Study of Video Image Fire Detection Systems for Protection of Large Industrial Applications and Atria

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ABSTRACT

This paper presents the results of full-scale fire and environmental tests to study the use of video image detection (VID) systems for the protection of large industrial applications and atria. The tests were conducted in a large test atrium facility and a large burn hall. The effects of VID system variables, fire sources and environments on the performance of VID systems were investigated in the test series. The test results showed that the VID systems evaluated in the research program worked well in various challenging fire and environment conditions. The field of view and camera height of VID systems were important factors that had a substantial impact on their detection performance.

Key Words: fire detection, video image detection system, large industrial applications, atria,

1.0. INTRODUCTION

It is very challenging for conventional fire detection systems to provide fire protection for large industrial applications and atria, such as power plants and petrochemical processing plants, shopping malls, churches, hotels, office buildings, and airports. These applications have large spaces and excessive ceiling heights. A recent study on the application of smoke detectors in spaces with high ceilings showed that it took a long time for the smoke produced from the various types of fires to reach the high ceiling and that there were limitations in ceiling height for smoke to reach, depending on the fire type and size [1]. The study recommended that smoke detectors should be used only in spaces with ceiling heights up to 6 m.

Video image detection (VID) systems have been identified to be an effective detection technology for the protection of large industrial applications, atria and other spaces with high ceilings [2]. They can quickly detect a fire by recognizing either smoke or flame anywhere within the field of view of the camera at a great distance. They can provide live video immediately available upon detecting a pre-alarm or an alarm condition. They allow monitoring personnel to easily view the protected area to determine the extent of the fire, to identify the fire location, and to activate emergency systems.

Performance criteria for the installation of VID systems for the protection of large industrial applications, atria, warehouses and other applications have been discussed in a workshop organized by Fire Protection Research Foundation (FPRF) [2]. The main goal of VID systems is to provide early detection for the protection of lives and properties and mission

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continuity. The workshop suggested that the performance of a VID system in fire protection must take in account on the following three general items:

- System variables, such as specific type of VID system being used, settings and quality of camera, field of view, sensitivity settings, delays, and image settings;
- Fire sources, including fire type, size, location and other hazard conditions that could be confronted in the protected area; and
- Environment, such as lighting conditions, background, foreground and contaminants.

Currently, performances of VID systems in road tunnel environments have been investigated [3], however, their effectiveness for the protection of large industrial applications and atria has not been evaluated. This paper presents the results of full-scale fire and environmental tests to study the use of VID systems for the protection of large industrial applications and atria. The tests were conducted in a large test atrium facility of the Carleton University (CU) and a large burn hall of the National Research Council Canada (NRCC). The VID system used in the test series was AlarmEye® smoke/flame VID system developed by InnoSys Corp [4]. A special test protocol, considering the effects of VID system variables, fire sources and environments on the performance of VID systems, was designed and used for this work. The fire scenarios and nuisance sources employed in the test series included not only those recommended by the FPRF report [2], UL 268 test standard [5] and ANSI/FM 3260 test standard [6], but also included additional scenarios such as spray fires and obstructed fires, as well as other environmental nuisance sources that could be encountered in large industrial applications and atria. The test results demonstrated the capability of VID systems working in various challenging environments, provided information for use in the development of performance criteria, guidelines and specifications for VID systems, and helped optimize technical specifications and installation requirements of VID systems in large spaces with high ceilings.

2.0. TEST FACILITY

The full-scale fire and environmental tests were conducted in the atrium section of the Carleton University Fire Test Lab. Its dimensions are 18.9 m wide x 18.4 m long x 26.4 m high. The atrium has two doors with dimensions of 4.5 m high x 3.65 m wide at the east side of the lab. These doors were closed during the tests. The lining of the atrium wall is made of galvanized sheet metal. A ventilation system is equipped in the test atrium and the smoke produced by the fire can be vented out after each test is completed. The schematic of the atrium, fire source location, and detector locations is shown in Figure 1.

Some environmental and fire tests were conducted in the burn hall of the National Research Council Canada (NRCC). Its dimensions are 50 m long x 30m wide x 15 m high.

