are overlaps between the categories above. In this article, video fire detection methods in visible/visual spectral range are presented in Section 2. Infrared camera based systems are presented in Section 3. Flame and smoke detection methods using regular and infrared cameras are also reviewed in Sections 2 and 3, respectively. In Sections 4 and 5, wildfire detection methods using visible and IR cameras are reviewed. Finally, conclusions are drawn in the last section.

2. Video fire detection in visible/visual spectral range

Over the last years, the number of papers about visual fire detection in the computer vision literature is growing exponentially [2]. As is, this relatively new subject in vision research is in full progress and has already produced promising results. However, this is not a completely solved problem as in most computer vision problems. Behavior of smoke and flames of an uncontrolled fire differs with distance and illumination. Furthermore, cameras are not color and/or spectral measurement devices. They have different sensors and color and illumination balancing algorithms. They may produce different images and video for the same scene because of their internal settings and algorithms.

In this section, a chronological overview of the state-of-the-art, i.e., a collection of frequently referenced papers on short range (<100 m) fire detection methods, is presented in Tables 1, 2 and 3. For each of these papers we investigated the underlying algorithms and checked the appropriate techniques. In the following, we discuss each of these detection techniques and analyze their use in the listed papers.

2.1. Color detection

Color detection was one of the first detection techniques used in VFD and is still used in almost all detection methods. The majority of the color-based approaches in VFD make use of RGB color space, sometimes in combination with HSI/HSV saturation [10,24,27,28]. The main reason for using RGB is that almost all visible range cameras have sensors detecting video in RGB format and there is the obvious spectral content associated with this color space. It is reported that RGB values of flame pixels are in red-yellow color range indicated by the rule ($R > G > B$) as shown in Fig. 1. Similarly, in smoke pixels, R, G and B values are very close to each other. More complex systems use rule-based techniques such as Gaussian smoothed color histograms [7], statistically generated color models [15], and blending functions [20]. It is obvious that color cannot be used by itself to detect fire because of the variability in color, density, lighting, and background. However, the color information can be used as a part of a more sophisticated system. For example, chrominance decrease is used in smoke detection schemes of [14] and [2]. Luminance value of smoke regions should be high for most smoke sources. On the other hand, the chrominance values should be very low.

The conditions in YUV color space are as follows:

Condition 1: $Y > T_Y$,
Condition 2: $|U - 128| < T_U$ and $|V - 128| < T_V$,

where Y, U and V are the luminance and chrominance values of a particular pixel, respectively. The luminance component Y takes values in the range $[0, 255]$ in an 8-bit quantized image and the mean values of chrominance channels, U and V are increased to 128 so that they also take values between 0 and 255. The thresholds T_Y, T_U and T_V are experimentally determined [37].

2.2. Moving object detection

Moving object detection is also widely used in VFD, because flames and smoke are moving objects. To determine if the motion is due to smoke or an ordinary moving object, further analysis of moving regions in video is necessary.

Well-known moving object detection algorithms are background (BG) subtraction methods [16,21,18,14,13,17,20,22,27,28,30,34], temporal differencing [19], and optical flow analysis [9,8,29]. They can all be used as part of a VFD system.