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Early fire detection algorithm based on irregular patterns of flames and hierarchical Bayesian Networks

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ABSTRACT

This paper proposes a new vision-based early fire detection method for real-world application. First, candidate fire regions are detected using a background and color model of fire. Probabilistic models of the fire are then generated based on the fact that fire pixel values in consecutive frames change constantly. These models are then applied to Bayesian Networks. This paper uses hierarchical Bayesian Networks that contain intermediate nodes. Four probability density functions for evidence at each node are used. The probability density functions for each node are modeled using the skewness of the color red, and three high frequencies obtained from a wavelet transform. The proposed system was successfully applied to various fire-detection tasks in real-world environments, and it effectively distinguished fire from fire-colored moving objects.

1. Introduction

With the increasing number of surveillance cameras being installed in buildings, there is a greater need for computer vision applications, such as object tracking, detection of abnormal events, and behavior recognition. Along with general surveillance based on human tracking, fire detection using surveillance cameras has also become an important area of research. Most current fire alarm systems are based on infrared sensors, optical sensors, or ion sensors that depend on certain characteristics of fire, such as smoke, heat, or radiation. However, these traditional fire alarm systems are not alerted until the particles actually reach the sensors, and they are usually unable to provide any additional information, such as the location and size of the fire and the degree of burning.

In contrast, vision sensor-based fire detection systems offer several advantages. First, the equipment cost is lower, as such systems are based on CCD (Charge Coupled Device) cameras, which have already been installed in many public places for surveillance purposes. Second, the response time for fire and smoke detection is faster because the camera does not need to wait for the smoke or heat to diffuse. Third, because the camera also functions as a volume sensor, as distinct from traditional point sensors, it can monitor a large area, creating a higher possibility of fire detection at an early stage. Finally, in the case of a false alarm, the system manager can confirm the existence of a fire through the surveillance monitor without visiting the location.

Recent studies have investigated the use of cameras for fire detection and have applied a variety of visual features, such as color, motion, edge and the shape of a fire region. Previous studies share a common assumption that fires generally occur from combustible materials, such as wood, paper, rags, rubbish, and other solids. Our research is proposed using the same assumption.

Töreyin et al. [1] detected moving pixels and regions in a video using a hybrid background estimation method. In this method, candidate fire regions are extracted from moving regions if they belong to pre-specified fire-colored models. A wavelet analysis in temporal/spatial domains is then carried out to determine high-frequency activity within these candidate regions. However, although good results have been shown for several test data, the use of heuristic thresholds at each step makes this method impractical for real-life application.

Phillips et al. [2] detected candidate fire regions using a color-lookup table created with pairs of training images. In this table, each pair consists of color images and binary images where '1' indicates a fire region and '0' indicates a non-fire region. To distinguish fire from fire-colored objects, a temporal variation is used in these candidate regions. However, because all parameters for features are decided from constrained data, the same results cannot be assured if the input data are changed.

Chen et al. [3] used an RGB/HIS color model and a dynamic analysis of flames that matches the disordered characteristic of flames to the growth of pixels to check for the existence of fire. However, because they measure the frame difference between two consecutive frames, the decision rule cannot distinguish real fire regions from moving regions or from noise.

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Han and Lee [4] proposed a fire and smoke detection system for use in tunnels. In this system, fire is detected by comparing the color information in a normal state image with input images. Smoke is detected using motion detection, edge detection, and a comparison of the color information from the input images. However, their study did neither compare the results with previous research, nor was there an objective performance evaluation.

Chen et al. [5] proposed a chromaticity-based static decision rule and a diffusion-based dynamic characteristic decision rule to detect smoke. The chromatic decision rule deduces the grayish color of smoke, while the dynamic decision rule analyzes the spreading attributes of smoke. However, this system cannot distinguish objects that appear gray in color from smoke or provide objective experimental results in dynamic fire situations.

Celik et al. [6] proposed a real-time fire detector that combines foreground object information with color pixel statistics for fire. The foreground information is extracted using an adaptive background subtraction algorithm, which is then verified using a statistical fire color model. However, despite fast detection results with 176×144 video sequences, numerous experimental thresholds are required for the color and background subtraction, and no performance comparison with related algorithms was presented.

