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LAB SIMULATION SYSTEM FOR CRITICAL SITUATIONS OBSERVED WITH THERMOVISION EQUIPMENT

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Abstract

The paper presents an experimental system enabling a laboratory simulation of several types of critical situations and aggravating circumstances (sources of smoke, fog, rain, heat) using a thermovision equipment. The critical situations taken into consideration are those caused by human negligence or natural disasters such as earthquakes. Aggravating circumstances are those considered as being limit. The proposed thermovision equipment with appropriate accessories must highlight and determine the measures useful in the such situations of risk. The acquired images are transmitted in real time and require using of special equipment which is presented in the work, to observe the occurred phenomena. It is also analyzed in the paper the calibration of that equipment to allow the selection of features and possibilities for adjusting of this thermovision system, to ensure optimum detection, warning, management and the intervention as a risk event. The presented experimental results show the performance of the proposed system and its possible future developments.

Key words: aerosol, disaster, modeling, simulation laboratory, thermal camera

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1. Introduction

A brief survey of literature proves that in the last decade there have been advancements in technologies supporting management and tactical emergency response to the disaster by the combined use of image processing, navigation, and Earth Observation technologies (Dull and Lee, 2001). Infrared (IR) thermography has become a powerful tool for basic and applied scientific research and for the application in various fields such as industry, environment, military and maritime problems, in the ecological monitoring, detection of oil spillages, establishment of the pollution sources and forecast of dangerous events (Vollmer and Möllmann, 2010; Pašagić et al., 2008). Many systems equipped with a thermovision camera devoted to thermovision monitoring of ground environments has been designed and analysed (Lievin et al., 2014). Special control algorithms based on the surface temperature image captured by an infra-red (IR) camera have been developed (Jaworski et al., 2013; Zabel et al., 2002). The development of the blackbody sources for the calibration of IR systems, against smoke and obscurants, and earth background scene generation in IR bands is largely presented in the literature (Johnson and Triplett, 1988).

Current mathematical models are insufficient to describe the current generations of thermal imagers. The impact techniques such as super resolution,

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sampling frequencies and the spatial image fusion, the performance impact of color images are unknown today (Moyer, 2006). There are additional investigation of the effects of discrete sampling of a scene, the performance impact of using multiple wavelengths (Ratches et al., 2001).

The objectives considered in the paper are people and their habitat (buildings and outdoor spaces) (Gavrilescu et al., 2015), where threats as: smoke, fire, fog, explosions, various aerosols dangerous in medical pathology are present (Căliman, 2002; Gallen, 2010; Sarafoleanu, 2003). The authors propose a thermographic equipment with appropriate accessories that can highlight and determine counter measures indicated in such the situations (Raqueno, 2008; Spulber et al., 2005). It is also analyzed calibration of equipment that allows the selection of features and possibilities for adjusting the thermal imagers, which ensures optimum detection, warning, management and interventions risk events. Next it shows experimental results demonstrating the performance of the proposed system and its possible future developments. The related objectives and possibilities of the proposed equipment refer to: pattern recognition in the infrared imaging, study of sources of thermal disturbances, estimating of the probability of false alarm for smoke or fog detectors, establishing of performance limits in the use of thermal images in various applications.

2. Experimental

2.1. Models studied and objectives

There are real situations that require undistorted visualization of events or phenomena that occur, called critical, to ensure timely decisions and fast or even in real time, because any delay could lead to accidents, disasters, destruction of life or of property (Moyer, 2006; Scutaru et al., 2014). Information from images acquired with video equipment can be decisive in the development of standard procedures for action as effectively as a correct decision taken at time. In the context of this work are taken into account and appreciated as being critical following situations: natural disasters such as earthquakes, those caused by human negligence (fires), or caused by chemical pollution hazards for human communities or agricultural areas etc.

The difference between a false alarm risk and real risk, is determined by the quality and specificity of the acquired images. Possible events in observation and possible risk, possible decision probability events / risks are presented below: 1.Target exists is detected. The possibility of not being surprised by the event and make the right decision and prompt in the best time; 2.Target does not exist, but it seemed there because of confusion with another object. The opportunity to make a wrong decision and initiating a false alarm; 3.Target exists, but does not detect various reasons (fog, fatigue or less observer training, camouflage, etc.). The possibility of being surprised by events and take a wrong decision; 4.The target not exist and is not be detected. The possibility of not being surprised by events and take a decision in the best time.

An example of the evolution of an explosion caused by a pyrotechnic mixture is shown (Wishna, 1979), in Fig. 1 (in the visible) and Fig. 2 (in infrared spectrum), the duration being of the seconds order. Determination of burning surface is performed using Image J program through the purchase of thermal images taken with cameras (thermographic equipment) (Baritz et al., 2013). During some of the events described, the fire and smoke can cause chemical reactions that produce aerosols and toxic gases (Neagu and Sarafoleanu, 2015).

