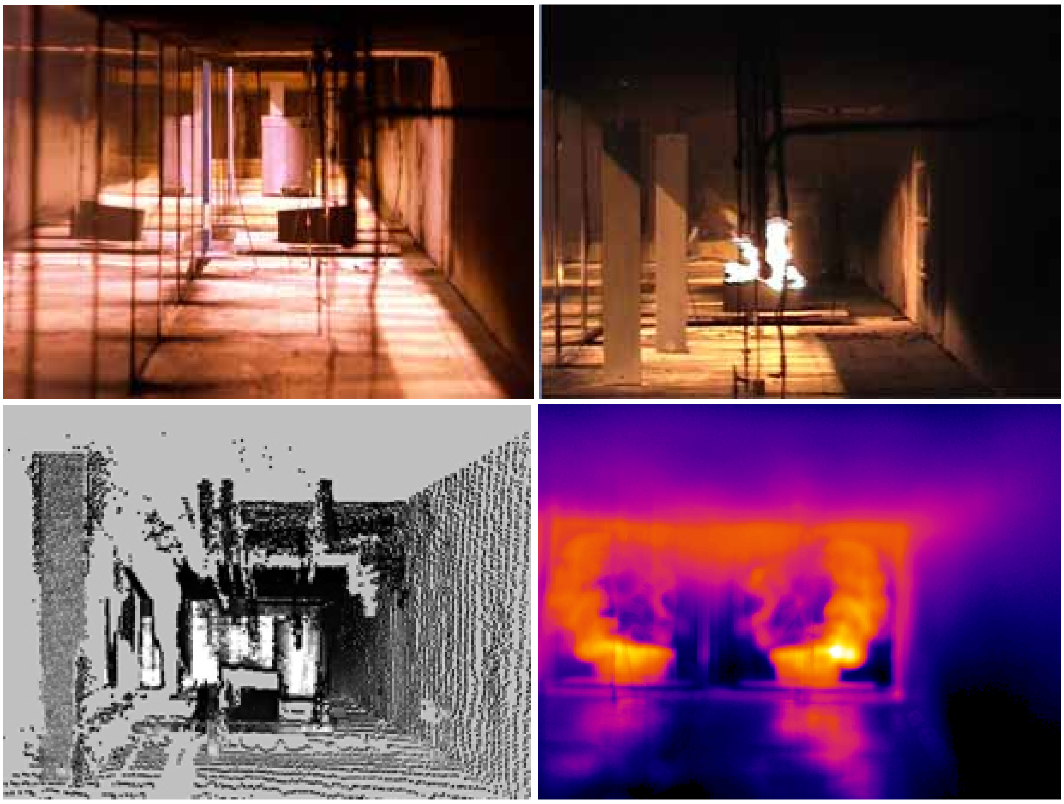
Measurements with Laser Radar During Fire Experiments in a Tunnel

Anders Lönnermark, Dietmar Letalick, Håkan Larsson and Haukur Ingason



Fire Technology

SP Report 2008:35

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Abstract

The conditions during a fire in a tunnel can become very severe due to flames and dense smoke. The rescue service may have difficulties to find tunnel occupants in need of assistance. IR cameras are often used to find occupants, but they have limitations. It may be very problematic to bypass or see through flames with IR cameras. Therefore, it is of interest to develop other methods that may solve the problem of optically seeing through flames.

Fire tests were performed where the ability of different systems to register a target (blasted aluminium bucket) behind a fire was evaluated. During the measurements three different types of optical instruments were added to the test set-up: 1) a system for gated viewing (GV), Aqua Lynx, 2) a 3D laser scanner, ILRIS-3D (ILRIS), and 3) a thermovision camera (THV), ThermaCam® SC2000. A DV camera was also used for visual documentation.

The tests show that the gated viewing system had problems registering the target when the smoke became dense. Some improvement could be made by optimising the setting of detector parameters, etc. However, the gated viewing system needs to be set to a specific distance which is a limitation.

The 3D laser radar (scanner) proved to be able to see through smoke, provided it was not too dense, and flames and was in that sense better at detecting the target than both the thermal vision system and the visual technique of the DV camera. This means that this system should have the ability to help the rescue services in situation where the IR cameras or visual aids have limitations.