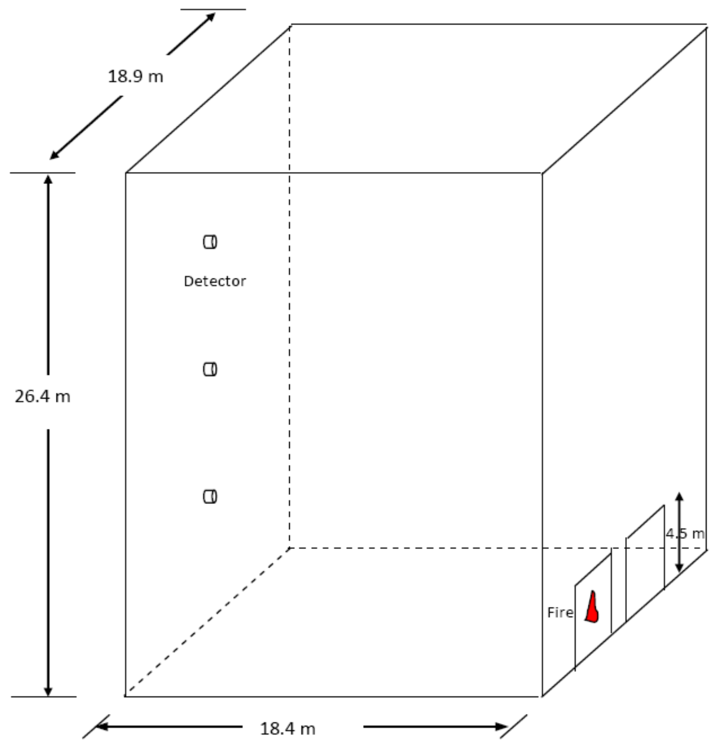

Figure 1. Schematic of test atrium, detector and fire locations

3.0. VID SYSTEM

The AlarmEye® VID system is a smoke/flame detection system. The system can act as an independent fire detector in which both the video processing and alarm algorithm execution are performed at the detector. It can also be used as a centralized detection system in which up to eight video cameras are connected together and processed in a single computer unit. The AlarmEye® detectors used in the test series were independent fire detectors. Each detector consists of one color camera, one IR camera, one IR light source, image capture and pre-processing, and digital signal processor (DSP) (Figures 2 & 3). The optical flame sensor, as an additional detection option, can be combined with the detector.

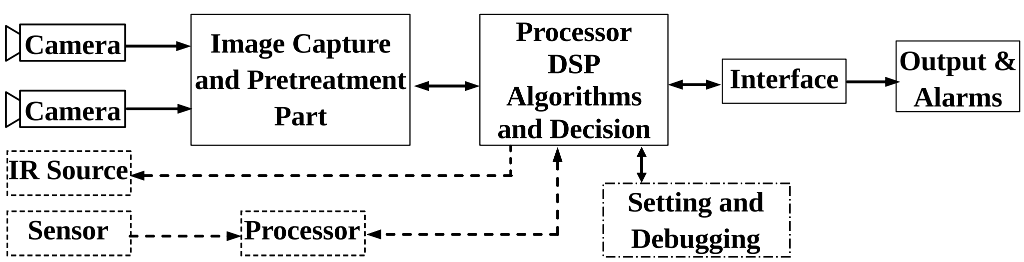

Figure 2. Schematic of the AlarmEye VID detector

Figure 3. A photo of the AlarmEye VID detector

Compared to conventional VID systems, the AlarmEye® system can extract more fire/environment information available from its multiple image sources, aiming to quickly and reliably detect the fire, and to minimize the impact of nuisance sources on system performance. The system can operate under all weather and light environments, including in the dark by using its IR light source. It divides its field of view into 16 sub-zones: key surveillance zones for close monitoring and non-surveillance zones that may have potential false/nuisance sources or very low possibility for occurrence of the fire. Its intelligent image recognition and processing algorithm is installed in the DSP. It consists of digital image input, data filtering processing, background learning and modeling, physical characteristics analysis, data fusion, alarm probability calculation and output. The characteristics of the smoke and flames obtained from its multiple image sources are quantized and processed in the DSP. A fire alarm is issued, once the probability of smoke and/or flame characteristics are higher than a preset threshold.

