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Economic justification for the new approach of using video-based smoke detection with the aim of decreasing total costs incurred by the untimely detection of fires on ships

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Abstract

Although various methods of using new techniques and technologies in ship fire alarm systems have been developed to date, some of which have made significant improvements in the functioning of such systems, in practice there is still plenty of room for further research regarding the operational efficiency of ship fire alarm systems and its impact on crew, passenger and overall ship safety. The application of electronic and computer technologies enables the development of intelligent solutions to improve the efficiency of ship fire alarm systems. Besides the economic justification, this paper presents a comparative analysis of classical and modern approaches based on video detection and computer vision in the detection of early phase smoke as a precursor to fire incidents. The economic justification of the new approach is concerned with decreasing the costs incurred by the untimely detection of the early stages of fire in ship engine rooms.

Introduction

To show the effectiveness of computer vision based smoke detection, experiments were performed using classical smoke detectors and advanced detection systems based on IP cameras. Assessment of the classical smoke detector response is based on optical density, changes in temperature, the alarm threshold and the speed and direction of spreading (Bistrović, Kezić & Komorčec, 2013). An operational engine room ventilation system reduces the optical density of the smoke due to the supply of fresh air; this means that the accumulation of an optical density sufficiently high to trigger an alarm is slowed when the engine room ventilation system is functioning. This parameter has no impact on smoke detection based on computer vision.

The model of smoke detection based on computer vision via the ship's IP cameras aims to develop and automate the early warning video system, i.e. smoke detection, by combining the ship's existing classical fire alarm and video systems into one advanced unit (Millan-Garcia et al., 2012; Brovko, Bogush & Ablameyko, 2013). The obtained data and measurements distributed throughout the central CCTV system by intelligent computer vision and recognition algorithms are automatically analysed (Bistrović & Tomas, 2014; Bistrović, Ćelić & Komorčec, 2016) and alarms signalling smoke detection are generated using the program. A big advantage of this new detection model is the provision for analysis of the transmitted information in real-time. The components and functionality of the proposed model meet certain conditions, including:

- program support;
- architecture of the proposed model;
- requirements for speed of detection;
- assessment and visualization of smoke spreading;
- economic and legal limitations;
- functionality, etc.

The slow response time of classical point detectors has lead researchers to propose the volumetric detection system, based on computer vision, as an alternative to classical detectors.

Time, as the main factor on which the more advanced video-based detection model improves, has an automatic, proportional impact on the reduction of possible damages. Simultaneously, the decrease in response time greatly increases the chances of timely fire extinguishing. The ship's existing video surveillance system scan be upgraded easily at, usually, low expense, providing automatic video detection of flames or smoke along with the existing video surveillance.

Application of computer vision to the detection of early stages of fires on ships

Nowadays, ship engine rooms are protected from fire by an automatic fire extinguisher system which is controlled from a room situated outside the engine room. For a water mist fire protection system to start, two different detectors must be activated; a flame detector, resistant to various currents caused by ventilation or draught, which activates quickly, and a smoke detector not resistant to such currents. Automatic extinguisher activation is often therefore late, which allows for the spreading of the fire to other areas. This paper describes the research conducted with regards to the use of existing ship CCTV systems for the early detection of smoke in engine rooms, which would contribute to faster prevention of the unwanted effects of engine room fires.

The traditional method of smoke detection demands the placement of detectors near the potential sources of smoke. To avoid this, video-based smoke detection was proposed to improve the chances of successful smoke detection and reduce the number of false detections, as shown in Figure 1 (Bistrović, Ćelić & Komorčec, 2016). Fires have been shown to be the second largest cause of accidents on ships, accounting for 20% of all accidents