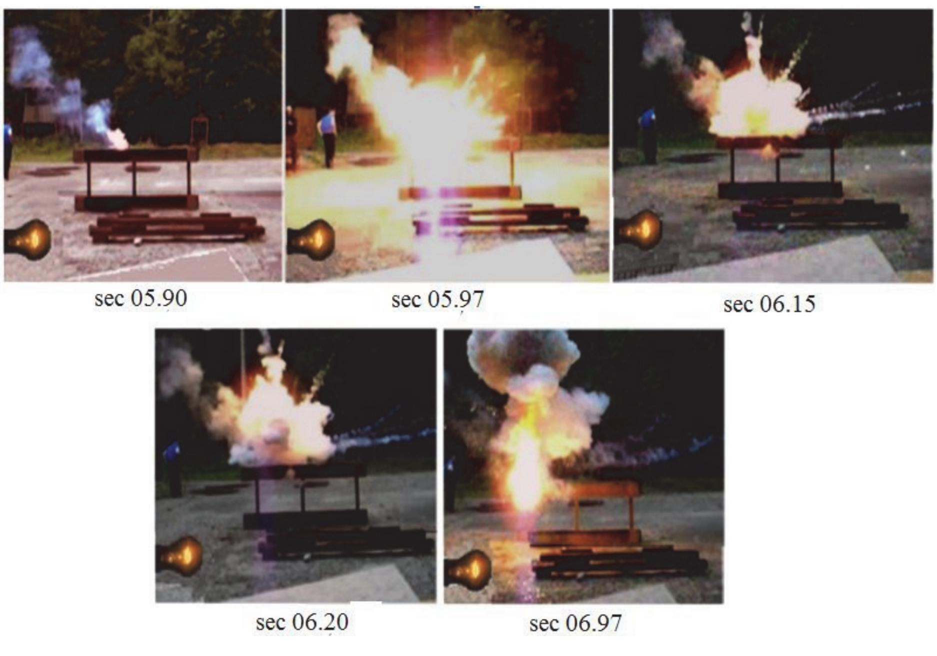


Fig. 1. An explosion dynamics as viewed in visible spectrum (pyrotechnic produced aerosol)

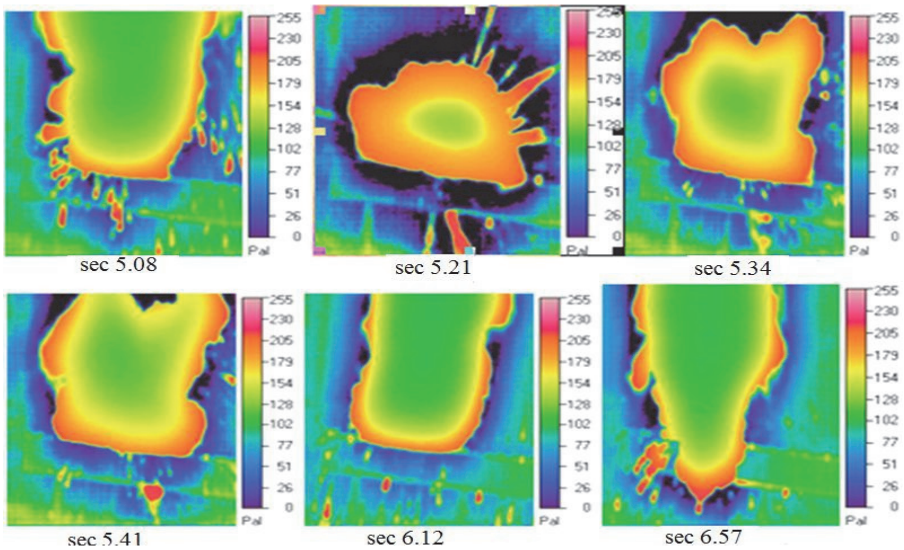


Fig. 2. An explosion dynamics as viewed in infrared spectrum

The possible techniques for the analysis of the presence are essential and can be made by thermographic specific equipment in the infrared (Kaplan, 2007; Maldague, 2012). Moreover, these types of equipment provide relevant information on the localization of persons in conditions for which human vision is ineffective, especially in time of night. However, adverse weather conditions and disturbances can lead to false alarms, decisions chaotic and inadequate distribution of the means of salvage - in spite of the fact that images concerning above events can be purchased and sent to decision-making centers. In this context, it is necessary to know what types of equipment can be used to acquire images which provide high quality information even before the occurrence of such critical events. To achieve and to use a database in real-time, two scenarios stand out in real conditions of useful operation for their laboratory simulation and evaluation based on the acquired images quality.