Three AlarmEye VID detectors were installed at heights of 5.5 m, 12 m and 20 m from the ground, respectively, at the west wall of the test atrium of the Carleton University (Figure 1). The distances of the three detectors to the fire source were approximately 17.3 m, 20.3 m and 25.9 m when the fire source was located 2 m from the east wall of the test atrium. For the tests in the NRCC facility, the three VID detectors were installed at the same height of 11.5 m at the north end of the burn hall. The distance of the detectors to the fire source was 46.5 m. The images provided from the three detectors were displayed on one computer monitor.

The detection sensitivity of the AlarmEye VID detector to smoke and flame is divided into five levels. Level I is the highest sensitivity and Level V is the lowest one. The sensitivities of the three VID detectors used in the test series were Level I for smoke detection and Level III for flame detection.

The effect of the field of view on the detection performance of the VID system was also investigated in the test series. The lens of three detectors was 4 mm, 6 mm and 8 mm, respectively. Detector I had a largest field of view with its 4 mm lens. Detailed technical information of the three VID detectors is given in Table 1.

Table 1. Technical Information of the VID System used in the Tests

Detector No.	Sensitivity Level		Field of View	Installation Height (m)	
	Smoke	Flame		CU	NRCC
Detector I	I	III	4 mm	5.5	11.5
Detector II	I	III	6 mm	12	11.5
Detector III	I	III	8 mm	20	11.5

4.0. FIRE AND ENVIRONMENTAL TEST SCENARIOS

The fire and environmental test scenarios used in this study were typical fire incidents and nuisance sources that could be encountered in large industrial applications and atria. They included unobstructed fires, fires obstructed by large obstacles, small fires located under a table, and between two cloth-racks with clothes. Tests were also conducted with fires with nuisance sources, under darkness and airflow conditions and with contaminated camera windows. The fire sizes with both Class A and B fuels were small and varied from 25 to 150 kW, as the VID systems are designed to detect the fires at their early stages.

The fire scenarios considered in the study are the following:

- A 0.3 m x 0.3 m alcohol pan fire with a HRR of 27 kW;
- A 0.3 m x 0.3 m n-heptanes pan fire with a HRR of 126 kW;
- A 0.3 m x 0.3 m JP8 jet fuel fire with a HRR of 146 kW;
- A n-heptanes spray fire with a discharge pressure of 4.1 bar (60 Psi);
- A paper fire that is constructed, according to UL 268 test standard [5];
- A wood fire that is constructed, according to UL 268 test standard [5],
- A cloth fire that was produced by burning a jean.
- Smoke produced by a smoke bomb (143 g);

Various nuisance sources were used in the tests to evaluate the impact of environments on the performance of the VID systems. They were:

- The artificial lights recommended in ANSI/FM 3260 [6]. They were one incandescent (100 W); two fluorescent (40 W tube type); one halogen (500 W quartz element shop light). The light was located 2.5 m above the ground;
- An arc welding in the field of view that consisted of a 0.3 cm type 7014 rod, and a 0.6-1.3 cm thick steel plate, and a 180-200 Ampere set.
- A chopped UV/IR light. The chopped UV/IR light consisted of a set of three, 500 W halogen work lamps with the glass covers removed. Chopping was achieved by rotating a segmented drum around the axis of the row of lamps positioned horizontal to the ground. The chopping frequency was 3.5 to 4.0 Hz.

- A chopped IR light. The IR light consisted of a 1500 W quartz heater (Windmere, Model 4396DB) which was mounted horizontally in the same rotating, segmented drum used with the UV/IR light. The chopping frequency was 3.5 to 4.0 Hz.

5.0. TEST RESULTS

The tests were conducted in two phases. Phase I consisted of fire tests including unobstructed fires, obstructed fires, and fires with nuisance sources, fires under dark light, fires under wind conditions and fires with contaminated detector lens. Phase II consisted of environmental tests involving various nuisance sources.

