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Editors: Kellie Beall, William Grosshandler and Heinz Luck



NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

T. Wittkopp, C. Hecker, D. Opitz

VIDAIR-AG, An der Eickesmühle 22/23, 41238 Mönchengladbach, Germany

The Cargo Fire Monitoring system (CFMS) for the visualisation of fire events in aircraft cargo holds

1 Introduction

Fire on board of an aircraft represents one of the most dangerous in-flight situations. Following a fire alarm from the freight compartment, the pilot is obliged to immediately activate the fire suppression system before proceeding with an emergency landing.

Up to now, detection of fire has most always meant the detection of smoke by threshold devices like photoelectric or ionisation smoke detectors. These devices are trouble-prone and lead to a reported rate of up to 200:1 false to genuine alarms [1]. Blake surveys fire alarms in aircraft cargo compartments from the last 25 years and finds that both the number of false alarms and the ratio of false to real alarms is steadily increasing [1]. This is also due to the conversion of class D to class C compartments, resulting in an increased overall number of fire detection units. This high rate of false alarms is unacceptable, as an alarm, followed by a diverting and landing at nearest suitable airport, causes high costs of approximately \$50,000 [1] and is possibly connected with a higher safety risk due to a variety of factors such as unfamiliar airports, less effective navigational aids, shorter runways, inferior fire fighting and the loss of the cargo load. Fire alarm may entice the pilot to an inadequately riskily landing, for example ditching on water during an over-water flight, and generally limits the credibility of fire alarm systems. Nevertheless, an unnecessary use of the fire suppression system often results, for the moment, still in an unwanted release of Halon 1301, which is identified as one of the substances contributing to stratospheric ozone depletion.

Additionally, with common threshold detectors used in “air tight” cargo areas, the smoke alarm equipment will continue to report an alarm condition, even if the fire has been extinguished by the suppression system. Thus, the pilot has no chance to know, if

a fire has been extinguished or if it is even continuing to grow. This situation is found to be unsatisfying and it is stated, that the pilot should have better and more reliable information about the cargo compartment status, especially about the fire growth and the effectiveness of fire suppression actions [2].

Cleary and Grosshandler [3] provide a broad survey on fire detection in aircraft cargo compartments, especially concentrating on the more common fire detection methodologies.

Digital imaging more and more becomes a means for the detection of fires [4-8]. Very early, Goedeke et al. [5] describe a detection system which is capable to detect open fire sources. Ultraviolet and infrared detectors produce event signals, an image processor then evaluates images from a colour video camera to determine bright area objects to confirm the fire event. In a detailed approach, Foo [6] applies a rule-based machine vision approach to detect and categorize hydrocarbon fires in aircraft dry bays and engine compartments. A set of heuristics based on statistical measures derived from the histogram and image subtraction analyses of successive image frames is used to differentiate between the fire and the non-fire status. Cheng et al. [7] propose a new video fire detection system and examine the underlying principles of a video based fire detection system in a more general way. They mainly conclude that fire detection could be carried out with the same video unit as the regular video observation and that is well suited for the fire detection in large spaces like warehouses. Another approach uses a colour video camera to monitor temperature and species sensitive sensors which change colour at a prescribed temperature or carbon monoxide concentration [8].

Fire detection by digital imaging is fast, can cover wide areas of observation and additionally allows visual inspection, e.g. in the case of an alarm. Most often, only the visible or infra-red radiation of a fire is monitored, which limits the detection to open fire sources. This is unsatisfactorily, because smouldering fires might remain undetected for long periods of time, containing a high risk of a sudden turning to a large open fire.

To partly overcome these restrictions, a new fire detection system based on digital imaging (CFMS) is introduced which creates the basis for an in-flight cockpit video surveillance system, combined with fire detection capabilities. It allows the fast detection of both open and smouldering fires and additionally the verification of fire alarms given by other, standard fire detection systems and the monitoring e.g. of fire growth and fire suppression actions in closed spaces like in aircraft cargo compartments. Deviating from most approaches, a fire can be detected and monitored even when the flame itself is not visible. This is done by a combination of a special illumination technique and a digital imaging algorithm which is capable to clearly emphasise the relevant fire signatures. These signatures include smoke and its characteristic properties, the visible light emitted from the fire and reflected from the walls and characteristic periodic phenomena like fire flickering.

