Studies and Prospects of Technologies for Monitoring Highway Tunnel Fire

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Abstract: Because the tunnel fire poses a great threat to the personal and property safety of the trapped people, it is urgent to monitor the tunnel fire in real time, which will help the emergency rescue and evacuation of the tunnel fire accidents. This paper summarizes the studies of technologies for detecting highway tunnel fire and traffic accidents, and discusses the prospect of monitoring the fire of tunnel vehicles through video images.

1. Introduction
The number and scale of tunnels are expanding with the development of construction. At present, China has become the country with the largest number of highway tunnels and the longest operational mileage in the world. According to The Statistical Bulletin on the Development of Transportation Industry in 2019 issued by the Ministry of Transport, by the end of 2019, China had built 19,067 highway tunnels with a total length of 18.9666 m. meters, up by 1,329 with a total length of 173.05 m. meters. Among them, 1,175 are extra-long tunnels with a total length of 5.2175 m. meters, and 4,784 are long tunnels with a total length of 8.263100 m. meters [1].

Fire is one of the most dangerous accidents in the operation and management of highway tunnel. Although the probability of tunnel fire accident is lower than other operational safety accidents, its consequences are more serious than other accidents. Due to the space limitation of highway tunnel, in case of a fire, the temperature may rise rapidly and the smoke and other toxic gases may be widely spread in a short time, which make it difficult for trapped vehicles and personnel to be evacuated and escape successfully. It is also difficult for rescue the trapped to carry out efficient rescue, which also poses a great threat to the life and property of the trapped. Therefore, the best time for a tunnel fire rescue is the forepart of the fire, and the prime time for a rescue is generally considered to be 10~15 minutes in the forepart of the fire.

In order to carry out the fire rescue work as soon as possible, it is of great significance to detect and monitor the disaster as soon as possible. At present, the tunnel is usually equipped with systems of fire detection and traffic incident detection, which plays an important role in tunnel fire monitoring and early warning. The main function of the existing facilities is to confirm whether a fire happens and then give an alarm, but the details of the fire cannot be monitored.
2. Technologies for Monitoring Highway Tunnel Fire

In recent years, tunnel fire accidents occur frequently. In order to grasp the situation of tunnel fire quickly and in real time, technologies for detecting fire and traffic incident are developing rapidly, which feature remote real-time monitoring and rapid response.

2.1. Studies of Technologies for Detecting Highway Tunnel Fire

The traditional tunnel fire detection system mainly includes the temperature sensitive fire detectors for the distributed optical fibers, Fiber Bragg Grating (FBG) and the flame fire detectors including dual-wavelength or three-waveband detectors. You Sanwei, Wang Xinjun and others introduce the principle of distributed temperature cable detector, optical fiber detector and dual wavelength detector, and made comparison and analysis [2, 3] in an economic and technical way; Li Xinxing, Wang Weiping and others carry out tests in the trail tunnel, comparing and analyzing the detection performance of distributed optical fiber fire detector, fiber grating fire detector and dual wavelength fire detector [4, 5]; Bai Xiaohui and others design four groups of tests of open fire, pollution, mobile fire basin and fireworks in Xianxiyao tunnel, and carry out comparative tests of FBG fire detector and dual wavelength flame detector [6]; Yang Ruixin et al. analyze the response performance and influencing factors of cable differential temperature, distributed optical fiber, FBG and other temperature sensitive automatic fire-alarm systems, as well as dual-wavelength and three-waveband flame sensitive automatic fire-alarm systems through the full-scale fire tests in Bijiguan tunnel of Kun’an expressway, Yingzuiyan tunnel of Pingshuo expressway, Liangfengwa No.1 tunnel and Laodianzi No.1tunnel of Shuima expressway in Yunnan province [7].