1. In disasters (destruction of buildings) the thermographic images allow: detection and location of natural disasters, real-time monitoring of the effects of disasters, highlighting areas most adequate for evacuation and protection, detecting people at risk, damages assessment.

2. In case of explosions and fires in open or closed places the thermographic images allow: the fire detection and tracking, detection of persons at risk, monitoring the fire outside and inside buildings (San-Miguel-Ayanz and Ravail, 2005). Their role is essential where the images can highlight objects of interest in different ways in an atmosphere disturbed by fire, smoke and water. Therefore, tests simulating various scenarios will be compared with the results obtained by other types of simulation softwares with thermographic equipment, validated internationally. If the environmental factors are disturbed, supplementary requirements are needed related to observe and predict (detection, recognition and identification) in the areas of interest (Gavrilescu, 2009).

2.2. Sources of aerosols for laboratory simulations

The obtaining of the smoke or fog can be performed using two methods: by dispersion and condensation. In the dispersion method, the specific surface increases the initial system, and in the condensation this surface reduces it. The generation of smoke or fog through the dispersal method consists in using of the dispersion of solids and liquids with an explosive charge. Condensation process occurs by itself and requires energy just to get supersaturated vapors. In general, the dispersion method is used to obtain aerosol particles larger than those produced by the condensation method. In some cases, both methods may be used at the same time as the combined generation method (Singh et al., 2018).

<u>a. Generation of aerosols by pyrotechnic means</u>

Aerosols generation by pyrotechnic means comes as a natural consequence of the burning of pyrotechnic mixtures. Thus, in applications such as the screening, the signaling or the fire-fighting, it is necessary to control the nature, quantity and flow of air to obtain the aerosols. The aerosols generation by pyrotechnic methods involves the use of pyrotechnic mixtures also.

<u>b. Aerosols generated for the screening</u>

The smoke generation process implies the volatilize of mixtures of substances of the smoke. The grey smoke consists of white particles of zinc chloride mixed with the carbon black particles.

3. Results and discussions

3.1. The experimental system proposed for laboratory simulation

In the paper is analyzed the architecture of the equipment proposed (Fig. 3), which enables laboratory simulation of several types of critical situations and aggravating circumstances (sources of smoke, fog, rain, heat). For example, a firefighter may encounter high temperatures, open flames, pools and water sprays and smoke. It is therefore important that the equipment of thermal imagers to be able to monitor the event, in these obstructive conditions with a minimum interference with the environment (dos Santos et al., 2016).

The equipment with IR thermovision for laboratory simulation uses a thermal camera THERMACAM PM350 Inframetrics-USA, with the following characteristics: Working spectral range: 3 ... 5 μm; Sensitivity: 0.10C) • External Display: 4 LCD (optional) • Measurable temperature range: -20 ° C ... + 2000 ° C; • Accuracy: ± 2 ° C, ± 2% of reading; Storing image: Flash-card (Min.128 MB).

Principle of working of the equipment components used to determine the concentration of aerosols is given in Fig. 3, as below. The irradiation source (8). produced aerosols in the aerosol test chamber (2). The determination of the concentration of aerosols is achieved by counting particles larger than the minimum detectable by the system thermal camera (1) - acquisition board - Laptop (10, 11), (approx. 40 μm) using a specific image analysis software. Aerosols are generated by performing an electrical spark generated by electrodes which are in contact with the pyrotechnic mixture. Test chamber for aerosols (2), in Fig. 3 has rectangular form of aprox.1m^3 volume. All walls are made of drywall, containing a rectangular slot located next to the lighting systems, except one of the side (for viewing inside) which is made of Plexiglas.

3.2. Experimental results

3.2.1. External calibration of acquired image

The equipment with IR thermovision for laboratory simulation provides the ability of calibration of the equipment using the same thermal camera for calibrating (test and reference) and to minimize the possible errors (Spulber and Borcan, 2009; Vollmer and Möllmann, 2010) in order to obtain comparable and repeatable results. The calibration of the external image PC, in optical density units, is based on the principle of proportionality between the light intensity of image areas, with aerosol particles and concentration of these particles (Spulber and Borcan, 2005). The image contrast achieved with a camera, by setting specific data values of the camera parameters (which must be maintained constant throughout the image acquisition process) is variable. Based on the selection of images representing portions of variable contrast and using software like ImageJ with "PlotProfile" was drawn the diagram of Fig. 4 and the calibration curve of the system (Fig. 5). It was found that the variation of pixel intensity (gray level) depending on the distance, in pixels, that is the contrast level of the target plate is variable, approximately linear for a certain optical density (Fig. 6). It is desirable to have a linear output video signal (gray level) versus the input signal (incident photons on the detector).

