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Fire detection and 3D surface reconstruction based on stereoscopic pictures and probabilistic fuzzy logic

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ABSTRACT

In this paper, a new fire detection method is proposed, which is based on using a stereo camera to calculate the distance between the camera and the fire region and to reconstruct the 3D surface of the fire front. For the purpose of fire detection, candidate fire regions are identified using generic color models and a simple background difference model. Gaussian membership functions (GMFs) for the shape, size, and motion variation of the fire are then generated, because fire regions in successive frames change constantly. These three GMFs are then applied to fuzzy logic for real-time fire verification. After segmentation of the fire regions from left and right images, feature points are extracted using a matching algorithm and their disparities are computed for distance estimation and 3D surface reconstruction. Our proposed algorithm was successfully applied to a fire video dataset and its detection performance was shown to be better than that of other methods. In addition, the distance estimation method yielded reasonable results when the fire was a short distance from the camera and the reconstruction of the 3D surface showed a shape that was almost the same as that of the real fire.

1. Introduction

In recent years, fire detection based on systems that use computer vision techniques has been widely researched because of the relative advantages of computer vision over conventional sensors, such as infrared, optical, or ion sensors, which depend on certain characteristics of fire. Unlike conventional sensors, which sense smoke, heat, or radiation, vision-based approaches using CCD cameras have the following advantages [1–3].

- The equipment cost is lower, as these approaches utilize surveillance cameras that are already installed in many public places.
- Vision sensors can monitor a larger area because the camera functions as a volume sensor, rather than as a traditional point sensor.
- Cameras can easily be used to gather additional information, such as the location, size, and degree of the fire.
- The system manager does not need to visit the location to check the surveillance monitor.

Although a vision-based approach can gather data on the exact location of a fire, exact information about its status, such as the volume and the distance from the fire to the camera, cannot be estimated using only the camera.

The purpose of this study is to estimate not only the exact location but also the volume of a fire, together with the distance between the fire region and the camera, as input for an automatic fire suppression system (AFSS). The main functions of AFSSs include detecting fire regions using a camera and suppressing the fire by automatically activating a water cannon. The water cannon, equipped with a camera, is installed at remote sites and transmits image sequences to a monitoring server over a wired or wireless network as shown in Fig. 1. If a fire region is detected, the warning system sends a command to the water cannon at the remote site to suppress the fire. The water pressure is controlled in relation to the size of the fire region, and the nozzle of the water cannon oscillates in order to suppress the fire, because the system cannot calculate the exact distance between the water cannon and the fire. Therefore, the estimation of distance and real volume is essential for designing a more efficient AFSS that will suppress fires rapidly.

In our study, we use a pre-calibrated stereo camera instead of a normal one for detecting the fire region, tracking the fire spread in three-dimensional space, and calculating the distance from the fire to the camera. In addition, because a stereo camera is influenced to estimate depth (distance) information according to the baseline between two cameras and the focus length, we show that the distance accuracy when a stereo camera is used is reasonable, particularly over a short distance, regardless of whether the environment is indoors or outdoors.

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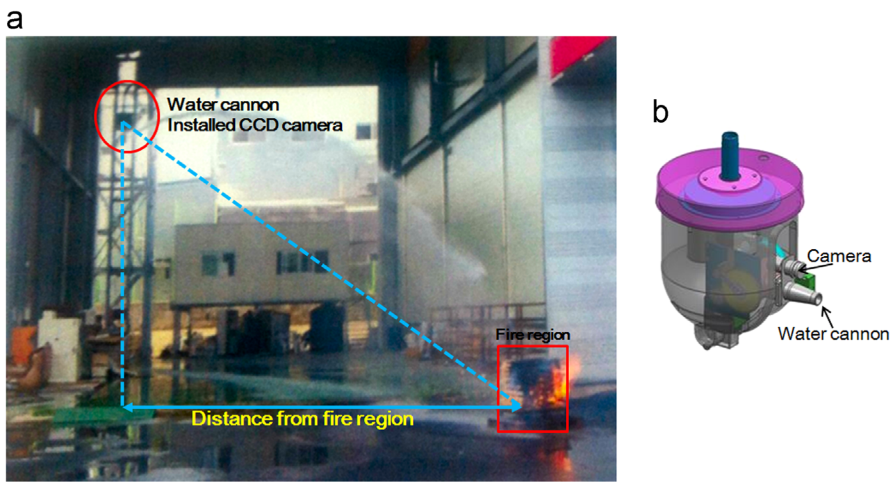

Fig. 1. Automatic fire suppression system. (a) Scene of an AFSS extinguishing a fire and (b) design of a water cannon in which a normal camera is installed.

