 DOI: 10.3217/978-3-85125-883-7-15

RAPID FIRE DETECTION AND NOTIFICATION USING A DUAL THERMAL+OPTICAL CAMERA

[1]Takuya Matsumoto, [1] Tatsuya Oshiro, [1] Kazuki Furuhashi, [2] Hideyuki Uemura, [3] Alan Vardy

[1] Sohatsu Systems Laboratory Inc., Kobe, Japan
[2] Teledyne FLIR, Osaka, Japan, [3] University of Dundee, Dundee, Scotland, UK

ABSTRACT

The latest fire detection standard of the Japanese Ministry of Land, Infrastructure, Transport and Tourism ("MLIT") requires that a 0.5m^2, 2 litre gasoline fire at a distance of 25 m must be detected and reported within 30 seconds of ignition. The paper shows that this requirement can be met reliably by using 'dual' video cameras, each with both thermal and optical functionality. It then describes how this capability can be incorporated into tunnel monitoring systems. The effectiveness of the method is demonstrated by the results of nine tests in a full-scale tunnel, namely three tests for each of three rates of airflow, nominally 0, 2.5 & 5.0 m/s. Every fire was detected in less than 10 seconds, thereby far exceeding the MLIT standard. Also, the passage of hot body vehicles through the test tunnel did not trigger false alarms. In addition to describing the system and the tests, the paper discusses related issues of practical importance to tunnel operators.

Keywords: rapid fire detection, rapid fire notification, thermal camera, fire test

1. INTRODUCTION

In 2019, the Japanese Ministry of Land, Infrastructure, Transport and Tourism ("MLIT") issued a revised tunnel-fire standard. The new standard requires that a 0.5 m^2, 2 litre gasoline fire at a distance of 25 m must be detected and reported within 30 seconds of ignition. It also requires that the detection must be linked to automated emergency notification equipment and it called for a new technology for such equipment.

The required speed of detection is very challenging for existing systems. For example, a relatively recent system based on a linear temperature sensor cable has not been proven to meet it. That system has been shown to be capable of detecting fire from a 12 litre N-Heptane on 1.0m^2 fire pan within 30 seconds [1], but it has not been validated with smaller fires. It cannot be assumed to be able to meet the new standard because smaller fires will generate less heat and hence will increase the time before detection. Linear temperature sensor cables continue to have a valuable purpose (see Section 5), but a different technology is needed to be certain of meeting the new MLIT standard.

2. DUAL-SENSOR VIDEO CAMERAS

The detection system introduced herein is based on the use of dual-sensor video cameras that have one optical sensor and one thermal sensor [2]. The thermal sensor fulfils the primary function of rapid detection. It is targeted to do this much sooner than the 30 s limit prescribed in the MLIT standard. Thermal cameras enable visibility in bad weather and in dark environments. They detect infrared wavelengths that correspond to the temperature of the object. Accordingly, they are highly suited to detecting temperature increases caused by fires. Furthermore, they can detect the presence of people and animals even in situations where an optical camera's view is obstructed by smoke or lack of light.

The optical sensor enables rapid verification of incidents reported by the thermal sensor. This is an important intended use, but it is far from being the only one because it will also be available for continuous monitoring during routine operation. The particular camera chosen for testing provides optical images of a similar quality to those of conventional high definition (“HD”) optical cameras. If linked to suitable image-processing technology, it could be used for rapid detection of non-fire incidents.

3. FIRE DETECTION TESTS IN A FULL-SIZE TUNNEL

In February 2021, a series of fire tests was undertaken in a full-size, experimental tunnel owned by Japan Construction Method and Machinery Research Institute (near Mount Fuji). The tunnel is 80m long and 7.8m high and its cross-sectional area is 78m^2. The purpose of the tests was to determine whether the cameras could detect fires reliably within the required maximum time of 30 s. Two cameras were installed, one at a distance of 25 m from the fire pan and the other at a distance of 50 m. Each was mounted at a height of 3.5 m, which is the same as the height of CCTV cameras in Japan. There was no communication between the cameras. The reason for having two of them was to enable their performance at different distances from the fire to be assessed. **Figure 1** shows the arrangement of the two cameras and the fire pan in the tunnel.

