

D.T. Gottuk, J.A. Lynch

Hughes Associates, Inc., Baltimore, Maryland USA

S.L. Rose-Pehrsson, J.C. Owrutsky, F.W. Williams

Naval Research Laboratory, Washington D.C. USA

Video Image Fire Detection for Shipboard Use

Abstract

The objective of this work was to evaluate the effectiveness of commercial video image fire detection systems for small, cluttered spaces as would be found on navy ships. The primary goal was to establish an understanding of the performance sensitivity and limitations of the video image detection (VID) systems to various setup and environmental conditions that may occur onboard ship while exposed to a range of flaming and smoldering fire sources and potential nuisance alarm sources. The response of the VID systems was benchmarked against standard fire alarm systems using addressable ionization and photoelectric smoke detectors.

Introduction

Computer processing and image analysis technologies continue to improve significantly, which has allowed the recent development of effective video image fire detection systems. Typically, these systems have been designed and used in large facilities, outdoor locations and tunnels. However, the technologies are also proving effective in smaller, cluttered compartments found on ships and in commercial and industrial sites. With the increasing move to use onboard video for surveillance and security, there are advantages in using the video images for other functions, such as fire detection. In addition, video image recognition technology has the potential for personnel tracking, flooding detection and physical damage assessment.

This work represents part of an ongoing multi-year program to identify, evaluate and adapt video image detection (VID) technologies for improved situation awareness and damage control assessment onboard navy ships [1]. Three commercial video image fire detection systems were evaluated in multiple full-scale test programs with a range of

flaming and smoldering fire sources and potential nuisance alarm sources. The primary objective of the last test series and the focus of this paper, was to establish an understanding of the performance sensitivity and limitations of the VID systems to various setup and environmental conditions that may occur onboard ship. Toward this end, 280 full-scale tests were conducted in a mockup of a shipboard compartment and passageway to evaluate the performance of the detection systems under various background, lighting and camera setting configurations while exposed to a range of flaming and smoldering fire sources and potential nuisance alarm sources. Conditions that were evaluated consisted of white and gray bulkheads (walls) and dim to bright white lighting, as well as red illumination. Camera settings were systematically varied to include optimal images, out of focus and poor contrast images. The response of the VID systems was benchmarked against standard fire alarm systems using addressable ionization and photoelectric smoke detectors. Due to the limited space in this report only highlights of the experimental setup and results are provided. Full details of the extensive test program are discussed in Reference [2].

Experimental Setup and Procedures

Test Spaces

The tests were conducted in a 10 m x 10 m x 3 m high (33 ft x 33 ft x 10 ft) test facility that was divided into three compartments and a passageway. As shown in Figures 1, only the 5.9 m (19.5 ft) x 8.8 m (29.0 ft) compartment and the adjacent 10.0 m (33.0 ft) long by 1.2 m (4.0 ft) wide passageway were instrumented with detection systems and used as locations for fire and nuisance sources during the tests. Though the other spaces were not directly used, the doorways between all spaces were open during the tests, but the multi-room facility was closed and isolated from the lab. No active ventilation was used during the testing.

The compartment contained “overhead beams” constructed of steel sheeting. These simulated “beams” created visible obstructions (camera line of sight) as well as physical obstructions to smoke travel in the overhead. The simulated beam obstructions were secured to the overhead with a spacing of 1.2 m (4ft) and depths of 30 cm (12.0 in), the passageway had a smooth overhead. The compartments contained multiple visual

obstructions such as electrical cabinets, chairs, tables, office equipment, cable trays and ductwork.

Consistent with the range of various lighting conditions on U.S. Navy ships, four nominal conditions were studied in this work: 1) 7 footcandle (Fc), 2) 14 Fc, 3) 28 Fc and 4) red illumination. Lighting was installed in general accordance to the military standard (DoD-HDBK-289) in the overhead of the test compartments to provide the illumination comparable to various spaces onboard naval ships. Commercial 20-Watt, 120 VAC fluorescent light fixtures [Lithonia model number LB 2 20 120 LPF] were suspended approximately 0.3 m (12 in) below the overhead, making them flush with the overhead beams. Two 20-Watt fluorescent bulbs [General Electric model number F20T12/CW] were used with each light fixture. The 28 Fc light level included the additional use of halogen lamps. The red illumination was accomplished by covering the fluorescent bulbs at the 14 Fc setup with colored sleeves [Arm-A-Lite Safety Sleeves model number TP312W/R/T12]. Photometric surveys were conducted to ensure the uniformity and level of illumination at 0.76 m (30 in.) above the deck as defined in the military standard. The nominal illumination levels determined per the U.S. Navy guidelines were slightly less than desired, for example the calculated 14 Fc level had an initial value of 12.2 +/- 2.0 Fc across the space.