Thermal camera acquires scenes of interest to allow further processing (Fig. 7). The analog signal given by image is amended on acquisition board, first by adjusting the gain (G) and then in balancing the zero signal corresponding to a current determined by darkness. Further the signal is digitized in real time by means of the analog-to-digital converter (A / D) corresponding to the input signal. For each pixel will be assigned a set of spatial coordinates and a value called gray level (Ng), which may vary between 0 and 255. Processing of the signal is continued with filtering, processing, equalization etc. At each gray level can be assigned a photometric value of luminance L, measured under standard laboratory conditions or a value of a standard optical density (OD). Finally, the output signal will be converted back through a digital - analog (D / A) converter to be viewed on a monitor.

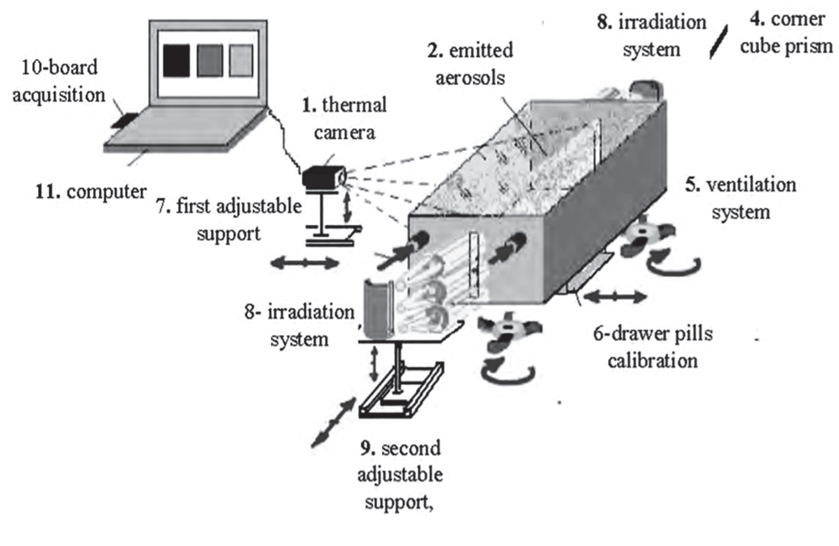


Fig. 3. Principle of the used experimental system using IR- thermovision equipment, where: 1-is thermal camera, 2-emitted aerosols, 3 (8)- irradiation system doubled, 4- corner cube prism, 5-ventilation system, 6-drawer pills calibration, 7 first adjustable support, 8- irradiation system, 9-second adjustable support, 10-board acquisition and 11-computer)

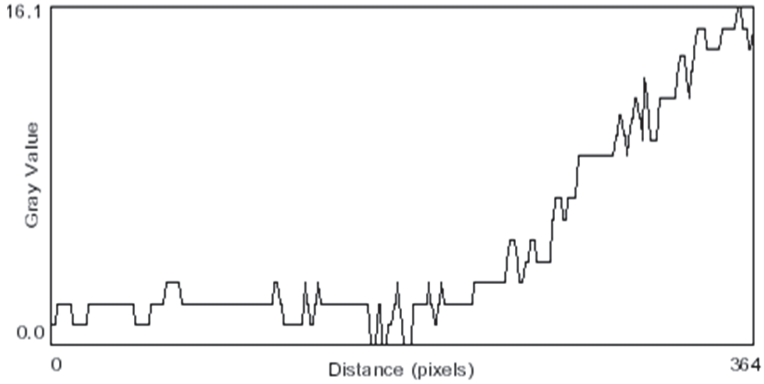


Fig. 4. The variation of pixel intensity (level of gray) depending on the distance, in pixels