The underlying concepts of this novel video-based fire detection system are described in detail and the advantages and limitations are discussed. To evaluate its efficiency, results are presented from experiments that were conducted in a mock-up of a typical aircraft cargo compartment.

If a fire is detected, it is very useful to have the opportunity to visually inspect the compartment. Unfortunately, it is almost not possible to perceive relatively small amounts of smoke. This is especially true if the scene is observed through a small gap as it is the case with containers loaded into the compartment (Fig. 8a) or the smoke develops slowly because human vision adapts on the slowly changing scene. Therefore, an algorithm is presented to drastically enhance the visibility of smoke or fire respectively and is discussed.

2 Experimental

Experiments are performed in a compartment as figured in Fig. 1. Various configurations, varying in the test fires used and the underlying set-up of lamps, cameras and the fire places were implemented from which a small selection is presented here (Table 1). The cargo compartment is monitored with a camera and the video stream is captured both real-time with a computer device and on tape.

2.1 Test location

The tests are performed in a mock-up of an Airbus A340 cargo compartment (Fig. 1), both in an empty (unloaded) cargo room and with two containers loaded into the compartment which confine the camera's field of view to a narrow band of 7 cm height. The difference between the two implementations is that in the case of the unloaded cargo freight, the fire, which is located on the floor, lies within the camera's field of view. In the other case, the camera peers through the gap between the compartment ceiling and the container's top, which makes the proper detection of fire more complicated because the fire can only be observed indirectly by the ascending smoke and the reflections of the fire glow.

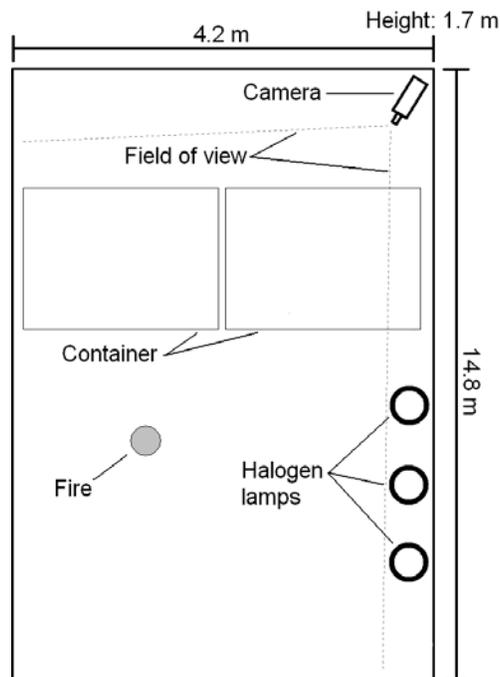


Fig. 1: Cargo bay mock-up (Airbus A340) as used within the framework of the fire tests

2.2 Test fires

Three test cases are defined in Table 1. The two mentioned test fires are described below.

2.2.1 Smouldering wood fire

About 25 pieces of birch wood (Dimensions 3.5 x 1 x 2 cm³) are placed on a heating plate which is provided with concentric ribs. Smoke of bright colour is produced after approx.. 3-5 min of heating

2.2.2 Open polyurethane foam fire

Two layers of polyurethane foam (Dimensions 25 x 25 x 2 cm³) are stacked one above the other and are ignited. A bright flame develops which produces large amounts of dark smoke.

Test case	Test fire, according to EN-54 [9]	Fire-type	Material	Container
1	TF4	open plastic fire	polyurethane foam	no
2	TF4	open plastic fire	polyurethane foam	yes
3	TF2	smouldering pyrolysis	wood	yes

Table 1: Definition of test cases 1-3

2.3 Imaging system, cameras and illumination

Regular BAS-video cameras in combination with a computer are used to record the scenes in digital form. Halogen lamps illuminate the scene. The set-up is shown in Fig. 1. It is noticeable that the lamps illuminate the scene indirectly in the sense of a dark-field illumination. This permits the visualisation not only of the open fire but of the smoke too, which would be invisible without lighting.