In addition to the changes in illumination and camera settings, different colored bulkheads were evaluated to analyze the video systems performance to various background colors typical of naval ships. Based on ship visits and design specifications, two colors were selected to provide a range of conditions. The test spaces were painted a standard Navy ship interior color of white and gray. The colors were matched by Sherwin-Williams to be indistinguishable by the naked eye to DOD-E-24607A chlorinated alkyl enamel paint color white (FED-STD-595 color No. 27880) and bulkhead gray (FED-STD-595 color No. 26307). The forward and port bulkheads were painted gray while the aft and starboard bulkheads in Compartment 1 were painted white.

Instrumentation

The primary instrumentation consisted of three video image fire detection systems and two commercial, smoke detection systems (referred to as Spot-1 and Spot-2) used to provide a benchmark of state-of-the-art, spot-type fire alarm equipment performance. Two of the three VID systems utilized both smoke and flame alarm algorithms; the third system used only a smoke algorithm. One of the systems with flame alarms utilized two different flame algorithms: one for fires in the field of view of the camera and an “offsite” algorithm for detecting the reflections of flames that are out of the field of view of the camera. All three of the video image detection (VID) systems used the same cameras located in the test spaces. Each camera image was sent to each VID system as well as a digital or VHS recorder via an amplified splitter.

The Spot-1 system smoke detectors were monitored using a corresponding manufacturer alarm panel with default alarm sensitivity levels, which were the least sensitive settings at 11.0%/m (3.5%/ft) for the photoelectric units and 5.1%/m (1.6%/ft) for the ionization units. The Spot-2 system detectors were controlled using a corresponding manufacturer alarm panel set to 6.76%/m (2.12%/ft) for the photoelectric units and 5.62%/m (1.75%/ft) for the ionization units.

The detector types and their respective locations in each test compartment were chosen to allow the response of the different detection methods to be compared based upon complete systems with full space coverage. The smoke detectors were installed to industry standards (i.e., NFPA 72 [3]). The VID systems were setup per the recommendations of each manufacturer. These systems received images from six cameras located around the periphery of the space as shown in Figure 1. These camera locations did not necessarily represent the optimum placement. Rather, the cameras were setup to provide a range of views that covered the entire test area. The optimum number of cameras and placement were evaluated by assessing the performance of different groupings of cameras within the spaces. Two models of standard CCD color cameras (Sony SSC-DC14 and Sony SSC-DC393) were used with Pentax manual iris 3.5 to 8 mm, variable focus lenses.

Fire and Nuisance Sources

Twelve fire and eleven potential nuisance sources were created to expose the detection systems to a range of scenarios. Small smoldering and flaming fires were used to challenge the detection systems and to provide performance results for early detection. The sources were located throughout the test spaces as shown with the numbered squares in Figure 1. Fire sources included smoldering and flaming cables and mattresses, various cardboard box fires and trash fires, and smoldering computer monitors and printed circuit boards. Potential nuisance sources were developed with a focus on the video detection systems as opposed to the spot-type smoke detection systems. These included, various numbers of people working and smoking within the space, waving white material, spray aerosol, overdone toast, welding, grinding steel, burst of sunlight, flash lights and flash bulbs.

Procedures

The focus and iris settings of the cameras were systematically varied for individual cameras to yield optimally set images, dark and light images, and out of focus images. The focus and iris of the cameras were adjusted to provide video images that were not optimal, yet still within tolerable conditions, in other words, conditions that may not evoke the need for immediate adjustments. The iris controls the amount of light into the camera; it is used to maximize and sharpen the division between dark and light objects (i.e., the contrast). If the iris is closed too far, the contrast will be very dark with loss of detail in parts of the image. If the iris is opened too far, the contrast decreases causing the image to become over exposed.

After baseline conditions were established for all camera settings and detection systems, sources were initiated and testing commenced. The test was terminated after all alarms had occurred or after conditions were deemed to have reached a maximum or steady-state level, such that no other detection alarms were anticipated.