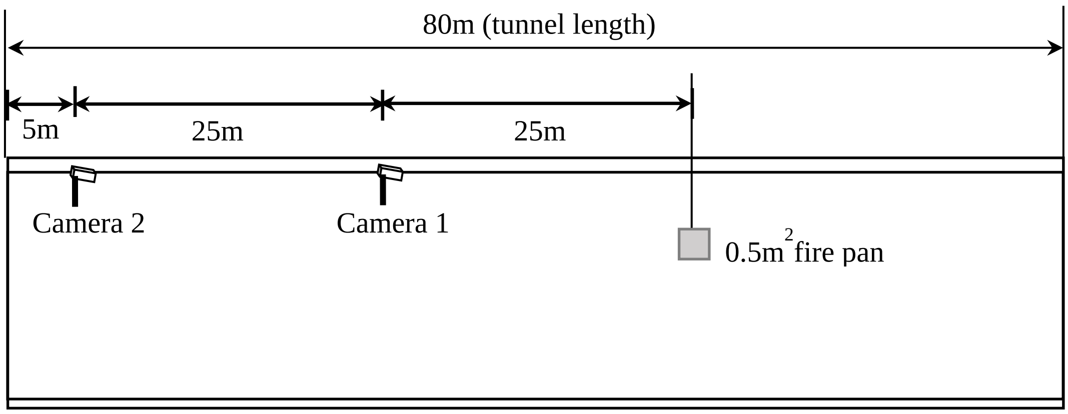


Figure 1 Arrangement of fire pan and cameras in the test tunnel

Tests were conducted at three airflow speeds along the tunnel, namely 0, 2.5 and 5.0 m/s. Three tests were undertaken at each speed so that repeatability could be monitored. The reason for testing at different wind speeds is that this influences the behaviour of fires. For instance, the greater the speed, the smaller the size of the image seen at the camera – because the flame bends over. In addition, higher wind speeds cause greater turbulence and this causes flames to fluctuate. One consequence of this is that true repeatability is not possible in tests such as this, thereby increasing the importance of undertaking repeat tests.

One limitation of the tests was the length of the tunnel. It is intended that further tests will be carried out at another location in future to test the performance of the cameras at greater distances – 100 m or even more. The results of such tests will imfluence the number of cameras needed for safe operation. This is important for maintenance and supervision as well as for initial cpital costs.

3.1 Test results - fire

The middle and right-hand columns in Figure 2, 3 and 4 show thermal images at the instants when the fires were detected. The images in the middle column are from Camera-1, which was 25m from the fire, and those in the rght-hand images are from Camera-2. The left-hand columns give the Test Number together with the measured speed of air flow. The time from ignition of the fire until dectection is listed beneath each image. In colour versions of the figure, the fire is seen as a red blob. In all cases, Camera-1 detected the fire before Camera-2, but the additionl delay was only about 2 s on average even though doubling the distance reduced the size of the fire image by a factor of two (width) and a factor of four (area). Importantly, all nine fires were detected by both cameras in less than 10 s, which is far inside the 30 s window required by the new MLIT standard.

No. Air velocity [m/s]	**Thermal image at the moment of detection Detection time**	
	Camera 1 (25m)	**Camera 2 (50m)**
No. 1 0.22 [m/s]	 3.0 [s]	 5.0 [s]
No. 2 0.15 [m/s]	 2.9 [s]	 5.7 [s]
No. 3 0.01 [m/s]	 3.8 [s]	 7.0 [s]

Figure 2 Thermal image at the instant of detection (air velocity = 0 m/s)

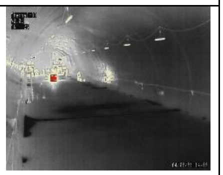
No. Air velocity [m/s]	**Thermal image at the moment of detection Detection time**	
	Camera 1 (25m)	**Camera 2 (50m)**
No. 4 2.96 [m/s]	 6.3 [s]	 8.7 [s]
No. 5 2.60 [m/s]	 7.1 [s]	 7.7 [s]
No. 6 2.57 [m/s]	 4.0 [s]	 5.8 [s]

Figure 3 Thermal image at the instant of detection (air velocity = 2.5 m/s)