2.4 Image processing

Foo [6] describes the basis for a fire detection system based on digital imaging and statistical analysis of the frames.

Among other, the mean \bar{g} and the standard deviation σ of the pixel values of one image are identified as parameters that determine whether a fire is likely or is not.

The mean \bar{g} is defined as follows:

$$\bar{g} = \frac{\sum_{i=1}^n g_i}{n} \quad (1)$$

The standard deviation is defined as:

$$\sigma = \sqrt{\frac{\sum_{i=1}^n (g_i - \bar{g})^2}{n - 1}} \quad (2)$$

A fire is likely if the mean \bar{g} of the image pixels is high, according to a very well lit room. A large standard deviation σ , which means that there are bright spots on dark background, then verifies the fire.

A fire is unlikely if the mean \bar{g} and the standard deviation are both low. Thus, to detect a fire, the time-dependent mean and the standard variation is monitored and a fire alarm is released if the change exceeds the pre-determined thresholds.

For the enhancement of smoke visibility, it is necessary to have a reference image. This can be calculated as the mean of the time series of undisturbed images, recorded in the non-fire-case. The actual image is first smoothed and then subtracted from the reference image, yielding after suitable thresholding the smoky areas as bright regions, which can be superimposed with the actual image to result in an image which can be easily interpreted (Fig. 8).

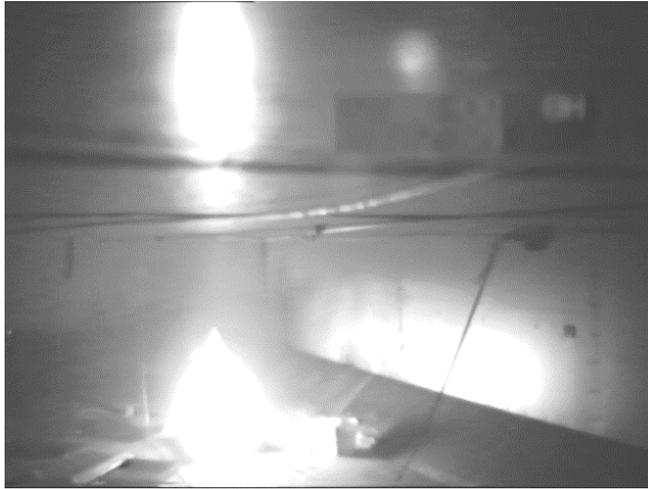


Fig. 2: Fire according to Test-case 1, 180 s after beginning of experiment

a)



b)



Fig. 3: Fire according to Test-case 2, viewed through the gap between container and ceiling. The fire itself is hidden.

a) Before fire is ignited.

b) 100 s after beginning of experiment, fire is fully developed.

3 Results and Discussion

For various test cases (cf. Table 1), time-dependent sets of the mean \bar{g} and the standard deviation σ are computed. The results are shown in Fig. 4-Fig. 6.

For test case 1 (polyurethane fire without container, Fig. 2), there is a good response of both the mean \bar{g} and the standard deviation σ (Fig. 4) to the fire. The mean approximately doubles and the standard variation rises by a factor of 3.

For test case 2 (polyurethane foam fire with container, Fig. 3), the response is much smaller, what could be expected due to the smaller relative image region where the fire itself or its luminosity is visible (Fig. 5).

In test case 3, the mean is approximately constant while the standard variation rises about 20% (Fig. 6). This is quite small compared with the test cases 1 and 2 but significant in relation to the statistical fluctuations of the values $\sigma(t)$. Nevertheless, it has to be considered the relatively small amount of smoke produced in that experiment. The response function can be improved if the image region is divided into separate, non-overlapping windows and the calculation of the mean and the standard variation is done for each individual window. To demonstrate, for test case 3 the image is divided into 4 sub-windows, 2 in the horizontal direction and 2 in vertical direction and statistical data is calculated for each sub-window. In Fig. 7, the calculated mean for the 4 single windows is presented.