Results and Discussion

A set of tests was conducted with all six cameras collocated at Camera Location 1 such that they had essentially the same view but different camera settings to yield a range of

optimal to out of focus and off-contrast images. The response of each algorithm (smoke and flame) was monitored individually for each VID system. Overall, the systems demonstrated the ability to detect smoke and fire for numerous camera settings and lighting conditions. Compared to VID system performance with the cameras set to provide optimal video images, the dark contrast and low illumination levels generally resulted in better detection of flaming fires, while the light contrast and high illumination levels resulted in improved detection of smoke. Although the VID systems demonstrated the ability to alarm to various camera settings and light levels, specific combinations of illumination, camera setting and VID system algorithm did result in undetected fires. The smoke algorithms for two of the systems generally did not alarm when cameras set to dark contrast were located in a compartment under red illumination. The flame algorithm for one of the same systems would not produce an alarm when the Sony SSC-DC393 cameras were in a compartment with red illumination. No problems were observed for the other model camera. With exception to these relatively extreme cases (cameras with dark settings at 14 Fc and then subjected to red illumination which made the images even darker), the VID systems were able to consistently produce alarms. These results indicate that the VID systems taken as a whole (i.e., considering the combined performance of both the smoke and flame algorithms) are not very sensitive to camera settings as long as reasonable video images are obtained; this includes images that are slightly out of focus and with non-optimal contrast.

The results collected indicate that the effect of potential shipboard background color on VID system fire detection performance is insignificant. The type of fire source and relative location to the field of view of the camera played a greater role in detection capability and activation times. For example, when a flaming fire is within the line of sight of the camera the VID-1 and VID-2 systems readily detected the fire source with the flame algorithms. When the fire was moved to an obscured location the flame algorithms became ineffective. The exception was the VID-1 offsite algorithm, considered an indirect flame algorithm, which maintains the ability to detect obscured flaming fires via detection of reflections. The tests indicate that the offsite algorithm may only be effective in circumstances where relatively bright or sizable reflection

areas are in the video image. In circumstances where the fire is across the room from the camera, fully behind obstructions, the general flickering illumination from the fire may not be sufficient. This diminished performance was observed for the flaming box fires, where the offsite algorithm did not pick up the fire when it was on the other side of the compartment. Additional work in the broader program [1], has shown that the use of near infrared video with luminosity algorithms are more sensitive to these lower intensity reflections [4].

An analysis was performed to assess the performance of the VID systems as a function of the number of cameras in the space. This analysis was based on a set of 83 tests in which the six cameras, set for optimal images, were distributed around the test compartment as shown in Figure 1. Figure 2 shows the percent of fires detected versus the percent of nuisance alarms as a function of the number of cameras used in the space for each VID system. As shown in the figure, using any two-camera combination in the test space, the two multi-algorithm VID systems alarmed to a range of fire sources and source locations with average alarm rates of 93% and 94%, respectively. The corresponding nuisance alarm rates were 33 and 17 percent, respectively. The third VID system did not perform as well detecting only 63% of the fires when considering any two-camera combination system in the space.

The commercial VID technologies clearly demonstrated the ability to alarm to more sources faster than the spot-type detection systems during the series of 83 multiple source fire tests. Based on the analysis above, Cameras 1 and 4 were selected as a representative two-camera system for the space. The performance of each VID system using this two-camera combination was compared to each of the spot-detection systems. Two aspects of detector performance were compared: number of fire sources detected and speed of detection. Table 1 presents the number of fire sources detected by each VID and spot-detection system. The VID-1 and VID-2 systems demonstrated comparable ability in detecting flaming fires to the Spot-1 and Spot-2 ion detection systems. The VID-3 system and the photoelectric detectors did not perform as well, detecting only 35 to 62% of the flaming fires. The VID-1 and VID-2 systems also detected more smoldering fires than the photoelectric spot-detectors, detecting 92% and 95% versus 76% and 71%, respectively. The results from the smoldering and flaming

fire tests were combined to give the overall performance of the systems. The VID-1 and VID-2 systems detected 95% and 96% of the fires, whereas the next best performance was the Spot-1 ion system, alarming in 67 of the 83 fires or 81%.

