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Performance assessment of video-based fire detection system in tunnel environment

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ABSTRACT

Compared to tunnels used for other modes of transportation, fire safety design problems in road tunnels are more challenging because of high-speed wind environmental impact. A video-based fire detection system (VFDS) applies inventive mathematical calculations and sophisticated computer models to analyze and tackle real-time video signals statistically and intelligently. VFDS-based temporal flicker modeling of flames and wavelet-based contour modeling approaches are used as weak classifiers. Experimental results have shown that false alarms issued by earlier methods can be significantly reduced by using separate flame and non-flame moving pixels. Whenever the system detects fire or smoke under wind or no wind environment, the VFDS server initiates actions, including visual and audible alarms, alarm messages, and video recording.

1. Introduction

To evaluate and compare performances of different ventilation systems, air flow induced by an accidental vehicular fire in a tunnel is simulated using CFD (Li and Chow, 2003). Smoke movement in a ventilated tunnel fire is simulated by CFD through large eddy simulation (Gao et al., 2004). Many studies have been performed on the effect of the various ventilation systems, such as forced longitudinal ventilation, natural ventilation, natural shafts, with different heat release rate of tunnel fires is quantitatively analyzed and experimentally examined (Hu et al., 2006; Yan et al., 2009; Li et al., 2010, 2012; Ji et al., 2011).

To guide the design of the installation locations of fire detectors and selection of heat sensors, and to well understand the physics of the fire growth in tunnels, the temperature distribution of the fire-induced smoke flow under the ceiling should be well investigated (Guo et al., 2010; Li et al., 2012).

We proposed an image processing technique for automatic real-time fire and smoke detection in a tunnel environment (Brousse, 2004). To forestall large-scale fire damage from occurring in a tunnel, the system must detect and minimize an incident as rapidly as possible. However, it is impossible to maintain human observation via closed-circuit television (CCTV) in a tunnel for 24 h per day. If a fire and smoke detection system can warn of a fire through image processing, it would be very convenient and could possibly minimize damage, even when personnel are not monitoring CCTV. Fire and smoke detection in a tunnel is different from forest fire detection as elements such as cars, tunnel lights, and other light sources are typically not relevant in a forest environment; accordingly, an algorithm specific to the tunnel environment has to be developed (Brousse, 2004). The two algorithms proposed in this study were able to detect the exact position of a fire at an early stage of a given incident. Moreover, by comparing properties of each algorithm throughout the experiments, we demonstrated the validity and efficiency of the proposed algorithms (Brousse, 2004). Conventional point-type smoke and fire detectors are widely used in buildings. These devices typically detect the presence of certain particles generated by smoke and fire via ionization or photometry. An alarm is not issued unless particles activate the detector sensors; therefore, these detectors cannot be used in open spaces or large covered areas, especially tunnels. Video-based fire detection system (VFDS), therefore, could be useful for detecting fires in tunnels, large auditoriums, atriums, etc. The strength of using video in fire detection makes it possible to adequately cover large open spaces. Furthermore, CCTV surveillance systems are currently installed in various public places that monitor indoor and outdoor environments. Such systems may gain an early fire detection capability with the use of fire detection software that can process data from CCTV cameras in real time. Our aim was to detect flame, fire, and smoke in real time by processing the video data generated by an ordinary camera monitoring a scene.

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Nomenclature

D	image sensor size (m)	h	image object height (m)
D_h	horizontal image sensor size (m)	θ	detection view angle (°)
D_t	detection distance (m)	θ_h	horizontal detection view angle (°)
D_v	vertical image sensor size (m)	θ_v	vertical detection view angle (°)
f	focal length (m)		
H	real object height (m)		

Compared to typical smoke detection systems, a VFDS is not hampered by the usual time delays associated with transportation of smoke particles from a fire to a detection chamber; rather, the information is transported almost instantaneously. This immediate detection capability is the greatest advantage of VFDS technology; however, this advantage can also be considered a liability under certain circumstances.