It can be recognized, that the mean of the windows in the image's upper half (window (1,1) and (2,1)) remain constant because the regions mapped by two windows are not affected by changes induced by the developing fire. The mean in the lower left window (1,2) grows around 4% and the mean in the lower right window (2,2) lowers about 3%, which is significant compared to the variation range of the undisturbed values $\bar{g}(t)$. The increase is due to the illumination of the smoke by the halogen lamps which are located on the left hand side of the image. The decrease in the lower right window can be explained with the light attenuation from the left to the right.

In Fig. 8 a comparison between a source image and the processed image is presented, where the smoke is emphasized to improve its visibility. From this example it is obvious that this emphasis leads to a better observability of the fire situation, allowing a better estimation whether a fire alarm is real or is not and, if the alarm is real whether there's a large open fire or a less dangerous smouldering fire.

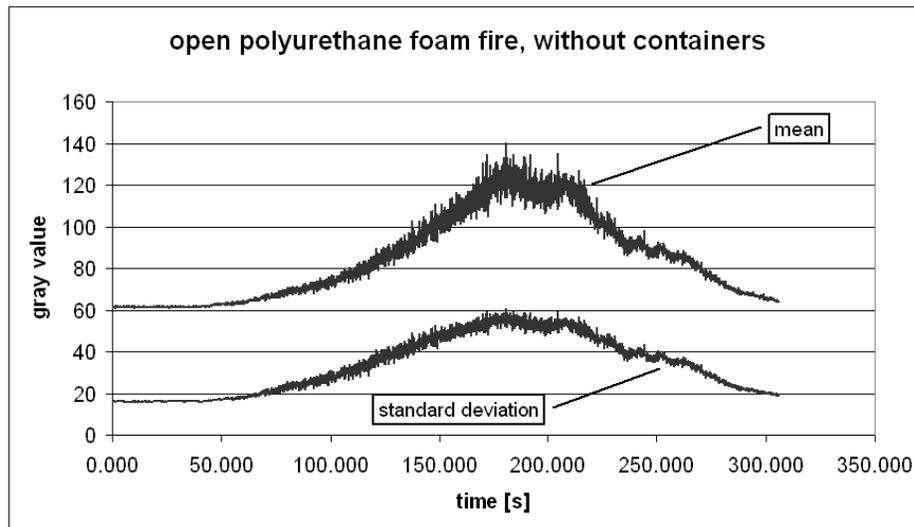


Fig. 4: Time-dependent mean and standard deviation for an open polyurethane foam fire, without containers (Test case 1).

