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Prediction of potential fire hot spots by using a model based on a computerized real-time view with IR cameras on ships

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Abstract

One of the key benefits of using thermal imaging is the ability to predict possible fire hazards due to increases in temperature in controlled areas in a particular marine facility or system. This study proposes the possibility of applying new electronic and computer technology as part of a ship's fire detection system, such as the use of computer vision, using existing marine CCTV systems and installing thermal imaging IR cameras on the same system. It also proposes communication between the CCTV system and the fire detection and central alarm system of a ship. In addition to visual analysis of certain areas on board the ship and the related facilities inside it, with the addition of certain software applications into the existing CCTV system, the system itself becomes a fire alarm system, with the potential to forecast and send early warnings to the ship's central fire alarm system in real time, thereby contributing to improved safety with regards to various areas, equipment, the ship as a whole, cargo and human lives.

Introduction

The application of infrared thermal imaging started in the mid-sixties when the company Aga (today FLIR) produced the first equipment for this purpose called *Model Thermovision 651*, as a result of which the term "thermal imaging" entered into everyday use. Thermal imaging, as a field of scientific research, represents one of the fastest growing technologies of testing and data collection in terms of safety, including the use of thermal imaging in the early detection of potential fire hot spots on ships. Thermal imaging on boats also plays a significant role in controlling and predicting failures and in the diagnosis of the state of functionality of a ship's engine system, enabling the early detection of eventual damage to certain systems or electronic equipment which could cause a fire due to increased operating temperatures.

The ways in which thermal imaging can be used are unlimited. With wider use in the protection and control of various other facilities in the industry and beyond, e.g. shipbuilding, the thermal processing of images can serve as an improvement to the basic fire alarm system of the ship.

Causes and origins of fire

It has been proven that human factors cause 80% of maritime fire incidents. Statistically speaking, fires and explosions of waste account for 1/4 of all maritime accidents. According to data collected by DNV, an average of 20 large marine fires in engine rooms is expected every 10 years. The direct costs of fires in engine rooms are in the range of $1 million to $5 million for cargo ships and even more for passenger ships.

According to the statistics of the world fleet, fires originating in a ship's engine room make up 63% of all ship fires, meaning that the area of the ship's engine room is especially susceptible to fire, as illustrated in Figure 1.

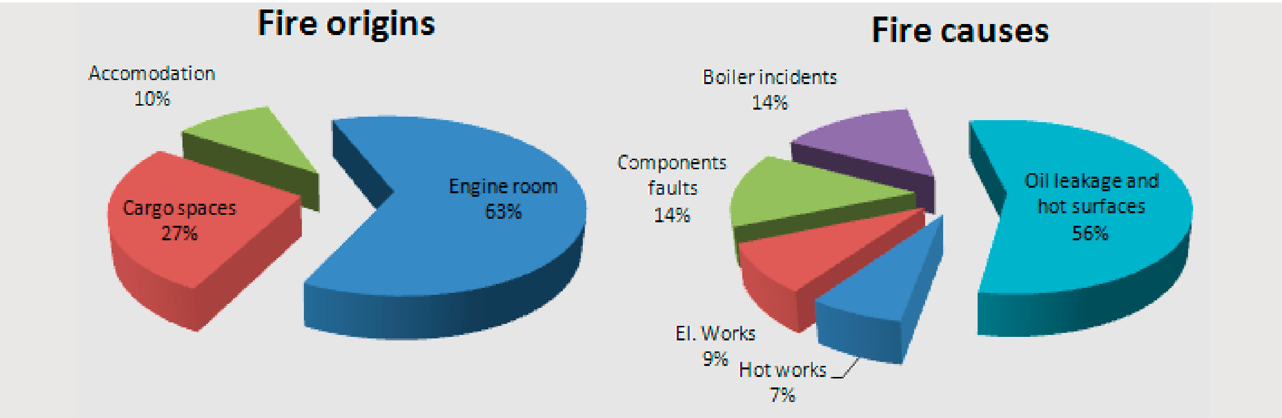

Figure 1. The origins and causes of fires on ships (DNV, 2010)