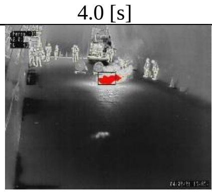
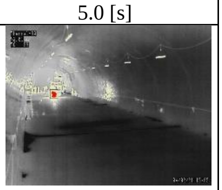
No. Air velocity [m/s]	**Thermal image at the moment of detection Detection time**	
	Camera 1 (25m)	**Camera 2 (50m)**
No. 7 5.53 [m/s]	 4.0 [s]	 5.0 [s]
No. 8 5.62 [m/s]	 6.1 [s]	 8.1 [s]
No. 9 5.95 [m/s]	 4.8 [s]	 6.0 [s]

Figure 4 Thermal image at the instant of detection (air velocity = 5.0 m/s)

Further quantitative data about the test configuration are given in Table 1. The outer columns give the same numerical values as those shown in Figures 2, 3 & 4 and the inner columns list environmental data. The correlation between the detection times and the air velocity was somewhat unexpected. For camera-1, the average detection times at air speeds of 0, 2.5 and 5.0 m/s were pproximately 3.2, 5.8 and 5.0 s respectively and those for Camera-2 were approximately 5.9, 7.4 and 6.4 s. Of these six averages, only the value of 3.2 s stands out from the rest. This gives some cause to suspect that the influence of air speed on behaviour of a flame (as described in Section 3) is significant only at small velocities. However, the evidence of the 2.5 and 5.0 m/s data certainly does not support any expectation that the effect would increase with increasing speed. This suggests that the thermal sensors are more senstive to the overall heat amplitude than to the size of the image presented by the heat source.

The illumination in the location of the cameras themselves was measured because, in principle, it can influence the performance of various types of camera. However, the evidence in Table 1 suggests that this did not have a significant influence on the performance of the thermal sensors. Camera-2 performed well even though it was at twice the distance of Camera-1 and also was close to the tunnel portal and thereby in an especially brightly-lit location.

Table 1 Results of fire tests

Case No.	environment						detection time [s]	
	air velocity on fire pan [m/s]	illuminance [lx]			temperature [deg. C]	humidity [%]	camera 1 (25m)	camera 2 (50m)
		fire pan	camera 1 (25m)	camera 2 (50m)				
1	0.22	120	140	1300	13.3	32.4	3.0	5.0
2	0.15	100	140	1300	14.0	30.7	2.9	5.7
3	0.01	100	140	1300	15.1	28.2	3.8	7.0
4	2.96	100	140	1300	15.1	20.9	6.3	8.7
5	2.60	100	160	1600	16.5	17.2	7.1	7.7
6	2.57	100	140	1700	15.1	19.0	4.0	5.8
7	5.53	80	140	2100	16.8	18.2	4.0	5.0
8	5.62	80	160	2500	15.4	18.0	6.1	8.1
9	5.95	80	140	2500	14.2	21.1	4.8	6.0

The other environmenta parameters recorded on site were the temperature and humidity of the inflowing air. Of course, such data cannot be conrolled, but, instead, are climate and weather-dependent. In practice, the temperatures did not vary significantly during the tests and, although the specific humidity variaied by almost a factor of two, all values were quite low. In practice, therefore, little can be inferred about any possible influence of either of these parameters.

3.2 Test results – non-fire heat sources

The 100% detection performance of the cameras in the fire tests is highly encouraging. However, it is also important that this is not achieved at the expense of allowing non-fire heat sources to trigger unacceptable numbers of false alarms. Accordingly, additional tests were conducted in which vehicles with hot spots (exhausts gases, etc) and hot body shells (from engines and long exposure to direct sunlight) passed through the factory road (Fig.5). These did not trigger alarms even though some (highly) local temperatures will have been close to those expected in the early stages of a fire. In addition, tests were conducted outside the tunnel on vehicles that had been exposed to hot sunshine for lengthy periods. Again, these did not trigger alarms.

Experience of continuous, day-to-day operation in an existing tunnel will be necessary before the true likelihood of false alarms can be determined unequivocally. However, the 0% record in tests designed to replicate real behaviour as closely as practicable is a strongly encouraging sign.