The VID systems and spot-type detection systems alarm times were compared on a test-by-test basis to identify detection performance as it pertains to speed of detection. In general, the Spot-1 ion detectors produced the quickest alarm times in a majority of the flaming fires while the VID systems produced quicker alarm times for the majority of the smoldering sources. When the Spot-1 ion detectors did produce a quicker alarm during a flaming fire, it was nearly 2 minutes before the VID systems. When the VID systems produced quicker alarms during the smoldering sources it was approximately 4 to 7.5 minutes before the spot-type detectors (ion or photo). One notable deviation from the general trend is this; the VID-1 system alarmed faster to more fires than all of the VID and spot-type detection systems, with faster alarm times independent of source type and type of spot detector.

The passageway provided a space with a different aspect ratio than used in any prior tests. The change in dimensions narrowed the field of view of the cameras. In general, the VID systems had similar alarm responses to fires, such as the flaming boxes and smoldering cable fires, in the passageway and in the compartment. Overall, the passageway did not present any clearly identifiable issues for the VID systems that were not identified in the compartment tests for either fires or nuisance sources.

Conclusions

Real-scale fire tests in mock ship compartments were conducted to evaluate the fire detection performance of three commercially available video image fire detection systems under various lighting and camera setting configurations. The VID systems demonstrated the ability to detect smoke and fire for numerous camera settings and lighting conditions, indicating reliable performance for sub-optimal video images. Using a two-camera system in the same compartment with two spot detectors, the VID systems generally detected more fires and also detected fires, particularly smoldering, faster than the spot-type detection systems.

References

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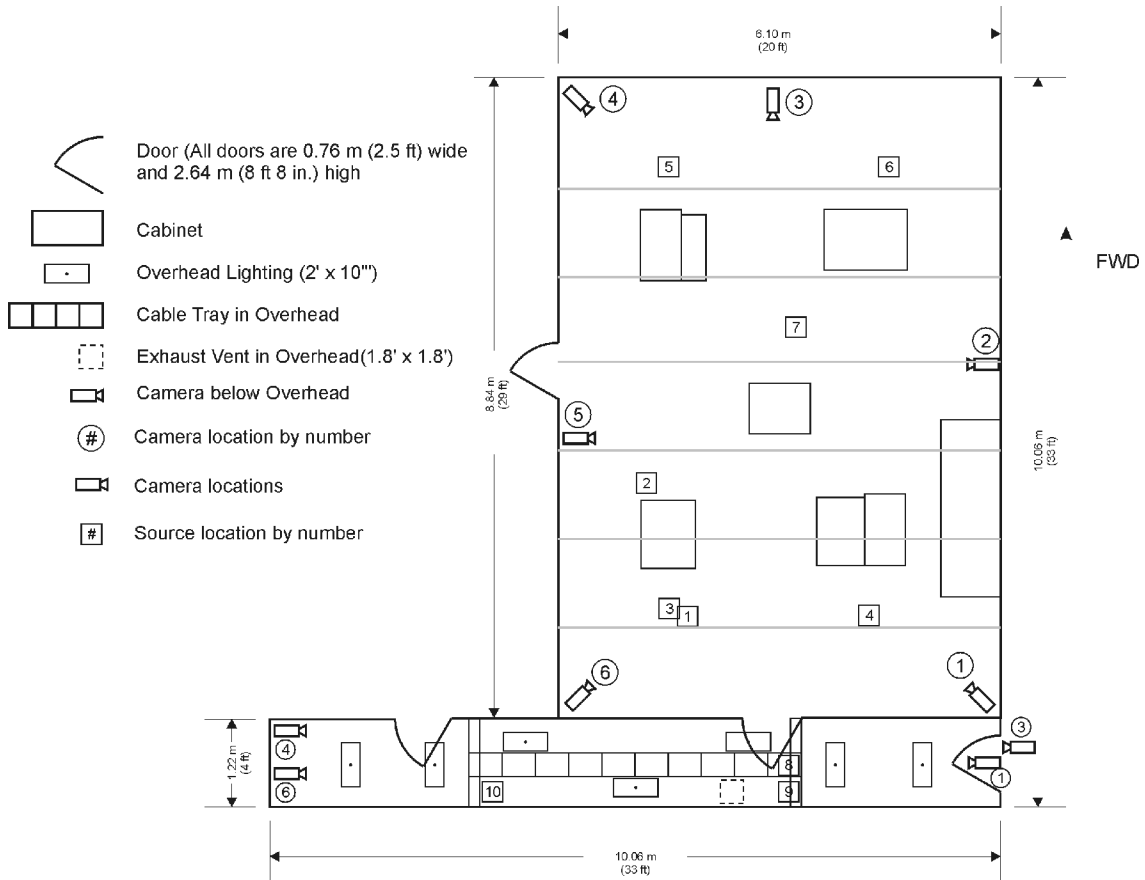