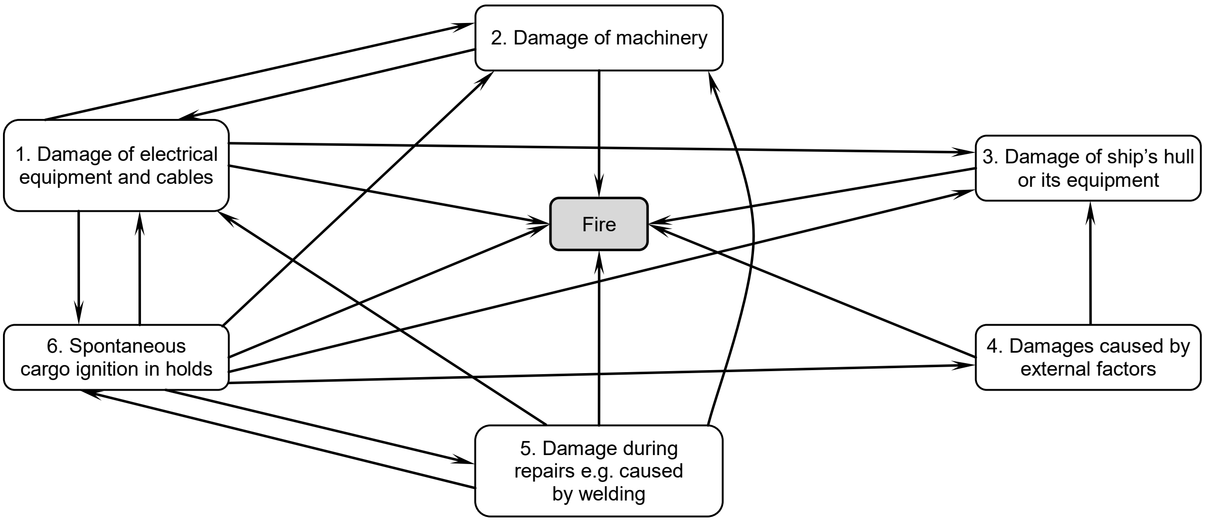

Figure 2. Cause-and-effect links relating to fires on ships (Kwiecińska, 2015)

Figure 2 shows the causes of ship fires, separated into six groups (Kwiecińska, 2015), and their interrelated effects in a ships environment. Although all of the illustrated causes could directly start a fire, it is worth noting that all of them can form chains of events (damages) which could also lead to fire. Monitoring these damages using thermal imaging within protected areas reduces the chance of fires starting.

Basics of thermal imaging

The basic assumption on which thermal imaging systems are based is that all objects above absolute zero (–273°C) emit an invisible infrared (IR) spectrum of radiation, affected by many different characteristics of the object, one of which is temperature. With increasing temperature of a controlled facility, the intensity of the emitted infrared radiation also increases. Infrared devices (radiometers, IR cameras) do not directly measure the temperature of the object, but they detect the radiation energy which is a function of temperature. As this method of temperature measurement does not require contact, thermal imaging is based on measuring the intensity of IR radiation from a certain area of an item or multiple elements. Temperature measurement from a distance is a well-documented phenomenon, where all bodies radiate energy (Petrović, 2016):

$$W = f(\varepsilon, T) \qquad (1)$$

where:

- W – work;
- f – certain frequency;
- ε – coefficient of transmission capabilities (emissions) which depends on the chemical composition of the material;
- T – temperature in K.

Since 0 K corresponds to a temperature of –273.3°C (absolute zero), there is no radiation of energy at this temperature; however, it is believed that everything that surrounds us radiates or transmits a certain amount of thermal energy.

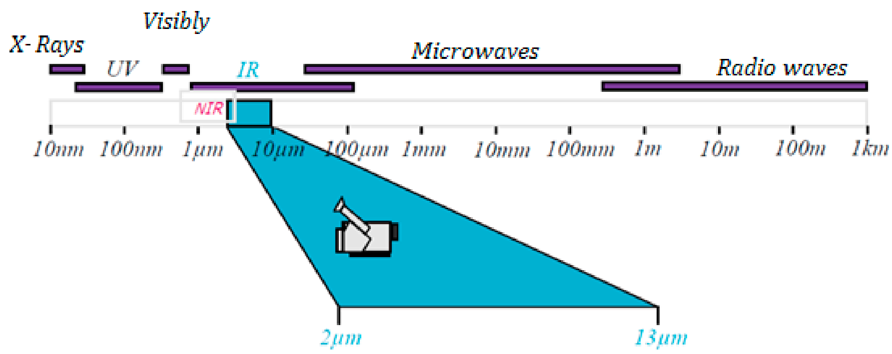

Figure 3. Spectrum of electromagnetic waves with a focus on the infrared area (Petrović, 2010)

IR radiation is a part of the electromagnetic (EM) spectrum that begins below the visible part of the spectrum and extends to over 200 µm. For practical use, the thermographic IR spectrum is from 2 µm to 13 µm, as shown in Figure 3.