5.1. Fire Tests

5.1.1. Unobstructed Fires

The fire sources in the tests conducted in the CU atrium facility included a 0.3 m x 0.3 m pan alcohol fire, a 0.3 m x 0.3 m n-heptanes fire, a 0.3 m x 0.3 m JP8 fuel fire, a heptanes spray fire, smoke produced by a smoke bomb, a paper fire and a wood crib fire. The fire source was placed 2 m from the east wall of the atrium. The tests involving liquid fuel fires had the duration of approximately 90 s. The tests involving paper, wood and smoke fire lasted approximately 120s. Some tests were repeated twice.

It was observed that no smoke was produced from the alcohol fire (Figure 4) and only small amount of smoke from the n-heptanes fire (Figure 5). The JP8 fuel fire produced substantial amounts of smoke during burning and its flame height was higher than the alcohol and n-heptanes fires (Figure 6). Shining lights were produced from the lining with the reflection of artificial lights and flames during tests, which presented an extra challenge to VID systems. Three VID detectors quickly detected all the liquid fuel fires based on the flame characteristics of the fires. Their detection times were 30 s, 23 s and 16 s for the alcohol fire, 30 s, 11 s and 24 s for the heptanes fire, and 25 s, 25 s and 20 s for JP8 fuel fires. For the same VID system, the changes in fuel type or fire size had no substantial impact on the performance of the detector. However, their performances changed with their position. Detector III that was located 20 m from the ground detected the fire faster than the other two detectors.

When the heptanes fuel pan was relocated from near the metal lining of the atrium facility to near the wood door, the response of the Detector I to the fire was enhanced and detection time decreased from 30 s to 15 s, because the effect of the shinning reflection from the metal lining was minimised. However, the relocation had no impact on Detectors II and III, since the ground was their major background, when they overlooked the fire from their high positions. No shinning reflection was produced from the ground.

Figure 4. An alcohol fire

Figure 5. A heptanes fire

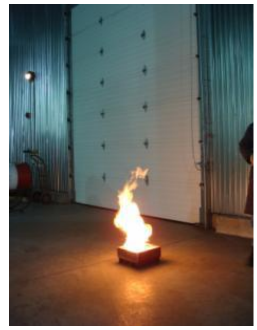

Figure 6. A JP8 fuel fire

Figure 7. A smoke bomb

Figure 8. A wood crib fire

Figure 9. A paper fire

In the case of detecting smoke produced by a smoke bomb, three detectors were very effective and detected the smoke quickly. The detection times of three detectors were very close ranging from 38 s to 44 s due to the large amount of smoke produced (Figure 7).

A wood fire was constructed using eighteen kiln dried Douglas Fir strips with a 19 mm square cross section and 152 mm length in three layers of six strips in each layer. It took a relatively long time for the fire to grow. The amount of the smoke produced was limited but steadily increased through the test period (Figure 8). Very small flames were visible over the wood crib and most of fuel was not consumed in the test. Three detectors detected the wood crib fires, mainly based on the detection of the smoke produced by the fire. Their detection times ranged from 65 s to 108 s. Detector III detected the fire faster than the other two detectors.

A paper fire was constructed by pouring and tamping shredded newsprint paper into a receptacle with dimensions of 102 mm diameter and 0.3 m high. The paper fire produced a substantial amount of smoke in the initial test period followed by a short flaming period (Figure 9). Both detectors II and III were able to detect the paper fire based on its smoke characteristics. Their detection times were 46 s and 58 s respectively. Detector I did not detect the paper fire.

A spray fire was constructed by using a P80 nozzle under a discharge pressure of 4.1 bar (60 psi) (Figure 10). Its fire size was larger than three liquid fuel pan fires. All three detectors quickly detected the spray fire. Their detection times were close and ranged from 26 s to 31 s.