Key words: tunnel, fire, measurements, 3D laser scanner, IR

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Preface

The work presented in this report was sponsored by SP, FOI, FORMAS (The Swedish Research Council) and the EU-project L-SURF (Large-Scale Underground Research Facility on Safety and Security). Within L-SURF, the work is a part of the work package (Work Package 4) dealing with the development of new measuring techniques. A special focus was on testing a sensor that has a 3D measuring capacity.

1 Introduction

In the case of a fire in a tunnel, the safety of the tunnel occupants is the most important issue. IR-cameras can be a good tool for the rescue services to use and find people trapped in the smoke. The IR-camera can, however, in such cases be disturbed by the temperature of the flames or fire gases that are considerably higher than that of humans during a fire. There are alternative methods available to observe objects through flames and smoke and these methods have been investigated here. In particular 3D optical measuring techniques traditionally used in other fields of science than fire were investigated and tested.

Fire experiments in a model-scale tunnel were used to test these techniques. The results are compared to IR-measurements during the same type of tests. The tests were performed in connection with another test series that is presented in a separate report [1]. In that report the model-scale tunnel with its components and measurement equipment is also described in more detail. Only the parts of the experimental set-up important for the study presented here are included in this report.

The work presented here was conducted as part of the work package (Work Package 4) dealing with development of new measuring techniques in the EU-project L-SURF (Large-Scale Underground Research Facility on Safety and Security). L-SURF was a feasibility study into the establishment of a pan-European facility for research on safety and security in underground constructions.

One of the main objectives of L-SURF concerns measurement techniques as it is important to investigate the requirements for new measurement technologies which are needed for a versatile large scale facility. The work presented here concerns equipment and measurement technologies for a new large scale facility. Other parts of the L-SURF project on measurement technology and visualisation of the measured data are presented in other reports [2-6].

2 Experimental set-up

A scale-model tunnel (scale 1:20) was built in one of the fire halls at SP Fire Technology. The ceiling, floor, and one of the walls were made of 15 mm thick PROMATECT®-H boards. One of the walls was comprised of 15 windows (555 mm × 410 mm visual access plus frame) of 5 mm thick fire proof glass. The tunnel was 10 m long (see Figure 2.1). The height of the tunnel was 40 cm. The width was varied between 45 cm and 60 cm. An air flow was created in the tunnel by a fan (at the left side of the tunnel in Figure 2.1, see also Figure 2.2). More details on the tunnel and other tests performed in the same tunnel can be found in a separate report [1].

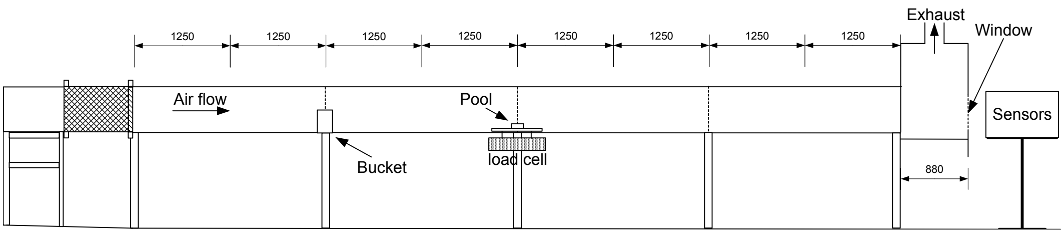

Figure 2.1 Side view of the model-scale tunnel.

Figure 2.2 The model-scale tunnel built at SP Fire Technology.

3 Description of the measurement equipment

During the measurements three different types of optical instruments were added to the test set-up: 1) a system for gated viewing (GV), Aqua Lynx, 2) a 3D laser scanner, ILRIS-3D (ILRIS), and 3) a thermovision camera (THV), ThermaCam® SC2000 (see Figure 3.1). The systems are described in separate sections below. Comparisons with the thermovision system are presented in the Results section. A DV camera was used for visual documentation.