Ko et al. [7] proposed a Support Vector Machine (SVM)-based fire detection method. As fires are generally brighter and have a higher contrast than neighboring regions, these characteristics are used to remove non-fire pixels using a luminance map. In addition, for final verification of the fire pixels, a two-class SVM classifier with a radial basis function kernel that includes a temporal fire model is used. However, despite a good detection performance, this method is not suitable for real-time applications as it requires additional computation time according to the number and dimensions of the support vectors.

In addition, apart from scientific research, commercial products related to fire detection using a CCD camera are beginning to emerge in the marketplace.

The axonX company [8] produces *SigniFire*, a fire-flame detection system that uses CCD cameras. This system is designed to monitor incoming video frames by first applying patented Digital Signal Processing (DSP) and, second, using a feed-forward Neural-Network (NN) to recognize flame-specific patterns and signatures. For the NN features, a red image is produced by applying a low-pass filter to the brightness values of the original video sequence, and a blue image is produced by applying a high-pass filter, thus highlighting pixels that have higher rates of change in their brightness. However, this system cannot distinguish flames from objects that appear red in color with irregular brightness, such as car headlights.

Fastcom Technology [9] produced the *SFA* (fire and smoke alert) system, which also uses CCD cameras. This system includes several algorithms that make use of image processing technology to examine many different analysis criteria, such as contrast, color, movement, and outline, among others. A set of independent algorithms running in parallel assess the situation while a decision fusion algorithm monitors their individual contributions in real-time. The system then "fuses" the information to arrive at a final risk assessment. Although this system showed good performance in diverse environments, such as motorway tunnels and oil rigs, it was not able to provide objective experimental results in dynamic fire-like (non-fire) situations.

For more accurate fire detection, the present study first detects candidate fire regions by detecting moving regions and fire-colored pixels. Then, because fire regions change in an irregular fashion due to the airflow caused by wind or burning material, probabilistic models are created and applied to nodes of hierarchical Bayesian Networks, which are used for the final fire-pixel verification. This paper is an extension of previous initial research [10]. Fig. 1 shows the fire detection procedures involved in the proposed algorithm.

2. Candidate fire region detection using motion and color information

One of the main characteristics of fire is a constant change of shape due to the airflow caused by wind or burning material. Thus, candidate fire regions are initially detected using a simple

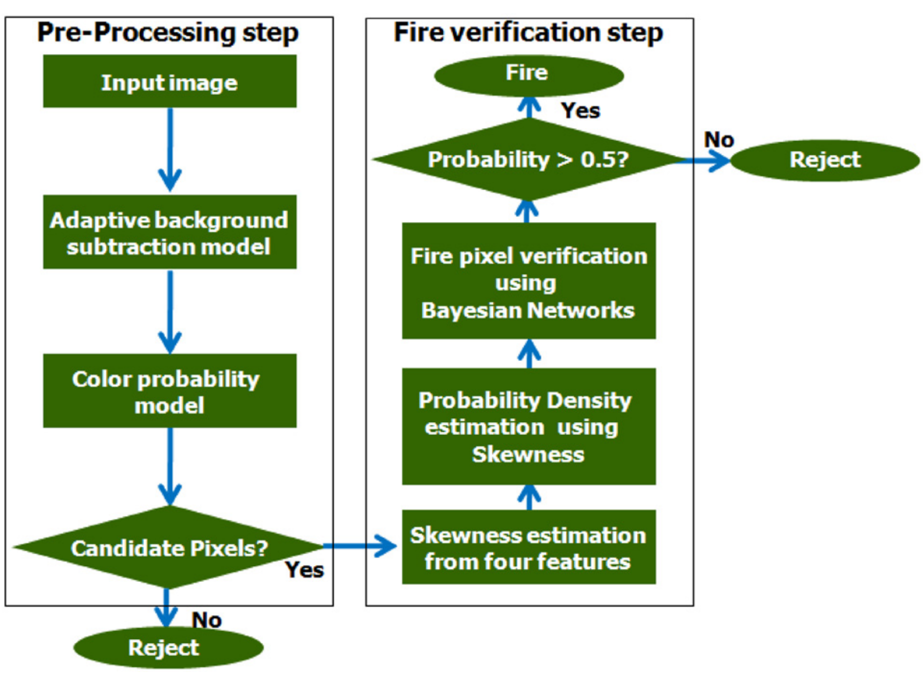

Fig. 1. Fire detection procedures involved in proposed method.