Figure 10. A heptanes spray fire

Figure 11. A heptanes pan fire under wind conditions

The effect of airflow conditions on the performance of VID systems was investigated in the tests. A longitudinal airflow was produced by operating the ventilation system in the test atrium and the door near the fuel pan was lifted 1 m up. The air velocity measured around the fuel pan was approximately 2.5 m/s. A 0.3 m x 0.3 m heptanes fuel and a 0.3 m x 0.3 m JP8 fuel were used in the tests. The fire plume became short and tilted toward the ground (Figure 11), and at the same time, the trembling of the flame increased under the airflow conditions. All detectors quickly detected these fires. Their detection times ranged from 13 s to 24 s for the heptanes fire and 12 s to 15 s for the JP8 fuel fire. The detection times were shorter than those under non-airflow conditions, showing that the low longitudinal airflow had a limited impact on the performance of the VID systems.

The effect of the field of view on the performance of VID systems was investigated in the tests conducted in the NRCC's burn hall. A 0.3 m x 0.3 m JP8 fuel fire was placed 46.5 m away from the three VID detectors that had the same height (11.5 m) from the ground but different field of the view. The test was repeated twice. Both detectors II and III quickly detected the fire at 33 s and 23 s, while Detector I had no response to the fire. This suggests that the VID detector with small field of view performances better than the VID detector with a large field of view.

5.1.2. Obstructed Fires

Obstructed fires in the test series included a small liquid fuel fire located under a table, behind a plate, between two cloth racks, as well as a paper fire located behind a large plate and between two cloth racks.

The view of three detectors to a 0.3 m x 0.3 m heptanes fuel fire was partially obstructed, when it was placed under a table with dimensions of 2 m long x 1 m wide x 1 m high (Figure 12). The three detectors were still able to quickly detect the obstructed fire. Their detection times were 43 s to 45 s. These times were longer than the detection times for the unobstructed fires but there was no substantial change in detection time with the field of view and the height of the detectors.

Figure 12. a heptanes fire under table

Figure 13. A fire behind a plate

Figure 14. An obstructed fire overlooked from 20 m height

When a 0.3 m x 0.3 m heptanes pan was placed 1.5 m behind a plate with dimensions of 2 m long x 1.0 m high and 0.3 m from the ground (Figure 13), the view of Detectors II and III to the fire was not obstructed by the plate (Figure 14), but the view of Detector I was partially blocked. All three detectors quickly detected the fire. The detection times ranged from 6 s to 29s, with the higher detectors requiring shorter time to detect. When the plate height increased to 2 m high, the three detectors were still able to detect the fire, but the detection times significantly increased ranging from 51 s to 79 s, as their view was partially or fully obstructed.

A paper fire was also placed 1.5 m behind the plate with 1.0 m high and 0.3 m from the ground. The smoke produced from the paper fire spread behind the plate. Detectors II and III were able to detect the fire based on the smoke characteristics, as their view to the fire was not blocked. Their detection times were 40 s and 69 s. Detector I, however, did not detect the obstructed paper fire.

A series of obstructed fire tests were conducted to simulate the fires that may occur in shopping centers. The liquid fuel fires, paper fires and a cloth fire were placed, respectively, between two cloth racks. The racks were 2 m long x 1.2 m high and full with clothes. The flame tip produced by the 0.3 m x 0.3 m heptanes fuel fire was slightly higher than the cloth rack, and no fire reflection was produced from the cloth racks (Figure 15). The view of Detector II and III to the fire was not obstructed, but the view of Detector I was almost fully blocked. Detectors II and III quickly detected the fire with detection times of 9 s and 19 s. Detector I had no response to the fire. When the heptanes fuel was replaced by JP8 fuel, a large fire plume was produced and all the three detectors detected the fire. The detection times ranged from 16 s to 39 s, with Detector I having the longest detection time.