A thermal imaging or IR camera is a device that generates an image based on infrared radiation. The principle of operation is related to the fact that the infrared spectrum of radiation, invisible to the human eye, which is transmitted by an object, is converted into a visible image (thermogram) on which information is received on temperature and the areas are classified according to the different amounts of infrared radiation that they emit (greater radiation – brighter colours), the same colours represent isothermal surfaces emitting equal amounts of heat.

The use of IR cameras is widely used in cases where a thermal change on an image can indicate an anomaly. The basic components of IR cameras are:

- Lens (collects radiation);
- Filter (releases radiation of certain wave lengths);
- Detector (reads radiation and transfers it to an electronic signal);
- Monitor (the electronic signal is displayed as an image or thermogram).

The thermographic camera converts the IR radiation into a visible thermogram through its sensors. This image is based on the infrared radiation at the surface of the observed item or object. The quality and accuracy of the thermal image depends on the parameters of the thermographic camera. Today, thermographic cameras have a resolution of 0.1°C to 0.01°C, which is sufficiently precise for using thermal imaging for early detection of fires on ships, especially in ship engine rooms.

Ship systems in the engine room have very high emission factors which contribute to a much more realistic display and better quality of thermal images. In addition to its own emitted radiation, the camera also registers reflected radiation which can cause interference with the thermal image. Therefore, in order to get a realistic picture, reflected radiation has to be eliminated. For practical temperature measurement, infrared wavelengths between 0.7 µm and 20 µm are used. Figure 4 shows a schematic representation of general thermographic measurement (Gaussorugues & Chomet, 1994; Pašagić, Mužević & Kelenc, 2008).

According to Figure 4, the total strength of the radiation can be expressed with the formula (FLIR Systems, 2005):

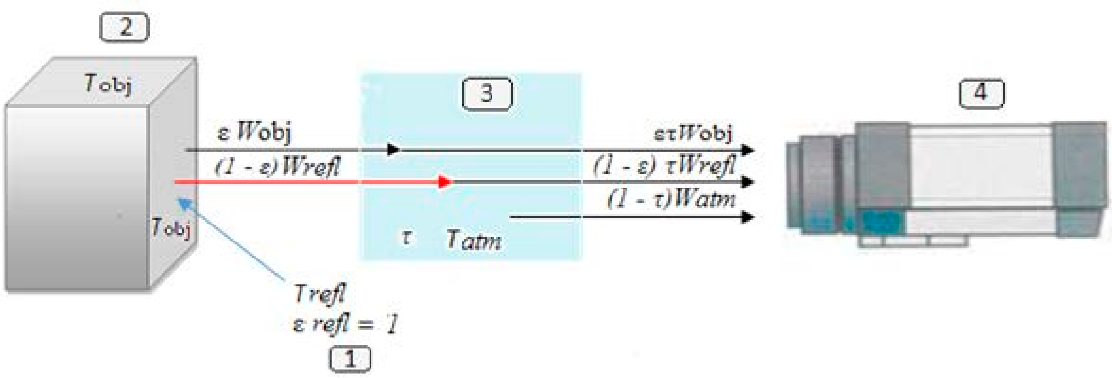

Figure 4. Schematic representation of general thermographic measurement; 1 – environment, 2 – object, 3 – atmosphere, 4 – camera (Pašagić, Mužević & Kelenc, 2008)

$$W_{tot} = \varepsilon\tau W_{obj} + (1-\varepsilon)\tau W_{refl} + (1-\tau)W_{atm} \quad (2)$$

where:

$\varepsilon\tau W_{obj}$ – is the emission of radiation from the object, where ε is the emission of the object and τ is the atmospheric release;

$(1-\varepsilon)\tau W_{refl}$ – is the reflection from the environment where $(1-\varepsilon)$ is the reflection of the object and τW_{refl} is the temperature of the environment;

$(1-\tau)W_{atm}$ – is the emission of radiation from the atmosphere where $(1-\tau)$ is the emission of the atmosphere and W_{atm} is the temperature of the atmosphere.

$$\text{Emissivity} = \frac{\text{Radiation emitted by an object at temperature } T}{\text{Radiation emitted by a Black Body at temperature } T}$$