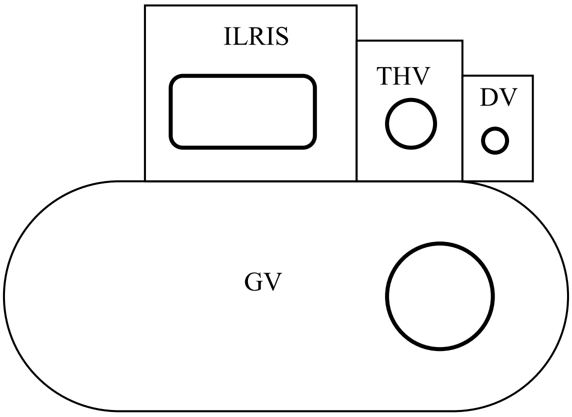

Figure 3.1 A package of optical sensors including a gated viewing camera (GV), a laser scanner (ILRIS), a thermovision camera (THV), and a DV camera.

3.1 Gated viewing camera, Aqua Lynx

Aqua Lynx (see Figure 3.2) is a gated viewing pulsed laser camera optimized for submerged application. Gated viewing laser camera systems are developed to have the capability to see through rain, snow, fog, and smoke. In these tests the capability of seeing through smoke is tested. The shutter can be opened and controlled precisely. This makes it possible to decide where to see and how far. By not opening the shutter until the laser beam has passed a certain obstacle (in this case the smoke), it is possible to see what is hiding behind. The laser used in the Aqua Lynx is not eye-safe and safety goggles are needed. Table 3.1 summarises some of the technical details of the system.

Figure 3.2 The gated viewing laser system Aqua Lynx.

Table 3.1 Technical data of Aqua Lynx.

Parameter	**Data**
Wavelength	532 nm (Nd:YAG; green)
Pulse repetition	0.2 Hz
Pulse length	7 ns
Pulse energy	7 mJ
Beam divergence	25 degrees
Resolution	350 × 250 pixels
Weight	35 kg

3.2 3D laser scanner Optech ILRIS-3D

Optech ILRIS-3D (Intelligent Laser Ranging and Imaging System) is in addition to a laser also a detector and an advanced scanner. To obtain the distance to the target of the laser beam, the time in air of the beam is measured (Time-of-flight, TOF). An accurate scanning of the laser beam between each laser shot, both horizontally and vertically, gives points in three dimensions. Each laser shot has its own coordinates in space (x, y, z) and intensity. The laser of the ILRIS is considered eye-safe outside the optical equipment of the apparatus. Table 3.2 contains a summary of some of the technical details of the system.

Figure 3.3 The laser scanner Optech ILRIS-3D

Table 3.2 Technical data of Optech ILRIS-3D

Parameter	**Data**
Wavelength	1540 nm (Nd:YAG; green)
Pulse length	<10 ns
Laser power	10 mW
Maximum measurement distance	350 m (4% reflectance) 800 m (20% reflectance)
Accuracy (single shot)	X-Y @ 100 ±8 mm; Z @ 100 m ±7 mm
Scanner field of view	40° × 40°
Beam divergence	170 μrad
angle resolution	26.6 μrad
Sampling frequency	2000 points/s

3.3 ThermaCAM® SC2000

ThermaCAM® SC2000 by FLIR is an infrared (IR) camera (or thermographic or thermovision camera). IR cameras are often used by the rescue services to search for people in smoky environment. The IR camera was here included and used to compare with the systems described above. The SC2000 utilizes an uncooled microbolometer detector. Table 3.3 contains a summary of some of the technical details of the system.

Table 3.3 Technical data of ThermaCAM® SC2000

Parameter	**Data**
Measurement accuracy	± 2 %
Thermal sensitivity	< 0.08 °C @ 30 °C
Field of view (F × V)/min. focus distance	24° × 18° /0.5 m
Detector type	Focal Plane Array (FPA), uncooled microbolometer, 320 × 240 pixels
Spectral range	7.5 – 13 µm, built-in atmospheric filter with cut-on @ 7.5 µm.