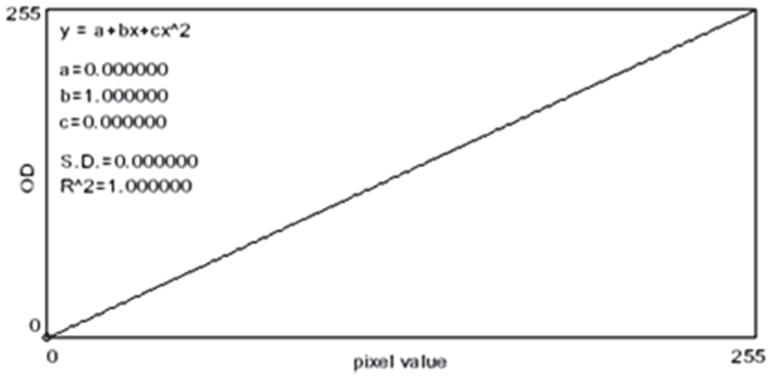


Fig. 5. Polynomial approximation curve of calibrated image acquired on site

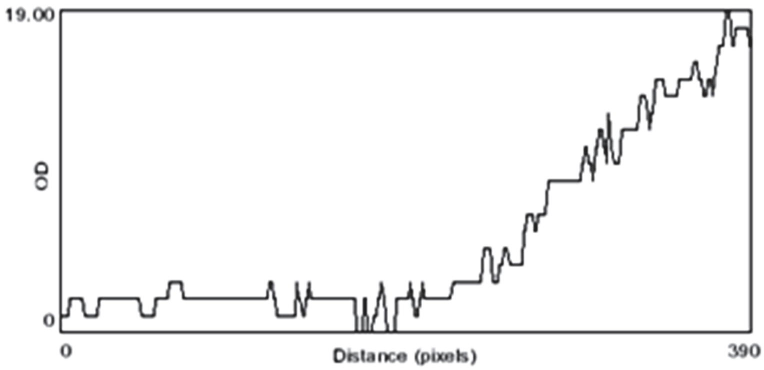
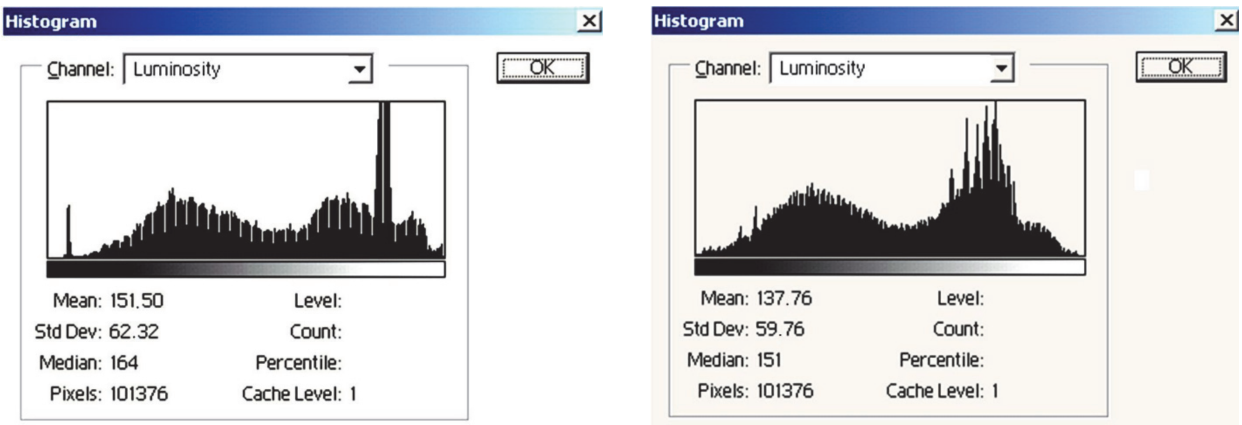


Fig. 6. The variation in the contrast of the image (expressed in optical density units)



(a) (b)

Fig. 7. The histograms of an image acquired and of a calibrated image: (a). The histogram of an image acquired converted into gray levels (8-bit); (b). Calibrated image histogram

3.2.2. Direct determination of the size of aerosol particles

Dimensions of aerosol that can be highlighted depend on the capabilities offered by the equipment used: geometric resolution, sensitivity and dynamic range of detection matrix elements thereof. Depending on the values of these features, you can view the aerosol particles of microns; dimensions between 1 ... 20 μm can be determined indirectly, calculating concentrations by statistical estimation, but dimensions between 20 ... 120 μm result by direct visualization of gravity settling (Cozma et al., 2018).

Using the method of analysis of the aerosols, the image histogram may include particles of size larger than the minimum value detected by the acquisition board of the system CCD - laptop, by means of specific software for image analysis (Fig. 9). Then, by the command "Analyze particles" after a pre-scaling a size of the measured object plane, we determine the average number of particles and their average size. To directly determine the size of aerosol particles by visualization was used a digital camera with 3000×2000 pixels resolution and ImageJ software using option "Macro"; (Figs. 10 and 11).

A comparativ study of the contrast variation of the IR pattern at different moments of the smoke generation process is presented in Fig. 12 and a general view of a simplified system used by the authors is presented in Fig. 13.