Table 1. Emissivity values for various materials (McGrath, 2016)

Material	Emissivity values	Material	Emissivity values
Aluminium, polished	0.05	Platinum	0.08
Brick	0.85	Rubber	0.95
Bronze, polished	0.10	Snow	0.80
Bronze, porous	0.55	Steel. galvanized	0.28
Copper, oxidized	0.65	Steel. rolled	0.24
Copper, oxidized to black	0.88	Steel. rough	0.96
Skin	0.98	Tin	0.05
Nickel	0.05	Tungsten	0.05
Paint	0.94	Water	0.98
Paint, silver finish	0.31	Zinc. sheet	0.20

Application of thermal imaging in the ship's engine room

According to the International Convention for the Safety of Life at Sea (SOLAS) CH II-2, the maximum surface temperature of machines, parts and components in the ship's engine room should not exceed 220°C. In order to prevent possible fire incidents on surfaces with temperatures above 220°C, these surfaces must be isolated (IACS, 2016). The great majority of fires in ships' engine rooms are caused by leaking fuel or oil and their contact with hot surfaces. Such a fire would have serious and costly consequences for the ship, cargo, crew and shipping company. Furthermore, SOLAS regulations stipulate the types of protection required for certain electrical or electronic components. It is precisely the regulations of SOLAS infrared thermograms that allow for the meaningful use of thermal imaging in preventing possible fires and their consequences.

An infrared camera (Figures 5, 6, 7, 8) (FLIR, 2017) shows the thermal state of the main and auxiliary mechanical equipment, electronic systems and other ship parts in real time.

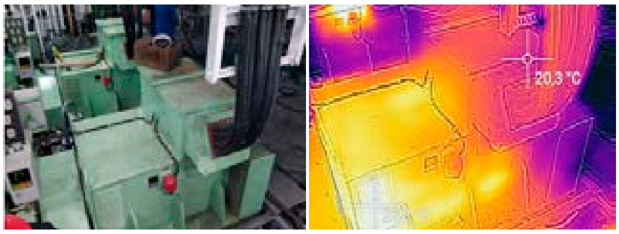

Figure 5. Visible light image (left) and thermal image (right) of a generator of the ship's auxiliary engine

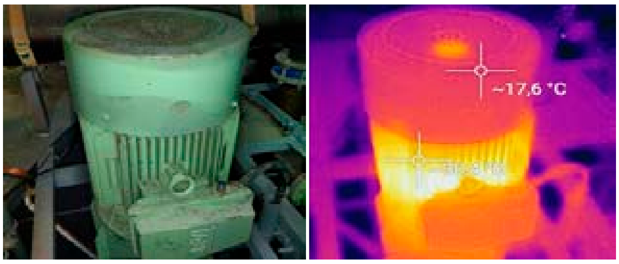

Figure 6. Visible light image (left) and thermal image (right) of a ship's electric pumps for cooling water

Figure 7. Visible light image (left) and thermal image (right) of an electrical circuit in the pumps

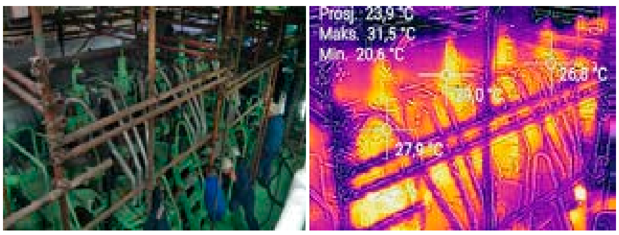

Figure 8. Visible light image (left) and thermal image (right) of the upper part of a ship's main propulsion engine

Model based on predicting fire incidents based on computer imaging in real time with the use of an IR camera

Figure 9 shows a model for the prediction of possible fire incidents, based on computer imaging in