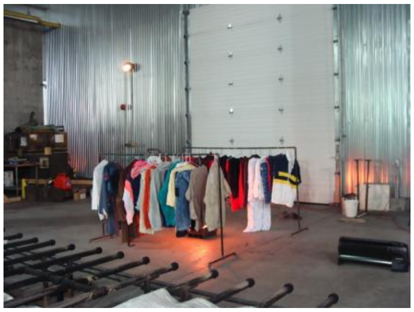

Figure 15. A heptane fire located between two cloth racks

Figure 16. A paper fire located between two cloth racks

Figure 17. A cloth fire located between two cloth racks

When a paper fire was placed 0.8 m between two cloth racks, the smoke produced rose slowly above the clothes (Figure 16). Detectors II and III detected the fire with detection times of 61 s and 32 s, based on smoke produced by the fire. Detector I had no response to the fire. The tests were repeated with the test setup at a new location that was 8 m from the east wall of the test atrium, and close to the detectors. In this test, all three detectors detected the paper fire, as the size of the smoke image in the detector increased. The detection times of the three detectors were 67 s, 43 s and 78 s.

The response of VID detectors to a cloth fire was also evaluated. A small amount of heptane fuel was poured over a jean hanging behind the first cloth rack and the jean was set on fire. The fire grew quickly and its flames were clearly displayed in the monitor of the three detectors (Figure 17). All three detectors quickly responded to the fire and their detection times ranged from 18 to 22 s. The difference in the detector height and their field of view had no impact on the detectors' performance.

5.1.3. Fire Tests under Dark Conditions

Two fire tests involving a 0.3 m x 0.3 m heptanes fuel and a paper fire were conducted in the night under dark conditions. The fire source was located 2 m from the wall and there was no obstacle around the fire.

The IR source of the AlarmEye VID detector was automatically activated under dark conditions, and the atrium conditions were clearly displayed on the computer monitor from three detectors. Detectors II and III quickly detected the 0.3 m x 0.3 m heptanes pan fire. Their detection times were 16 s and 64 s, respectively. Detector I had no response to the heptanes fire.

Smoke produced by the paper fire was also clearly displayed in the monitor under dark conditions. Detector II quickly detected the paper fire at 23 s. Detector III also detected the paper fire at 73 s after the ignition. Detector I, which did not detect this fire under light conditions, had no response to the paper fire.

5.2. Environmental Tests

5.2.1. Tests with Nuisance Sources

A number of tests were performed to evaluate the response of the VID detectors to various nuisance sources. The nuisance sources used were either standing-alone or used together with a fire, in which case they were placed in the background 2.5 m behind the fire.

Three VID detectors had no response to the halogen light, fluorescent lights and the incandescent light, when these lights were used alone or when they were switched on-and-off 20 times per minute.

In another two tests, three VID detectors faced the flashing lights emitted from chopping IR and UV/IR sources with a frequency of approximately 3.5 to 4 Hz, respectively (Figure 18). None of the detectors had any response to the chopping IR and UV/IR sources.

Figure 18. A UV/IR source

Figure 19. A welding test

Figure 20. A fire under halogen light as the background

A welding test was conducted in NRCC's burn hall. The welding source was located 25m from the detectors. It was observed that the welding itself was a kind of combustion when the rod with high voltage touched the metal. Bright flashing lights were produced during welding (Figure 19). However, the shape and frequency of the welding light were different from the flame produced by the fire. All three VID detectors successfully distinguished the welding from a fire did not respond.

In order to further investigate the effect of welding on the performance of VID detectors, a 0.6 m x 0.6 m JP8 fire was placed 45 m from the detectors while the welding source was still located at the same position. All the three detectors quickly detected the fire with detection times of 28 s, 15 s and 14 s, showing that the detection of VID detectors to the fire was not interfered by the welding process.

The effect of artificial lights on the detection of VID detectors to fires was also investigated in the tests. A 0.3 m x 0.3 m heptanes pan was placed 2 m from a halogen lamp (Figure 20). All the VID detectors detected the heptanes fire. Their detection times ranged from 49 s to 89 s. Compared to the tests without light, the detection times increased with the presence of the yellow light emitted from the lamp. However, the lamp light had no impact on the response of the detectors to the 0.3 m x 0.3 m JP8 pan fire, as a large fire plume was produced. Their detection times were almost the same as those without the presence of the lamp light.

Detectors II and III also detected the paper fire under the lamp light conditions, based on smoke characteristics. Their detection times were longer than those without the lamp light. Detector I had no response to the paper fire under the lamp light conditions.