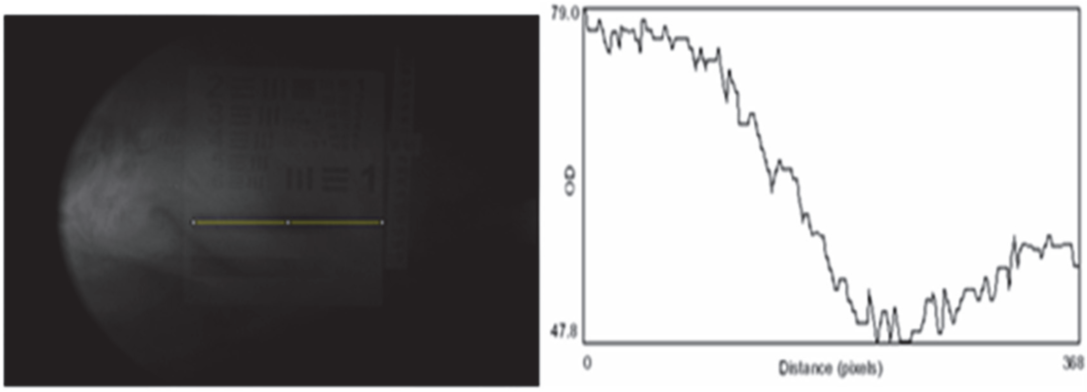


Fig. 8. Acquired image of a variable contrast (optical density) placed in the enclosure, in order to calibrate the image - left and the nonlinearity which is observed due to lack of uniformity distribution of aerosols inside the test chamber-right

Fig. 9. Lamella with aerosol deposition at an average height of the camera test-left. Scaling the image in units of length after a known size of the object plane

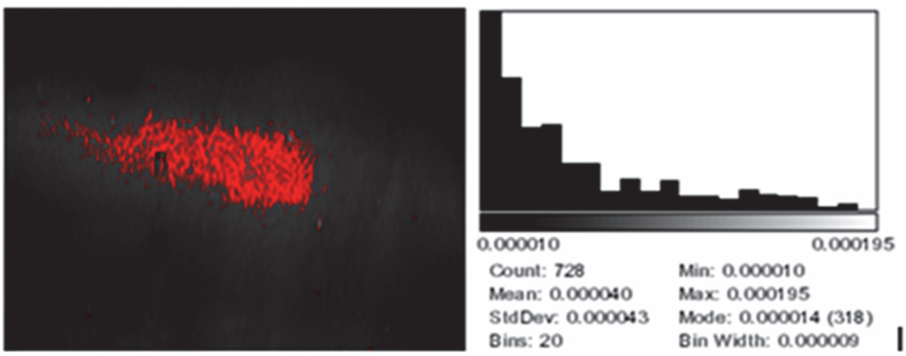


Fig. 10. The limitation of the interest area through software –left and related distribution of particles-right

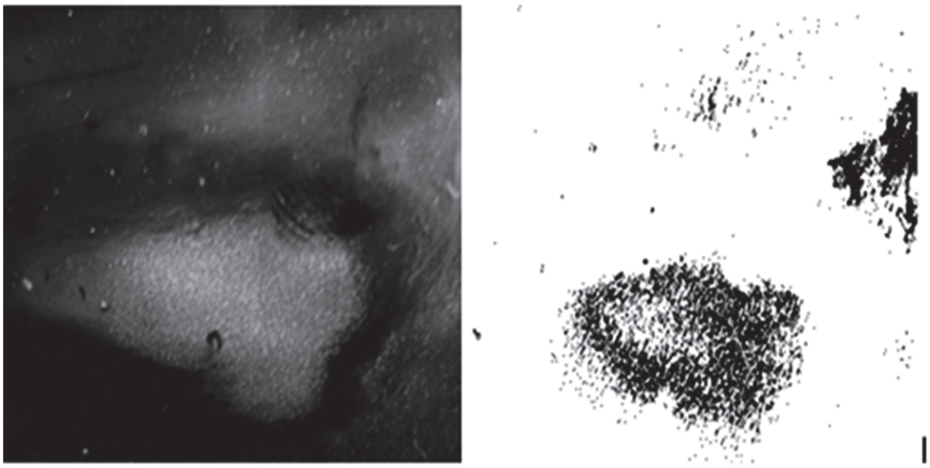
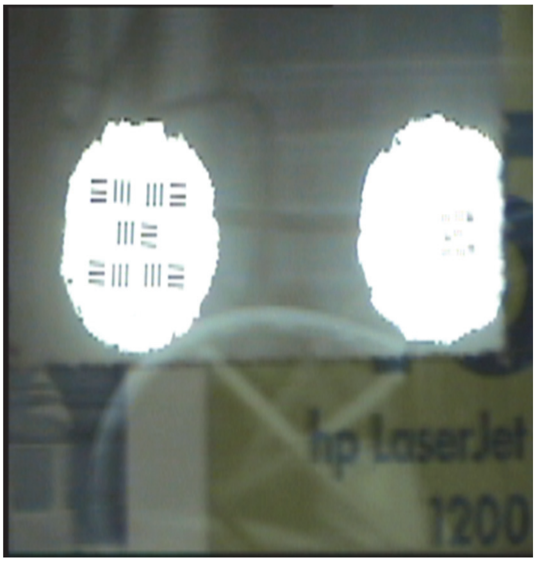
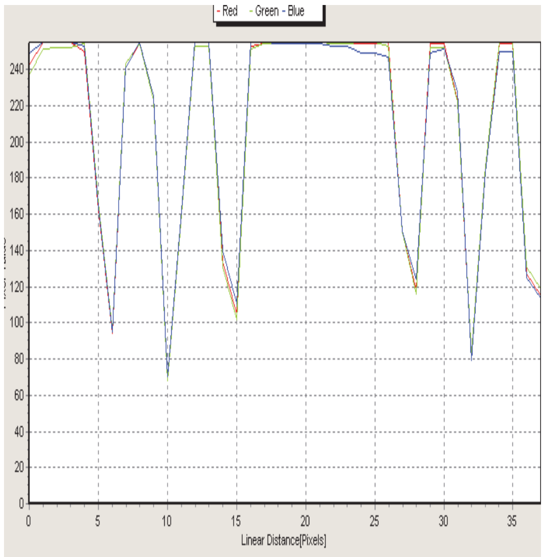