4 Experimental procedure

Three tests were performed with the different sensor systems. In all three tests, a pool fire (155 mm × 160 mm) with heptane was used (see Figure 4.1). Since the tests were part of a larger test series, the tests will be referred to as Test 6, Test 8, and Test 9. The other parts of the test series are presented elsewhere [4, 7, 8]. In Test 6 and Test 9 the heptane pool was placed on the centre line of the tunnel, while in Test 8 it was placed so that one side of the pool was 10 cm from one of the side walls. The pool was filled with heptane to give a 50 mm layer. Since the pool was standing on a Promatect®-H board with the upper surface 20 mm above the tunnel floor, the fuel surface was 70 mm above the tunnel floor. The mass of heptane was in the three tests 848 g, 842 g, and 856 g, respectively. The total burning time was approximately 12 minutes. The heat release rate curves for the three fire tests are presented in Section 5.

Figure 4.1 The heptane pool on a Promatect®-H board, connected to a load cell.

The width of the tunnel was 45 cm in Test 6 and 60 cm in Test 8 and Test 9. The gas flow in the tunnel was maintained using a fan at one end of the tunnel. In Test 6 the centre line air flow was approximately 0.67 m/s, while it was approximately 0.5 m/s in the other two tests.

The gated viewing system Aqua Lynx was used in Test 6, while the laser scanner Optech ILRIS-3D was used in Test 8 and Test 9.

As a target to be recorded by the different systems, a blasted aluminium bucket was used. In Test 6 it was placed 2 m into the tunnel, i.e. 8 m from the exit. In Test 8 and Test 9 the bucket was place 2.5 m into the tunnel. In Test 6 the bucket was placed somewhat to the left of the centreline (closer to the wall with windows), see Figure 4.2. In Test 8 the bucket was placed on the centreline, while in Test 9 the bucket was placed more to the right (closer to the back wall).

In Test 9 two white target plates were added, 289 cm and 166 cm from the exit of the tunnel (see Figure 4.3).

Figure 4.2 **The target constituted of a blasted aluminium bucket. This was placed 2– 2.5 m into the tunnel (the distance was varied between the tests), i.e. 7.5–8 m from the exit from the tunnel. The pool with heptane was placed 5 m from the exit of the tunnel. The photos are from Test 6.**

Figure 4.3 **White target plates were used in Test 9, to get a good picture of the distance the different systems could “see” through the smoke.**

5 Results

5.1 The fire

In each of the three tests presented and discussed in this report, a pool with heptane was used. The size and development of a fire can be defined by the heat release rate (HRR). In Figure 5.1 the HRR curve for each test is presented. The high peak at approximately 10 min in Test 8 is the result of the restart of the fan after a stop due to an electrical ground fault.

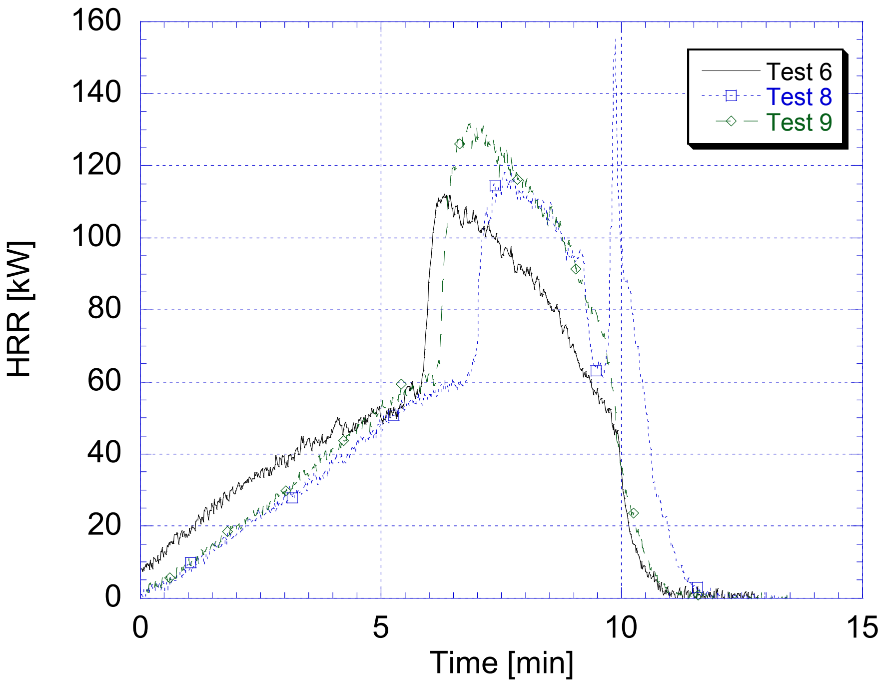

Figure 5.1 Heat release rate (HRR) for the three tests (Test 6, Test 8 and Test 9).