1.1. Related works

A number of papers on the subject of computer vision-based fire detection has been published because it is a relatively new subject in computer vision research; some promising results have already been reported. However, many problems remain completely unsolved, as in most such systems, because the behavior of uncontrolled flames varies and cameras may produce images of the same scene that have different colors as a result of their different internal settings and different illumination balancing algorithms [4]. In several types of studies [1–13], researchers have attempted to solve the drawbacks of vision sensors so that dependable fire detection results can be achieved.

Töreyin et al. [1] proposed a real-time fire detection method in which the motion, color clues, and flame flickering are analyzed. A temporal wavelet transform is used for detecting quasi-periodic behavior of flame boundaries and a spatial wavelet transform of moving fire-colored regions is used for detecting color variation in flame regions. The irregularity of the boundary of the fire-colored region is also used for verifying fire regions.

Ko et al. [2] proposed a support vector machine (SVM)-based fire detection method. In this method, candidate fire regions are detected using motion and fire color. Then, since fire regions generally have a higher luminance contrast than neighboring regions, a luminance map is made and used to remove non-fire pixels. Finally, a temporal fire model with wavelet coefficients is applied to a two-class SVM classifier for the final fire-pixel verification. In addition, Ko et al. [5] used fuzzy logic for fire-flame detection, whereby the probability membership functions for each logic set are modeled using intensity, wavelet energy, and motion features.

Ho [6] proposed a video-based flame and smoke detection method in which a motion history detection algorithm is implemented to register a possible flame and then analyze the spectral, spatial, and temporal characteristics of the flame in the image sequences. Statistical distribution, temporal probability density, and the continuously adaptive mean shift-tracking algorithm are employed to detect the flame in real time.

Wang [7] used flame color probability based on a Gaussian color model and employed motion probability for updating the background image. The color and motion probabilities are integrated to obtain flame candidates and the successive feature vectors are then applied to the randomness test in order to obtain the flame probability.

For a video-based fire analysis, Pastor et al. [8] proposed a thermal image processing method for computing the rate of spread (ROS) of forest fires. To estimate the ROS, the correspondence between points in the thermal image obtained and the real plane is calculated using a direct linear transformation, and the position of the flame front is determined by applying a threshold-value-searching criterion within the temperature matrix of the target surface.

Martinez-de Dios et al. [9] presented computer vision techniques for forest fire detection involving the measurement of forest fire properties such as the fire front, flame height, flame inclination angle, and fire base width required for the implementation of advanced forest fire-fighting strategies. The system computes a 3D perception model of the fire and can be used for visualizing the fire evolution on a remote computer system.

Verstockt et al. [10] fused low-cost video fire-detection results from multiple cameras using a multi-view localization framework. This framework merges the single-view detection results of the multiple cameras using a homographic projection on multiple horizontal and vertical planes slicing the scene. To provide a more reliable fire analysis, this framework creates a 3D grid along with spatial and temporal 3D filters by extending the concept of existing 2D filters.

Although computer-vision based fire detection and analysis methods yield good detection results, they cannot provide the additional information required for extinguishing a fire, such as the fire's volume and spreading direction, and the distance between the camera and the fire region, when only one camera is used. Unlike previous methods that focus on fire-flame detection using one camera, the instrumentation system proposed by Rossi et al. [11,12] for the visualization and quantitative characterization of fire fronts in outdoor conditions is based on stereovision. This paper introduces the modeling of 3D fire fronts and the extraction of geometric characteristics, such as volume, surface area, heading direction, and length.

In a previous study [13], we proposed a simple fire-region detection system that implements a 3D modeling algorithm and uses a stereo camera in outdoor settings. However, in the present study, to estimate the exact fire volume and the camera's distance from the fire region as input for the AFSS, the candidate fire regions are first detected using fire-colored pixels and moving regions. Next, the Gaussian membership functions (GMFs) for fuzzy logic are learned from the image sequences based on the temporal variation in the fire regions, and GMFs are then applied to a pre-defined fuzzy logic model, which is used for the final verification of the fire region. For 3D reconstruction and a distance calculation, the feature points and their disparities are estimated from stereoscopic images of the fire region.

In brief, the main contributions and overall procedures of our work are as follows:

1. We introduce the AFSS for fire suppression by automatically activating a water cannon based on its distance error when using a single camera. To solve this problem and for the design