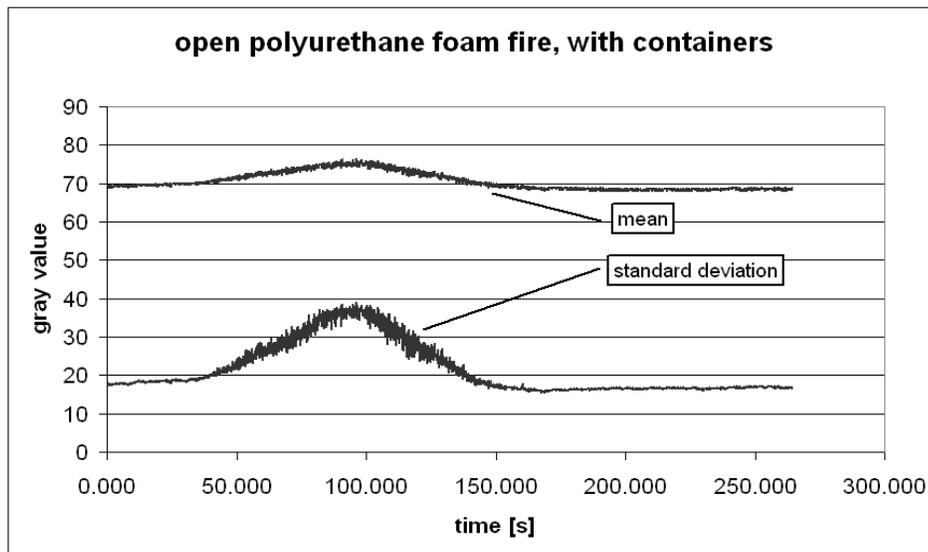


Fig. 5: Time-dependent mean and standard deviation for an open polyurethane foam fire, with containers (Test case 2).

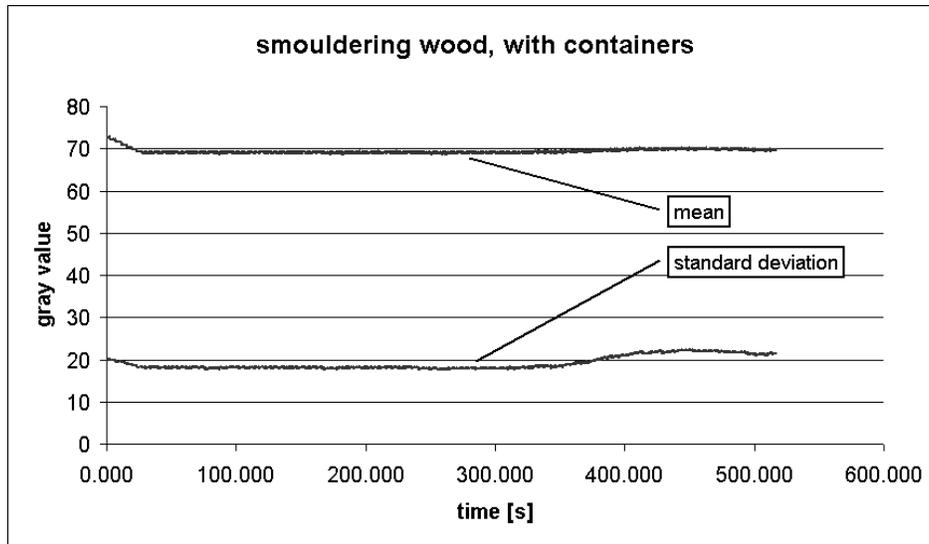


Fig. 6: Time-dependent mean and standard deviation for a smouldering wood fire, with containers (Test case 3).

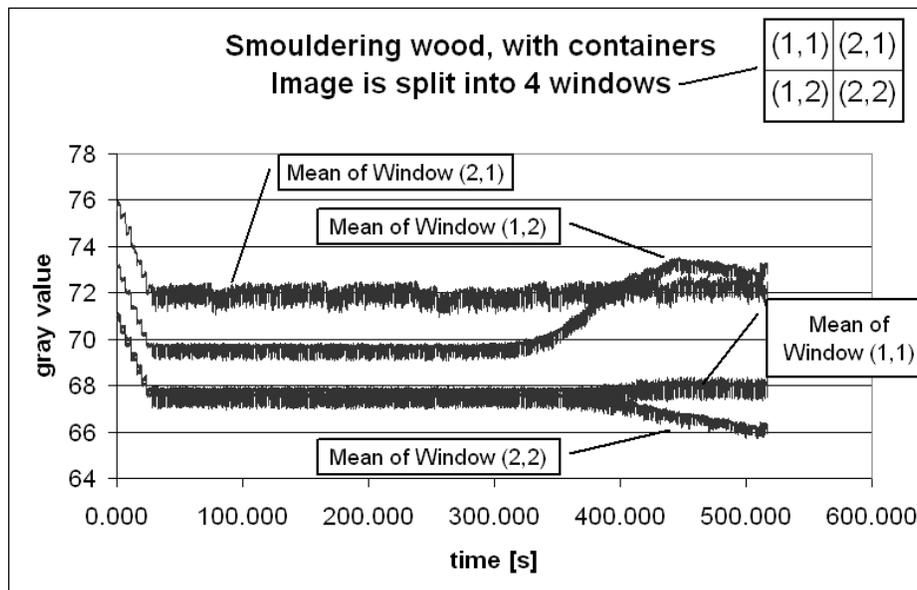
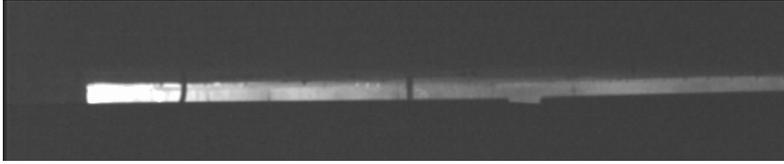