Figure 5.2 Heptane fire during Test 8.

5.2 Reference measurements

To get a picture of how the sensors see the target during a fire, reference measurements were conducted during non-fire conditions. For Aqua Lynx the distance gate was set so that the laser light from the area with the bucket was detected.

Figure 5.3 Reference picture from the gated viewing system Aqua Lynx, taken before the start of Test 6.

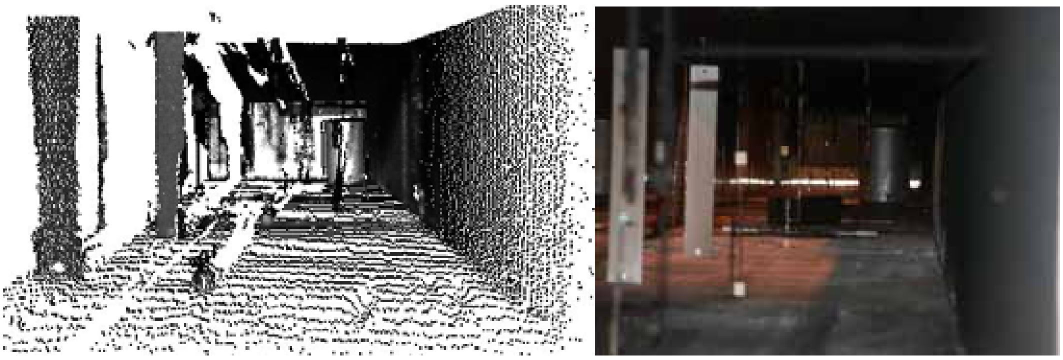

Figure 5.4 Reference picture for ILRIS-3D, taken before the start of Test 9, compared to a digital photograph.

When the tunnel is cold and there are no flames or hot smoke present, there is no contrast between the target (bucket) and the background in the registration of ThermaCam® SC2000 (see Figure 5.5). The open flame from the ignition source can be seen. The dark field in the centre of the picture is the fuel pool. The image is mirrored in the glass in the left wall. However, the bucket cannot be seen.

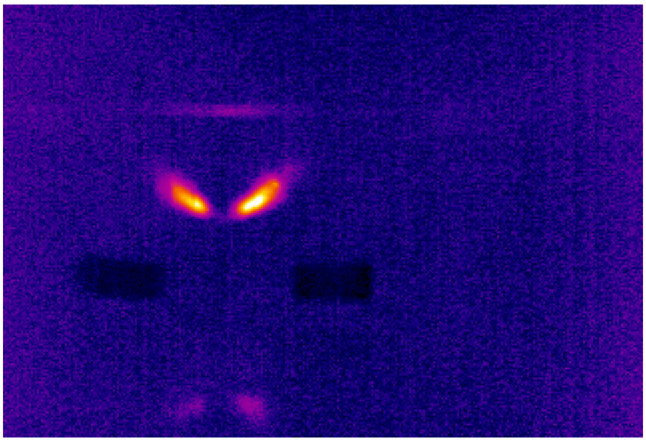

Figure 5.5 Reference picture for ThermaCam® SC2000 (IR camera) just before the ignition of the pool fire (the flame from the ignition source can be seen).

5.3 Results from measurements with the gated viewing camera, Aqua Lynx

It was difficult for the gated viewing system to see the bucket. The gain in the receiver was not changed during the tests. The result was that the bucket was only visible when the smoke was very thin. For thick smoke the image was black. It is possible that the bucket would have been visible for a longer period of time (i.e. through thicker smoke) if more adjustments have been made during the test.