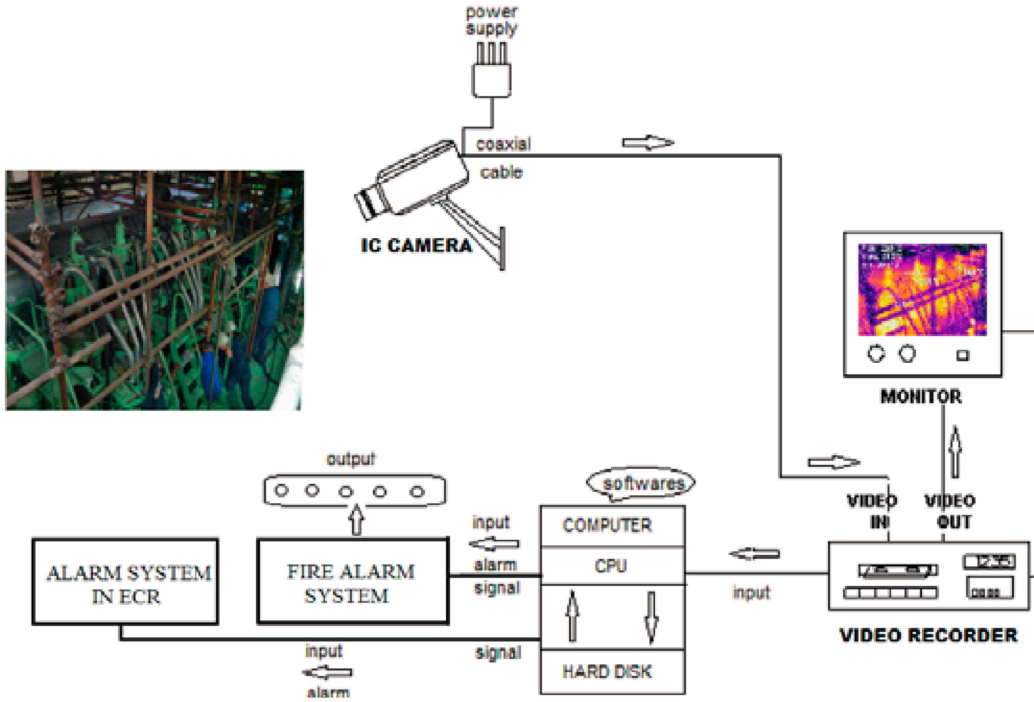

Figure 9. The main components of the detection system for unwanted changes temperature

real time using an IR camera, for the development and automation of early warning video systems for the detection of temperature increases in controlled areas: the ship's existing conventional fire alarm system and video system, based on thermal imaging, are combined into one advanced unit (Bistrović & Tomas, 2014). The data collected in real-time is distributed via the central unit of the CCTV system, with the help of intelligent computer imaging and recognition algorithms, is automatically analysed (Kim Hee Chul, 2016) and, with the help of the program, early warning signals are generated followed by an alarm indicating the unauthorized increase in temperature.

Thermal imaging in combination with a fire alarm system greatly contributes to the security and speed in preventing possible fire situations, by using a monitor with which the potential origin of the fire can be accurately and quickly located.

The components and functionality of the proposed model meet certain conditions such as: software, demand for the speedy detection of rising temperatures, visualization and functionality (Bistrović, Ćelić & Komorčec, 2016).

The key features of the system based on thermal imaging were stated by Kukushkin (2016):

- With the thermal processing of infrared camera images, alarm systems can provide an audible or visual signal.
- In combination with a PLC or PC controller, a more advanced control system based on thermal imaging is created.
- The system allows for defining the temperature alarm levels for the controlled object or surface.
- It allows the possibility of controlling multiple target points.
- The system provides trend analysis of the temperature rise with the purpose of identifying existing problems before the activation of the defined alarm point.
- Reproduction of videos and a quick search by date in order to detect the cause and location of the fire incident.

The location of the IR camera is of high importance for a good overview of the targeted controlled object. In addition to the main fire alarm system, the proposed model serves as a significant additional aid.

The increasing demands of today's ship owners, to reduce risks and increase safety on board, has encouraged manufacturers of ship equipment and the scientific community to develop and implement new solutions. As a result, fire protection today is a top priority when designing a ship, in particular passenger ships. IMO rules and regulations for protecting human life at sea (SOLAS Convention) provide a framework of fire protection. The introduction of ship automation attempts to increase the reliability, security and functionality of a ship's systems, including the system of fire detection. Over the last decade, with the development of ship automation, advanced fire detection systems have also been developed. This was achieved by a great amount of