Fig. 7: Time-dependent mean for a smouldering wood fire, with containers (Test case 3). The image is split into 4 Window, each covering one quadrant of the image region. Thus, Window (1,1) is the upper left, Window (2,2) the lower right.

a)



b)

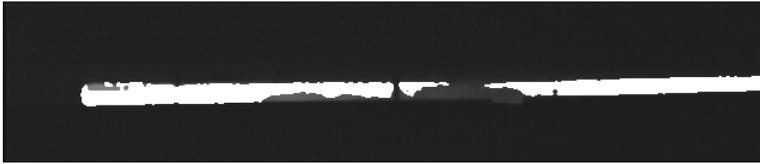


Fig. 8: Fire according to test-case 3 (smouldering wood fire, $t = 400$ s after start of the experiment), seen through the gap between the container's top edge and the ceiling.

a) Original image.

b) The produced smoke is reliably detected and is masked bright white.

4 Summary and Outlook

The novel CFMS concept is capable to detect fires by means of a computer-based imaging system. It is able to detect both smouldering and open fire sources, even when the fire source is hidden, e.g. behind containers and if the fire produces only small amounts of smoke. From these first experiments it can be expected that the CFMS system can become a reliable fire detection tool, which provides the possibility to visually inspect the monitored compartment as an add-on, both to verify a fire alarm or, in the non-fire-case, to serve e.g. as monitoring equipment. The conducted experiments clearly demonstrate that a “naked eye” detection of fire signatures, e.g. smoke, from the captured sequences is very failure prone.

This new concept will lead to a significant improvement in the detection and observation of cargo compartment fires and the results encourage further studies.

5 Symbols

\bar{g}	Mean of pixel values
g_i	Pixel value
n	Number of pixels in an image
σ	Standard deviation

6 References

- [1] Blake,D., Aircraft Cargo Compartment Smoke Detector Alarm Incidents on U.S.-Registered Aircraft, 1974-1999, DOT/FAA/AR-TN00/29, Federal Aviation Administration, Atlantic City, NJ
- [2] Phillips,T., Cabin & Fire Safety: A Perspective From the Cockpit, International Aircraft Fire and Cabin Safety Research Conference, Atlantic City, NJ (1998)
- [3] Cleary,T., Grosshandler,W., Survey of Fire Detection Technologies and System Evaluation/Certification Methodologies and Their Suitability for Aircraft Cargo Compartments, NISTIR 6356, NIST, Gaithersburg, MD (1999)
- [4] Audoin,L., Kolb,G., Torero,J.L., Most,J.M., Fire Safety Journal 1995; 24:167-187
- [5] Goedeke,A.D., Droa,B., Viglione,S., Gross,H.G., Fire detection systems, US-Patent 5'153'722 (1992)
- [6] Foo,S.Y., Knowledge-based systems 1996, 9:531-540
- [7] Cheng,X., Wu,J., Yuan,X., Zhou,H., Fire Safety Journal 1999; 33:57-69
- [8] Plumb,O.A., Richards,R.F., Development of an Economical Video Based Fire Detection and Location System, NIST GCR 96-695, NIST, Gaithersburg, MD (1996)
- [9] EN54: Components of Automatic Fire Detection Systems, European Comitee for Standardisation, July 1982