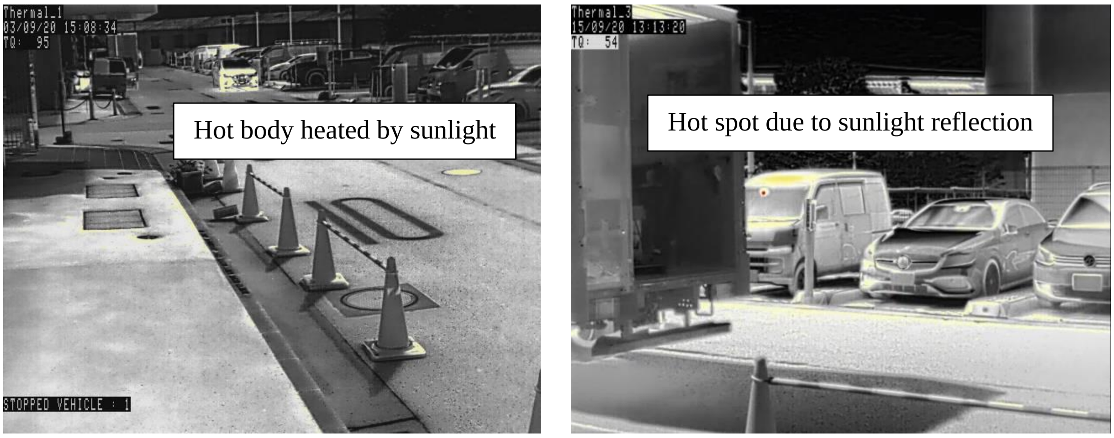


Figure 5: Hot body testing failed to cause false alarms

4. FIRE DETECTION AND TUNNEL MONITORING SYSTEMS

In a practical implementation in a road tunnel, there would be multiple cameras. The most suitable distance between successive cameras cannot be finalized until further tests have been undertaken at greater distances that were possible in the test tunnel. Provisionally, however, it is assumed that reliable detection will be possible in much less than 30 s at distances in excess of 100 m. Accordingly, it is expected that cameras will be installed in pairs at intervals of 200 m, with one facing in each direction. This arrangement has the following practical benefits:

- It enables fires to be seen from both directions. This has obvious advantageous for the optical sensors, but it is also useful for the thermal sensors because it reduces the possibility of non-detection caused by vehicles blocking lines of sight to a fire.
- If it is found to be necessary to install a local panel or box adjacent to the camera, the required number of such boxes will be halved.

The integration of the cameras into the tunnel monitoring system is illustrated in Figure 6. The left-hand box shows successive pairs of cameras, one from each pair being needed to cover both sides of an incident in the intervening 200 m. The signals from the cameras are passed to the control panel that is responsible for triggering automatic responses as well as for communicating with operators when the system is being monitored by humans. The details of the control panel and its algorithms are not given here, partly because some will be site-specific even though others will be universally applicable. However, the proposed methodology closely resembles that described by Sakaguchi et al [3] for detection using linear-temperature sensor cables.