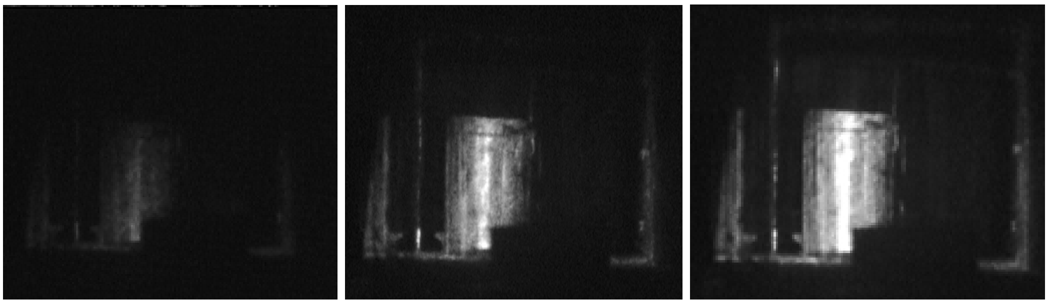

Figure 5.6 Series of images from the Aqua Lynx system. From left to right, the smoke gets thinner during the last 30 s of the fire.

5.4 Results from measurements with the 3D laser scanner, Optech ILRIS-3D

The resolution on the bucket was set to approximately 4 mm. In Table 5.1 the visible height of the bucket and percentage of points hitting the bucket during Test 9 are presented. The visibility is significantly decreased after 4–5 minutes.

In Figure 5.7 to Figure 5.12, results obtained from the Optech ILRIS3D during different periods of the fire are presented. Digital photographs are also included. The decrease in visibility of the bucket can be clearly seen from the images. However, in Figure 5.12 it can be seen that after 10 minutes, when the smoke is not as dense, that the bucket is completely visible with the laser scanner system. The flames do not constitute any problems for the system, while the bucket is completely obscured in the photograph. One should also note that in the tests there were several measurement sensors (for temperature and velocity measurements) obscuring the view. Those sensors can be observed both in the image from the Optech ILRIS3D and in the photos.

Table 5.1 Summary of the measurements with Optech ILRIS-3D during Test 9.

Time after ignition [min]	Visible height of the bucket [cm from the bottom]	Visible points [number; fraction in relation the total number at start (%)]	Figure nr
At ignition.	24	1525; 100 %	Figure 5.7
2	24	1474; 95 %	Figure 5.8
3	19	1302; 85 %	Figure 5.9
4	18	1289; 84 %	Figure 5.10
5	12	834; 55 %	-
6	8	579; 38 %	-
7	9	580; 38 %	Figure 5.11
9	10	583; 38 %	-
10	24	1054; 69 %	Figure 5.12

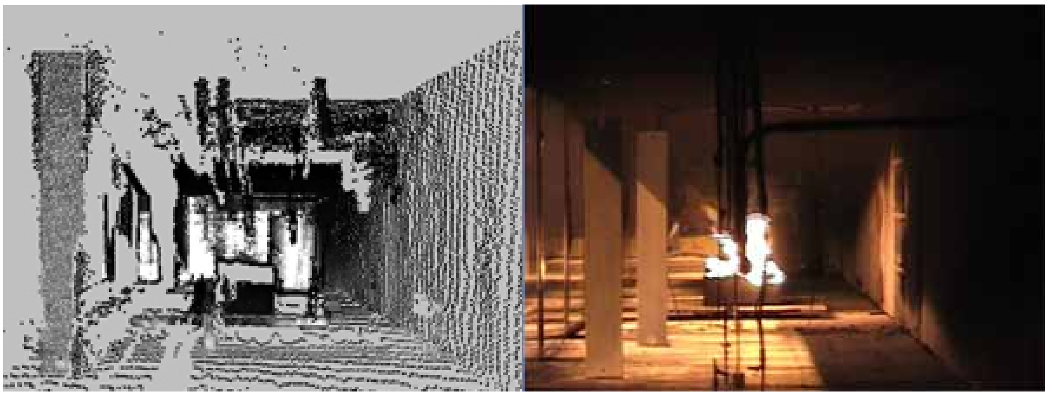

Figure 5.7 Results from ILRIS-3D and photo from Test 9, just after ignition.