Fig. 11. The aerosol particles on a lamella, at floor level –left and the related distribution of the sample particles -right.

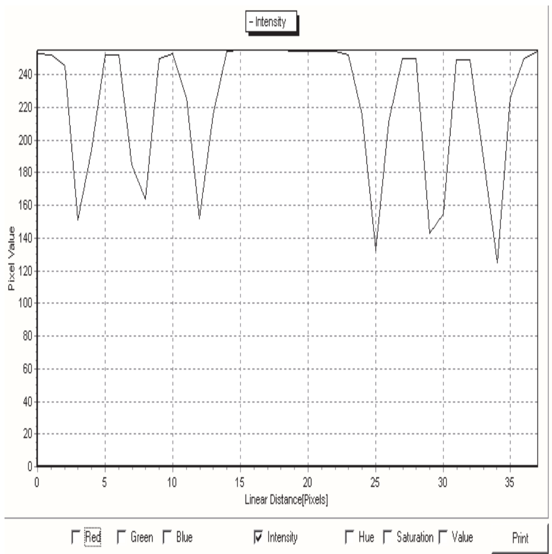


(a)



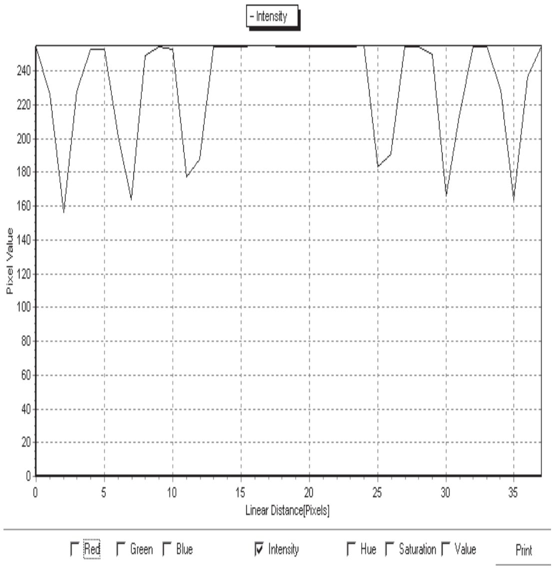
(b)

(c)



(d)

(e)



(f)

Fig. 12. The contrast variation of the IR pattern at different moments of the smoke generation process (comparativ study) a) Images of the mira (IR pattern, created by us in lab) before the combustion - left and at 3 minutes after ignition – right; b)Variation of the contrast mira from Figure a) at 3 minutes after ignition. It observes an increased concentration of aerosol in the enclosure, to a contrast C = 51.5%; c) Images of the mira (IR pattern) before the combustion - left and at 10 minutes after ignition – right; d) Variation of the contrast mira from Figure c) at 10 minutes after ignition. It observes an increased concentration of aerosol in the enclosure, to a contrast C = 21.9%; e) Images of the mira (IR pattern) before the combustion - left and at 13 minutes after ignition – right; f) Variation of the contrast mira from Figure e) at 13 minutes after ignition. It observes an increased concentration of aerosol in the enclosure, to a contrast C = 19%

There are still many aspects of the research in the area that have not been investigated: for example, improvements to the electronic images, the models modified to accurately describe performances of thermal imagers, the coefficients of correlation and others (Leachtenauer and Driggers, 2001).