In addition to the traditional temperature sensitive and flame type fire detectors, fire detection based on video-image technology has also been widely studied, the flow chart of fire detection based on image processing is shown in Figure 1. Liang Junshan et al. [8] propose an image-based fire detection algorithm based on fuzzy clustering. On the basis of establishing the flame color model in RGB space, the fracture parts in the same suspicious flame area were merged by fuzzy clustering method. The algorithm can effectively segment the flame core area of the flame, and the edge information is relatively complete. Zhu Guoxing [9] adopted a fire detection algorithm based on T-S model FNN, which integrates the image features of flame and smoke, and detects the video of highway tunnel fire simulation and traffic interference under different lighting environments. The results show that the algorithm can effectively identify fire and eliminate the influence of interfering substances. Yang Weisong [10] respectively studied the flame detection algorithm (FDA) and smoke detection algorithm (SDA) based on videos. FDA uses HSI color space model to segment the target area which meets the flame color characteristics after removing moving objects, and then extracts the color, number of sharp corners, circularity, flame jump frequency and shape change of suspected flame area, and uses BP neural network to effectively fuse these features to realize comprehensive fire discrimination. For SDA, firstly, the background difference method is used to extract the moving objects (including smoke, moving vehicles, car lights and taillights) in the tunnel, and then the non-smog moving areas are eliminated according to the invariable location of smoke source, and the existence of fire smoke is comprehensively judged by the transparency and diffusion characteristics of smoke. Fang Nan of Chang’an University [11] uses a system based on salience to detect the highway tunnel fire and identify fire video in a section of tunnel to construct a two-layer significance detection model and detect background and target at the same time, and then obtains the final result to judge whether the fire occurs with the combination of the two-layer salient charts. Wang Lin, Yao Xin [12] et al. Based on the establishment of the video database of highway tunnel fire and pseudo flame interference samples and the previous research work, Wang Lin, Yao Xin et al. propose a method of early fire detection in highway tunnel according to multi features of flame image and an algorithm named AdaBoost (Adaptive Boosting) through the studies on the visual characteristics of runaway flame. Li Ying [13] of the University of Science and Technology of China collected the video data of flame from moving fire sources. Meanwhile, in order to compare with the video data of flame, the video data of stationary tungsten filament lamp and moving lamp are also collected. Harris algorithm is used to extract the sharp corners in the image. Through researches on the
threshold of the number of closed angels between frames, and analysis on the threshold value of the product of the area difference between two adjacent images in three consecutive frames of video image, the flame image and lamp image can be finally identified by setting the threshold.

![Flow chart diagram of video fire detection](image)

Figure 1. Flow chart diagram of video fire detection

2.2. Studies of Technologies for Detecting Accidents in Highway Tunnel

Through the investigation of fire accidents in tunnel operation period, it is found that almost all tunnel fires are related to vehicles, especially those tunnel fires with serious consequences. The fire cases involving heavy trucks account for more than 85% of the total fire cases [14]. Therefore, it is urgent to identify, track and monitor the vehicles in the tunnel, eliminate the potential fire hazards of suspicious vehicles and monitor the vehicles after the fire. As a result, it can quickly collect the information of vehicles and personnel and help with emergency evacuation and rescue of tunnels.

From the perspective of traffic safety management in expressway tunnels, Lu Shibo, Li Ming et al. [15] analyze various abnormal states affecting traffic safety in tunnels. They focus on the video-image recognition method for abnormal parking in the tunnel, and put forward a method that combines the image texture features, geometric features and edge features to describe the vehicle features, and uses BP neural network as the base classifier to monitor the abnormal vehicles in the tunnel. Yao Mingming [16] of Chongqing University studies the problems of vehicle target lost and vehicle mutual occlusion and interference in tracking process, and proposes a special method to quickly delete the interference target and the target leaving the monitoring scene while retaining the temporarily lost target due to occlusion and other reasons to track and monitor the vehicles.
Aiming at license plate recognition of high-speed driving in complex tunnel environment, Zhang Xi, Tang Tian et al. [17] propose to use infrared camera to collect monitoring video, and use the edge positioning operator and morphology of Canny to determine the license plate area of the picture. The method combined with projection and fixed boundary is used for character segmentation, feature extraction and BP neural network are introduced to recognize characters and extract license plate information. At the same time, a large number of sample experiments of license plate images are carried out by means of Matlab to verify the speed and accuracy of license plate recognition algorithm. Chen Di [18] of Fuzhou University studies the video monitoring technology in the complex and changeable highway tunnels, and proposes a vehicle positioning and tracking method for the tunnels without street lights. The method follows the principle of tracking first and then clustering to identify and group the front lights. Firstly, the judgment method based on the edge characteristics of bright spots is used to eliminate the non-light source bright spots, and then the robust inter frame matching of bright spots is realized by using Kalman filtering based inter frame tracking method. Then, the extracted stable bright spots are clustered in pedigree to realize the same vehicle grouping. Finally, the vehicle positioning and tracking are realized by determining the center of the headlight group. Wu Xiong and Li Xin [19] of Wuhan University of Technology also propose a new background update model on the basis of previous studies, using HSV color space features to detect and eliminate shadows, and using morphology to improve the extracted moving vehicle information. Based on tracking model algorithm combined with Kalman filtering model and multi features of vehicle, the involved vehicles can be tracked by multi feature matching. Based on the experience of Wuhan Zhongshan road tunnel monitoring system project, Li Yanjun [20] of Wuhan University of Technology proposes a license plate recognition system architecture suitable for tunnel monitoring and a new location method according to license plate color features, based on the researches on previous license plate recognition.