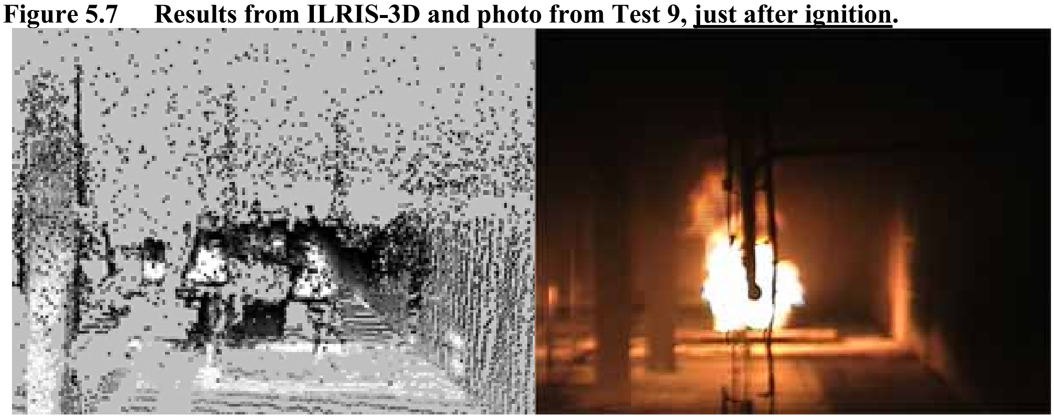

Figure 5.8 Results from ILRIS-3D and photo from Test 9, 2 minutes after ignition.

Figure 5.9 Results from ILRIS-3D and photo from Test 9, 3 minutes after ignition.

Figure 5.10 Results from ILRIS-3D and photo from Test 9, 4 minutes after ignition.

Figure 5.11 Results from ILRIS-3D and photo from Test 9, 7 minutes after ignition.

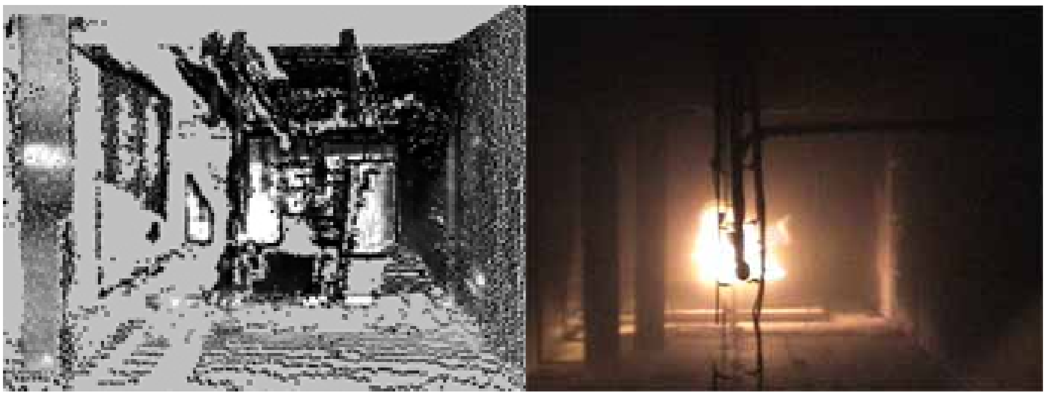

Figure 5.12 Results from ILRIS-3D and photo from Test 9, 10 minutes after ignition.

5.5 Results from measurements with ThermaCam® SC2000

In Figure 5.13 images taken with the ThermaCam® SC2000. Since a thermovision camera measures the heat passively, it cannot "see" behind the fire. In the left image, taken two minutes after ignition, the bucket cannot be observed. Note that there is a reflection of the thermal image in the windows on the left hand side wall.

When there are no flames, the temperature difference between the bucket and background makes it possible to discern the bucket. However, it is difficult to observe its shape and in Figure 5.13 one really needs to know that the bucket is present to observe it.