5.2.2 Environmental Contaminated Tests

Two layers of metal mesh with estimated 25% light obstruction (Figure 21) and one layer of cloth with estimated 75% light obstruction (Figure 22) were placed in front of the camera windows of Detectors II and III, respectively to simulate fouling of the detector window caused by dust, water and oil droplets. They were used to evaluate the impact of environments on the performance of the VID system. It was observed that the image provided by the contaminated Detector II was only slightly distorted, but the image provided by contaminated Detector III was blurred. No light obstruction was placed in front of Detector I camera window.

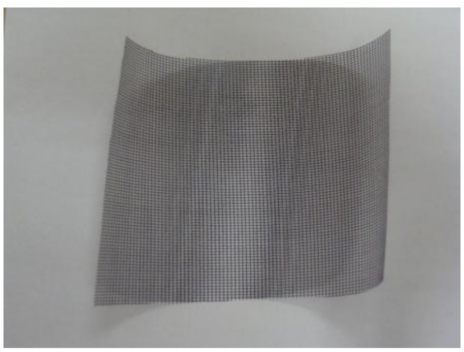

Figure 21. A metal mesh for light obstruction

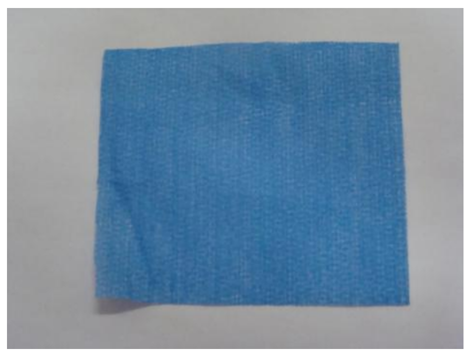

Figure 22. A layer of the cloth for light obstruction

Liquid fuel fires including a 0.3 m x 0.3 m heptanes fire and a 0.3 m x 0.3 m JP8 fuel fire, and a paper fire were used in tests to evaluate the impact of the contaminated camera window on the performance of the VID detectors. The test results showed that the VID systems were able to quickly detect the small liquid fires. The detection times of Detectors II and III were 16 s and 20s to the heptanes fires, and 40 s to the JP8 fuel fire. The detection times were almost the same as those with the non-contaminated camera window as contaminated detectors were still able to identify the basic flame characteristics, such as its shape, and turbulent flashing.

Contaminated Detector II was also able to detect the paper fire but its detection time was increased to 59 s. Detector III had no response to the paper fire, as smoke characteristics produced by the paper fire were hardly recognized through the highly light obstructed camera window.

SUMMARY

The effect of system variables, fire sources and environments on the performance of VID systems for the protection of large industrial applications and atria was investigated through full-scale tests. The test results showed that:

- The evaluated smoke/flame VID systems, equipped with multiple image sources, an IR source and an intelligent image recognition and processing algorithm, were able to detect various unobstructed and obstructed fires at their early stages. They were immune from various nuisance sources, such as artificial lights recommended by the ANSI/FM 3260 test standard [6], chopping UV/IR source, chopping IR source as well as arc welding;
- Changes in liquid fuel type or fire size had a limited effect on the performance of VID systems for unobstructed fires, but increased their detection times for obstructed fires;
- The detectors had shorter detection times to Class B fires (liquid fuel fires) than to Class A fires (paper and wood fires);
- The detectors were able to work under dark conditions, and to detect both flame and smoke fires;
- The impact of low airflow (2.5 m/s) on performance of VID systems to unobstructed liquid fuel fires was limited. Their detection times were even shorter than those under non-airflow conditions;
- Location of VID cameras and their field of view had a substantial impact on the performance of VID systems for the detection of small fires. The systems that had a higher camera position from the ground were less obstructed by the obstacles, and less interfered by the environment. However, the effect of the location of the detectors and field of view on the performance of VID systems for the detection of relatively large fires, such as spray fires, 0.6 m x 0.6 m JP8 fuel fires, a cloth fire and smoke produced by a smoke bomb presented in the tests, was limited.
- The contaminated camera windows had a limited effect on the detection of VID systems to flame fires but made the detectors more difficult to detect smoke fires.

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