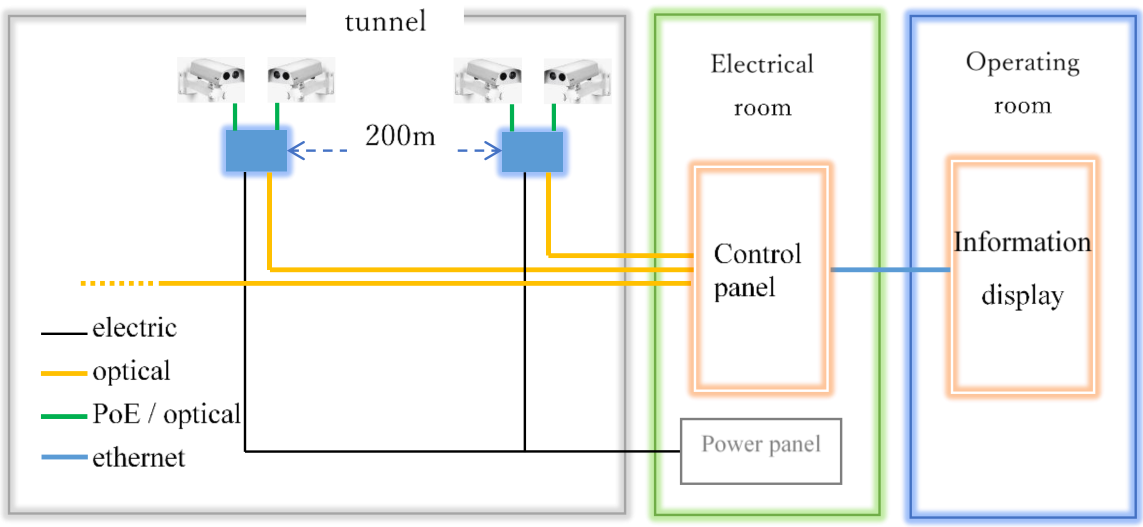


Figure 6 Integration of cameras in the tunnel monitoring system

5. OPERATIONAL CONSIDERATIONS

The system can provide fire detection comparable to conventional systems using combinations of infrared sensors and CCTV cameras. However, the use of dual cameras that combine the two types of sensor in single unit has obvious advantages for installation and maintenacnce purposes as well as for system integration and capital cost. Furthermore, the tests reported above give preliminary evidence that the proposed system is likely to be both quicker and more reliable than existing systems, although there is not yet enough evidence to justify such a conclusion rigorously. Also, any new approach requires careful attention be paid to possible disadvantages, inadequacies and maintenance issues and this process has revealed some scope for future development as well as issues that can be addressed during further development and/or through appropriate maintenance specifications. One example of each of these possible types of counter-measure is now given.

Any surveillance system that relies upon having a direct line of sight between a sensor and an incident can be rendered ineffective by obstructions to the line of sight. In road tunnels, such obstructions can be caused by intervening vehicles. This is especially likely when one or more such vehicles are large and stationary – although that is less likely during the early stages of a fire when detection is most effective at reducing potential consequences. Examples of such detection delays with existing systems using flame-based sensors have been reported where a fire was not detected for many minutes due to the vehicles blocking the line of sight to the fire flame. In principle, this issue could be addressed by installing the cameras at shorter intervals than currently envisaged, but that is not the only option. Another possibility is to make use of linear-temperature sensor cables that are easily installed and, as indicated above, have been shown to effective, albeit not sufficiently responsive to meet the new MLIT requirements.

As an example of potential maintenance issues, attention is drawn to the need for one of the dual cameras at any particular location to face in the direction opposite to the main traffic flow. This will increase the rate at which the lenses become dirty and thereby cause the quality of the images to deteriorate. Specially-designed hoods are being developed to reduce this problem. In the case of bi-directional tunnels, the problem could also be reduced by installing each camera on the side of the tunnel in which the direction of traffic flow is the same as the camera direction.

6. SUMMARY AND CONCLUSIONS

A new fire detection system for road tunnels is at an advanced stage of development and its core function has been tested in a full-scale tunnel. The system is based on the use of dual video cameras that have two sensors, one for thermal imaging and one for optical imaging. The motivation of the development is the existence of of a new fire standard in Japan, requiring fire to be detected and automatic responses initiated within 30 seconds of ignition. This has to be achieved for a 2 litre gasoline fire size of 0.5 m^2 at a distance of 25 m.

An outline of the new system has been presented. One pair of dual cameras is installed at intervals of 200 m along the whole of the tunnel. One camera in each pair faces forwards and the other faces backwards, giving cover of any incident from both directions.

The full-scale tests were conducted in a tunnel that is used only for R & D and is only 80 m long so the new system has yet to be proven at distances implied by the proposed design. However, in the tests, a camera at a distance of 50 m from the pan fire achieved a 100% detection rate in less than 10 s. Furthemore, the passage of vehicles with hot-spots did not trigger false alarms.

Attention has been drawn to examples of issues that need to be addressed by any detection system and possible counter-measures have been identified. These include tunnel-specific modifications to hardware that will reduce implications for maintenance schedules.

There is a strong expectation that the required detection standards will be met with existing technology and that future developments in camera technology will enable even greater distances between successive camera locations to be accceptable.

7. REFERENCES

[1] Nakahori, I., Oshiro, T., Fukuda, K., Matsumoto, T., & Abe, S. (2018). *Fast fire detection by linear temperature sensor cable and its application,* 9th International conference 'tunnel safety and ventilation', Graz, pp. 165-174.

[2] Teledyne FLIR, ITS Series DualAID 316L Datasheet, 21-0337-INS-USL, Revised March 2021.

[3] Sakaguchi, T., Matsumoto, T., Yamamoto K. & Takegaki M., I., (2020). *Road tunnel temperature monitoring system using a simulation mode*, 10th International conference 'tunnel safety and ventilation', Graz.