As designed by Industrial Technology Research Institute (ITRI) and National Taiwan Police College in Taiwan, the VFDS applies in the current study uses image signals from CCTV cameras or other compatible video-capturing devices. Visual features of flame and smoke are analyzed with the VFDS, advanced image-processing and statistical methods; hence, fire can be recognized and alerts can subsequently be sent. Equipped with standard hardware, the VFDS can detect fire events faster than conventional smoke detectors with up to eight cameras present. VFDS provides an innovative video surveillance solution for the prevention of fire-related disasters.

2. Fire detection requirement of tunnels

The National Fire Protection Association (NFPA) 72, National Fire Alarm Code (2007 ed.) adopts specifications that video signals generated by cameras that are components of video image smoke/flame detection systems should be permitted to be transmitted to other systems for other users only through output connections provided specifically for that purpose by the video system. The location and sensitivity of the detectors should be the result of an engineering evaluation that includes the following:

(1) Structural features, sizes, and shapes of the rooms and bays.
(2) Occupancy and users of the area.
(3) Ceiling height.
(4) Ceiling shape, surface, and obstructions.
(5) Ventilation.
(6) Ambient environment.
(7) Burning characteristics of the combustible materials present.
(8) Configuration of the contents in the area to be protected (NFPA 72, 2011).

Fire detectors should provide early warnings of a fire incident at its initial stage and facilitate early activation of emergency systems. Fire detectors are crucial in the prevention of smoke from spreading in tunnels, to the controlling of and extinguishing of fires, and in the assistance of the management, direction of evacuations, and firefighting operations of fire incidents (NFPA 502, 2011). No other types of fire scenarios, such as stationary or moving vehicle fires, were considered. Moreover, interest in the use of CCTV as a component of fire detection systems has increased, but very limited information on CCTV performance has been reported (Versavel and Collins, 2011). Currently, five fire detection technologies have been used or tested for tunnel protection (Zalosh and Chantranuwat, 2011): linear heat detection systems, flame detectors, CCTV fire detectors, smoke detection systems, and spot detectors. The main features of these technologies and their applications in tunnels are listed in Table 1.

2.1. Requirements for a fire detection system in tunnel environment

Fire detection using video, or so-called "cold fire detection," is frequently mentioned in publications; however, so far no video system has been produced for applications in tunnels which can independently guarantee reliable and false alarm-free fire detection, which has international approval. Nevertheless, video technology is currently improving rapidly. Three basic performance requirements for a fire detection system used in tunnel applications have been established for the project: capability, reliability, and availability.

According to the International Road Tunnel Fire Detection Research Project (Liul et al., 2004), the detection capability criterion implies that a fire detecting system should quickly identify a fire incident at its initial stage, and simultaneously locate the fire incident. It is also desirable that a system be able to provide information on fire development, such as its size and developing direction.

The second performance criterion requires that the fire detector should be reasonably reliable, that it should not overlook a fire incident while simultaneously dealing with emissions of pollutants from vehicles and blowing ventilation air. Essentially, the ideal detection system false alarm rate should be established at an acceptable level. The third criterion implies that a fire detection system should be available to work properly in a range of harsh tunnel environments with limited maintenance requirements. Specifically, the tunnel environment can be subjected to significant changes during daily operation in temperature and level of air pollutants emitted from vehicles. Such a harsh environment should not block the proper operation of the system.

The VFDS is oriented as an early fire detection system, and can be integrated with traditional smoke/heat detectors. VFDS has many advantages:

(1) Simultaneously detects smoke and flame.
(2) Solves the problem of large indoor space (height >8 m) fire detection.
(3) Solves the problem of outdoor fire detection.
(4) Initiates earlier detection than conventional detectors.
(5) Actively notifies users if any system failure is occurring.
(6) Is cost-effective, without large sums of money on numerous detectors, wiring cost, maintenance cost, and routine inspection.

2.2. Principle and function of VFDS

VFDS is a line-of-sight device, which differentiates it from all other forms of smoke detection currently available and aligns it