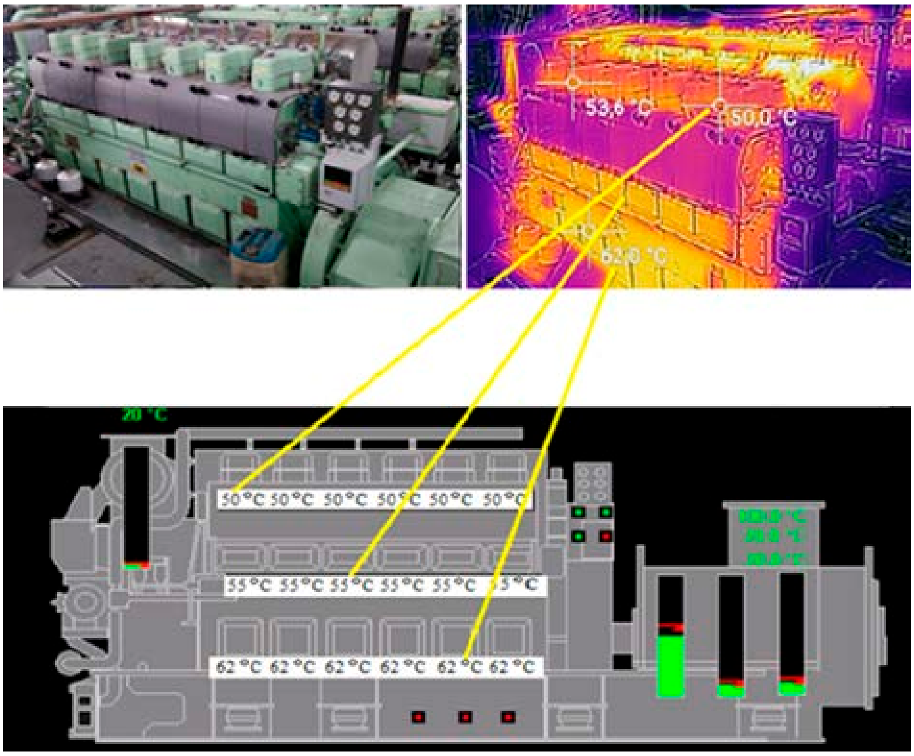

Figure 10. Using temperature data from the ship's auxiliary engine for the alarm system of the engine room

advanced research in both commercial and military applications, where the US Navy is a leader.

Integration of CCTV systems based on thermal imaging and the alarm system of a ship's engine room

Figure 10 shows the integration of CCTV systems based on thermal imaging and the alarm system of the ship's engine room, all for the purpose of a faster and more efficient detection and suppression of fire incidents. The figure shows the control panel of the ship's engine room with mime auxiliary engine and specified measurement points.

Using colours with the purpose of evaluating the temperature of the controlled object or a certain surface on fire

The colour and intensity of the flame depends on the material that is burning, the air volume, air currents and alike. Also, the colour of the area affected by the fire can be used to assess the temperature of the fire through thermal imaging. With thermal imaging IR cameras, each pixel is in fact a separate temperature sensor and the thermal image is a presented value of thousands of points of a controlled surface or a particular object. However, it must be emphasised that any controlled area or object has its own colour, which has its own emissivity. This means that two different controlled areas or objects at the same temperature do not have the same radiation, but also that the emissivity of the surface or object has nothing to do with its colour in the visible spectrum. Table 2 shows the relationship between colour and temperature (Radmilović & Kolar-Gregorić, 2010).

Table 2. Evaluation of temperatures based on colour

Thermography – colours	High-temperatures (°C)
light red	480–530
dark red	530–600
maroon – dark	600–650
– normal	650–700
– light	700–760
bright red	760–815
salmon red	870–930
orange	930–980
yellow	980–1050
light yellow	1050–1150
white	1150–1250
clear white	1250 –

The accuracy of the measured temperature of the controlled object depends on the ambient temperature, emissivity, vibrations and the distance between the camera and the controlled surface or object. It should be noted that measuring temperature using thermal imaging does not serve to accurately determine the temperature of the controlled object or surface, but rather sudden changes in temperature.

Conclusions

It is known that the first five minutes are the most important in the development of a fire, and after seven to ten minutes the fire spreads widely, develops extremely high temperatures and becomes a cause of great damage to ship equipment, often resulting in the loss of the ship. Due to these facts, videotapes from thermal cameras can be used for risk analysis and the prevention of future ship fire incidents. With key features such as fast detection of temperature changes, regardless of whether there is sufficient light or not, the proposed model in this study has some advantages over conventional ship fire alarm systems: primarily, reliable and very early warnings of the presence of temperature changes, a safe and remote verification of the location of the alarm, easy integration with existing fire alarm systems and low costs of maintenance. There are high temperatures in the engine room along with excessive vibrations that can cause problems with thermal imaging cameras posing a potential disadvantage to such systems.

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