2.3. Problems and Prospects
Although the tunnel is equipped with fire detectors, no theoretical support can be provided for scientific development of emergency rescue plan, due to insufficient alarm information and fire disaster detection. The commonly used fire detectors in tunnels can automatically alarm a certain scale of fire. However, these fire detectors can only send out the alarm information of whether there is a fire or not, and only solve the problem of “whether there is an automatic fire alarm”. They cannot report the specific situation of the train, the traffic situation in the tunnel when the fire occurs, the number and type of vehicles blocked, and the scope of smoke spread. At this time, the fire tunnel is like a “black box” of fire, which seriously affects the scientific decision making of the commander-in-chief in emergency rescue. However, sending firefighters to carry out fire detection in advance will often delay the best rescue. And the limited investigation means cannot provide the rescue commander-in-chief the detailed information of vehicles and the trapped in the tunnel. This may lead to the rescue commander in chief to underestimate the consequences of tunnel fire or judge in time, resulting in greater secondary casualties.

At present, traffic incident detection technology mostly relies on a single camera video for analysis. However, in the actual process, the bad effect of vehicle recognition is due to poor tunnel light conditions, large vehicle occlusion and other factors. In the follow-up study, fusion analysis on multi camera video can be considered to carry out more comprehensive vehicle information analysis.

At present, there are few applications in the dynamic prediction technology of tunnel fire. The development of intelligent prediction algorithm and system will be a hot topic in the future.

In the future, video-image fire detection, wind speed and temperature in the tunnel can be used as the basic data for rapid and real-time assessment of fire accidents in tunnels, and dynamic prediction for the development trend of fire accidents; according to the results of real-time evaluation and dynamic prediction, the emergency-disposal plan for the tunnel operations management department and the linkage control scheme of disaster prevention facilities and equipment can be proposed.

3. Conclusion
As a sudden event, the unpredictable characteristics of fire make the actual work of fire mainly focus on
the early detection of fire. It is necessary to monitor the whole process of the fire in real time for the whole tunnel operation. At present, the traditional detection technology is difficult to play full role in the complex environment such as tunnel. With the rapid development of processing technology of modern digital image and computer, video monitoring technology will become a more economical and practical real-time fire detection technology.

Analysis on vehicle tracking through video images not only has important practical significance and huge economic benefits in tunnel monitoring system, but also predicts whether suspicious vehicles may become potential fire hazards. It can help emergency rescue and evacuation of vehicles after fire and monitor whether vehicles near the accident vehicles will have secondary accidents. With the advance of image processing, artificial intelligence and other disciplines, the technical difficulties of vehicle detection and tracking based on video will be gradually solved and meet the requirements of practical cases. The vehicle analysis system based on video will have a wide range of applications.

The video-image monitoring technology cannot only detect the fire, but also monitor the fire disaster in real time. Combined with the security system, it can bring about an unprecedented growth momentum for technology of video-image monitoring. Informatization, routinization and intelligence of highway tunnel safety operation will be realized through the fire monitoring technology through video images.

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