Figure 1. Schematic of experimental setup

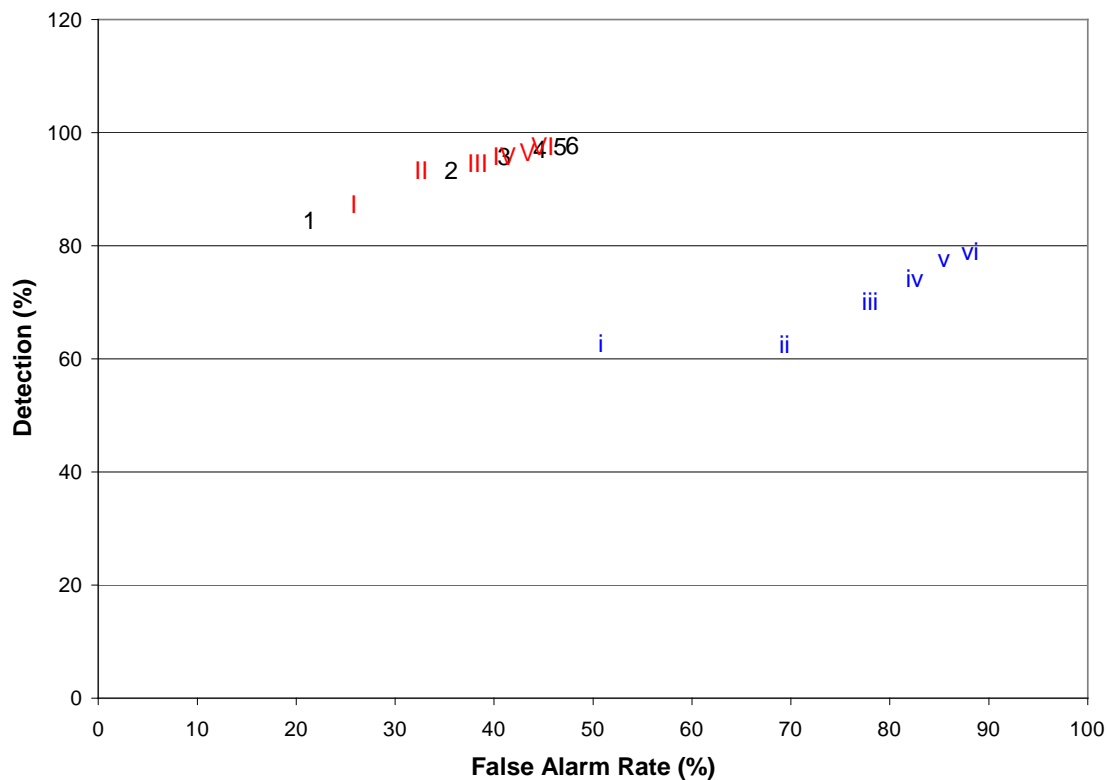


Figure 2. A plot of the percent of fire sources detected versus the percent of nuisance sources detected for various numbers of cameras in a VID system. The numbers indicate the quantity of cameras in a system. The color and font identify the system: black (1,2) is VID-1, red (I, II) is VID-2, and blue (i, ii) is VID-3.

Table 1. Ratios and percentages of sources detected by each detection system to the total number of sources tested for smoldering and flaming fires.

	Number of Flaming Tests	Number of Smoldering Tests	Total Number of Tests	% Alarm Activation (Flaming)	% Alarm Activation (Smoldering)	% Alarm Activation (All Tests)
VID-1	34/34	45/49	79/83	100%	92%	95%
VID-2	33/34	47/49	80/83	97%	96%	96%
VID-3	21/34	31/49	52/83	62%	63%	63%
Spot-1 Ion	34/34	33/49	67/83	100%	67%	81%
Spot-1 Photo	12/34	37/49	49/83	35%	76%	59%
Spot-2 Ion	34/34	19/49	53/83	100%	39%	64%
Spot-2 Photo	15/34	35/49	50/83	44%	71%	60%