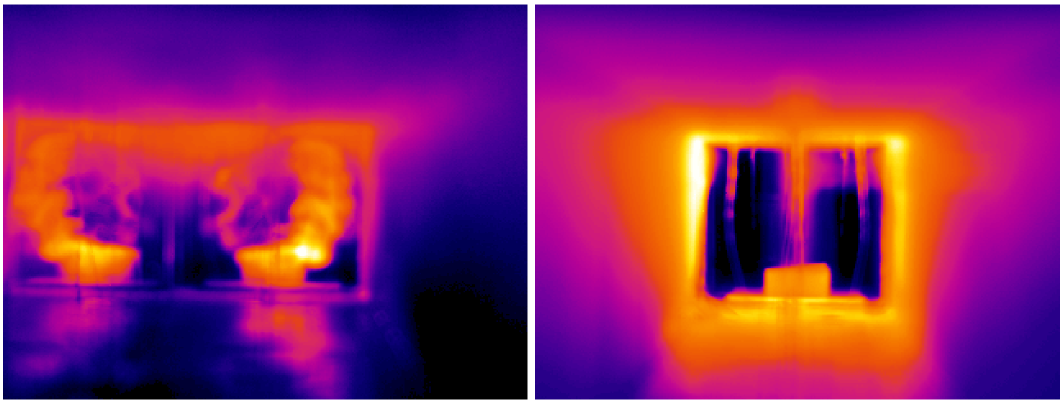

Figure 5.13 Images from the ThermaCam® SC2000. The left image is taken 2 minutes after ignition, while the right image is taken a few minutes after the fire.

6 Discussion and conclusions

Fire tests were performed where the ability of four different systems to show a target (blasted aluminium bucket) behind a fire has been presented and compared. The gated viewing system (Aqua Lynx) had problems registering the target when the smoke became dense. There might be room for improvement through optimisation of setting of detector parameters, etc. However, the gated viewing system needs to be set to a specific distance which is a limitation.

The laser radar scanner (Optech ILRIS3D) proved to be able to see through smoke, provided it was not too dense, and flames and was in that sense better at detecting the target than both the thermal vision system (ThermaCam® SC2000) and the visual technique of the DV camera. This means that this system should have the ability to help the rescue services in situations where the IR cameras or visual aids have limitations. One important advantage (in addition to the scientific results) of the ILRIS system over gated viewing system Aqua Lynx is that the laser of the former is eye-safe while the laser of the latter system is not.

The laser radar systems needs to be further investigated concerning how it is affected by for example the concentration of soot, soot particle size (distribution), distance, etc. Since IR cameras have been used by the rescue services for some time, they have been developed for the purpose. Therefore, development of the laser systems probably needs to be practical and user friendly in the same way.

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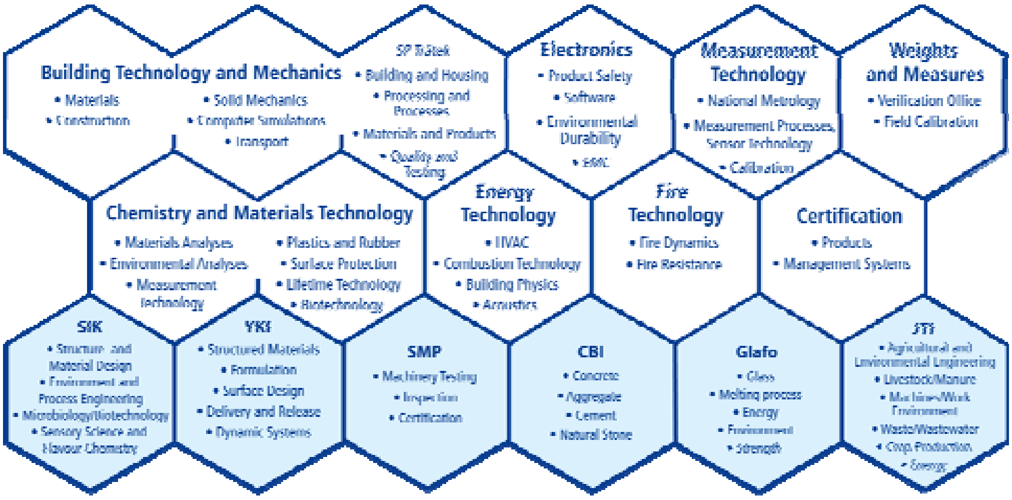

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