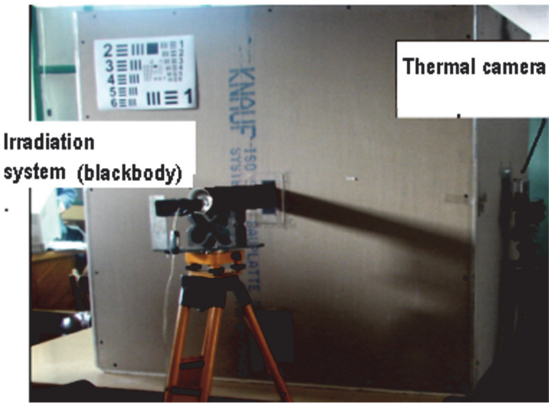


Fig. 13. General view of a simplified system used by the authors

a. It is possible to make a relative comparison between the combustion processes using a camera in visible and a thermal camera. Regarding the comparative results obtained for the same test, it is noted that the measurement accuracy is higher using a camera in visible than when using a thermal camera.

b. The radiant intensities are higher in smaller spectral ranges, making their detection more easily achieved with appropriate equipment for these spectral ranges (Balmus et al., 2017).

c. To increase the accuracy of characterizing aerosol clouds, we need for a system of interferential optical filters in the range of wavelengths studied;

d. The improving of the proposed measurement system with a laser rangefinder having the wavelength in the spectral region of interest is important also (Sterian et al., 2012). The study of experimental systems of pyrotechnic compositions generating aerosol for masking in the visible and IR spectral range and of the traps of heat.

e. Developing methodologies for detecting and measuring the performance of the critical situation with thermographic devices in severe weather conditions.

Other items needed for a depth study refer to the fact that the equipment for laboratory testing, address the complex problem of estimating of the probability of recognition of the micro particles also (Mitrică, 2013), proposing the innovative solutions to overcome the difficulties of calibration of these equipment operating in different special conditions.

The modeling is also useful and relates primarily to the ability to predict how the simulated model of the studied thermovision equipment meets the actual conditions of operation, or as it is close to reality, through a mathematical expression with as few parameters as possible (Fava et al., 2017; Moyer, 2006). Basically, to get a model as accurately as possible, we must take into account the following physical characteristics: distance to the object that is intended to be observed, the conditions of the environment and the thermal characteristics related to the atmosphere (humidity, transparency, temperature, solar reflections), the target-related features (temperature, emissivity, area), the background temperature (air and land), the position in the matrix of the sensing devices.

The expected results refer to: determining characteristics of the disturbing sources, smoke and heat at different wavelengths using interferential filters for IR windows of interest for study: shortwave infrared (SWIR), medium wave infrared (MWIR) and infrared long-wave (LWIR) the validation of the methods and procedures to operation; providing of the constructive solutions to be applied for integrators of thermal imagery and its users at the national level. The equipment operates in the meteorological infrared range (MIR) which is different from the meteorological optical range (MOR).

As an example, it should be noted that all ranges of detection for the IR are significantly better than those of the visible fog of type I (800 meters visibility); type II fog (400 m visibility) four times the results are best with a camera equipped with a LWIR detector, while the third type of fog (visibility 50 ... 200 m) there is virtually no difference as far as the eye can see, with a device in a visible and thermal camera because the atmosphere is the limiting factor. Radiation does not penetrate this dense fog in all areas of spectral bands (infrared: from 0.8 to 12 μm or visible).

4. Conclusions

The presented system enables a laboratory simulation of several types of critical situations and aggravating circumstances (sources of smoke, fog, rain, heat) using a thermovision equipment. The used thermovision equipment with appropriate accessories may contribute to highlight of these situations of risk, so to take suitable safety measures.

The calibration of that equipment allows the selection of features and possibilities for adjusting of thermovision system, to ensure both optimum detection and the warning as well as the management of the intervention. The testing of thermovision equipment in real working conditions of the situations to be simulated in laboratory, leads to results used in the most diverse applications, demonstrating the performance of the proposed system and the possible future developments of it. The design of this equipment can be modified for applications where the probability of detection and of the false alarm are essential to determine the effectiveness of the thermal cameras, depending on distance of observation and the weakness of thermal signal, in real operating conditions. The study can be extended to experimental predictions based on decision matrices for the equipments to working in different infrared spectral ranges.

The main objectives that will be possible to be followed refer to the study of the atmosphere disrupted by the heat in the visible (VIS) and infrared (IR) regions of spectrum, in severe environmental conditions as the ones using smoke sources and traps heat also.

The system permits to be considered and the errors caused by differences between the lab where the simulation is produced and the real conditions, for example: smaller size of the location proposed by the simulator compared the real field of measurements, the different composition of the atmosphere in the simulator in relation to the real one, to establish the correction factors for the decrease of the errors.

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