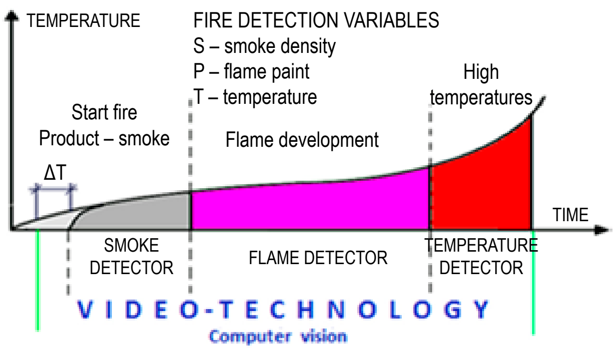

Figure 1. Comparison of detection areas of classic detectors and video technology using computer vision

on-board (Kwiecińska, 2015). Of those, the number of fatalities caused by smoke accounts for 50–80% of the total number of fatalities caused by fire (DNV, 2010), which means that smoke is the primary cause of these deaths. Engine rooms are places that are vulnerable to fires and explosions due to the ever-present factors which can lead to their development in these areas (Chybowski et al., 2015). On-board ships, and especially in the engine room, there are always various flammable types of waste, which produce large amounts of toxic gases and consume large quantities of oxygen during burning. More than 50% of all engine room fires (excluding yard repairs) were caused by the combination of oil leakage and a hot surface (Krystosik-Gromadzińska, 2016).

On the basis of smoke and flame characteristics (Toreyin, Dedeoglu & Cetin, 2006; Chen et al., 2012), by studying various classical concepts of smoke and flame detection algorithms and the distribution of output signals, a fire alarm system which combines the classical algorithm concept, upgraded with a video system using the ship's already installed CCTV system is proposed.

Selection and definition of initial conditions for the analysed scenarios of detection of the early stages of fire with the use of an optical smoke detector

To test the classical fire alarm and video-based models, an engine room on a bulk cargo ship, built in the Uljanik shipyard, Croatia, was selected as a specific area where, on average, fire incidents occur most frequently. The engine room is approximately 10 meters wide and 16 meters long, while the height between the point of smoke simulation and the ceiling is approximately 8 meters.

The testing conditions, approximate to real conditions in a ship during exploitation are:

- all lighting fixtures in the engine room are powered by an alternating current of 220 V from the main switchboard (28×64 W neon lamps, 1792 W in total) and are switched on;
- one auxiliary diesel engine is in operation and connected to the main switchboard;
- air compressor is switched on;
- fuel system is functioning;
- cooling and drive lubrication systems are in operation;
- fire alarm system is functioning;
- main engine is ready for operation;
- all emergency doors and exits are closed;
- engine room ventilation:

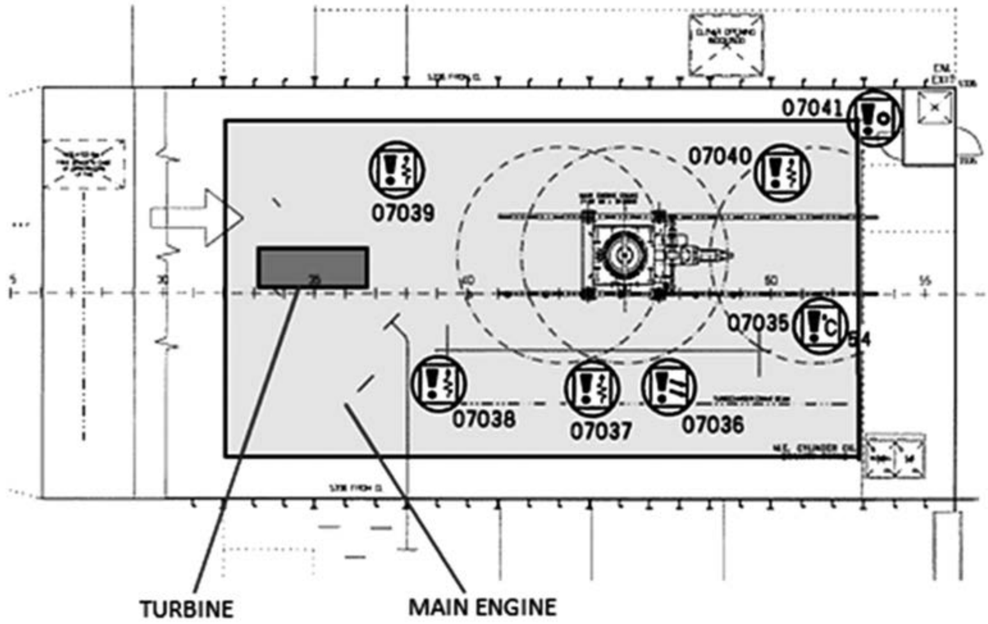

Figure 2. Scenario 1 – engine room ventilation switched off

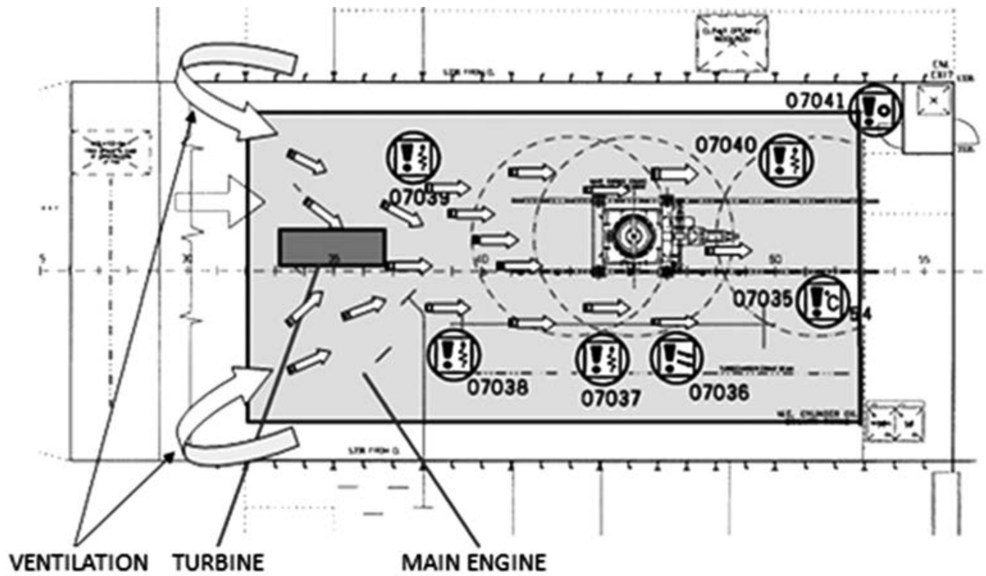

Figure 3. Scenario 2 – entire engine room ventilation system switched on

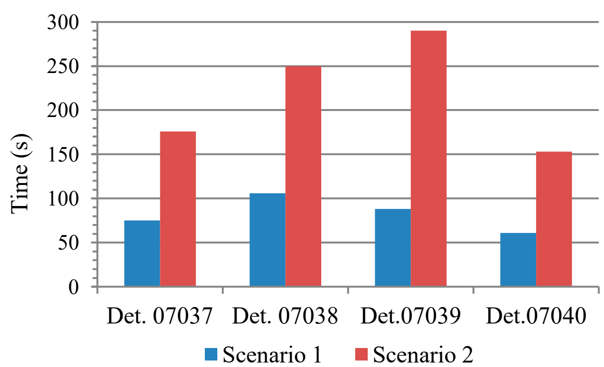

Figure 4. Comparison of the time to smoke detection alarm by classical detectors with (scenario 1) and without (scenario 2) engine room ventilation

- scenario 1: engine room ventilation switched off (Figure 2);
- scenario 2: entire engine room ventilation switched on with sufficient fresh air supply for undisturbed functioning of the whole system. The fresh air supply is 19.1 m^3/s i.e. 68 500 m^3/h, density 1.13 kg/m^3 at engine room temperature of +35°C (Figure 3).

During testing, a **ELRO DVR 74S** video surveillance system with four video channels and four outdoor **IP** cameras, installed in designated locations within the engine room, as shown in Table 1, and visible from Figure 5, was used. The video system can simultaneously display four images on its 7-inch screen and an additional screen such as the ship's computer or CCTV screen. The built-in hard drive recorder allows for writing files to the hard disk with a 500 GB capacity. The horizontal screen resolution is 450 TV lines with a picture element of 628×586 pixels. Video is recorded in the AVI video format. The software used during the video smoke detection test is similar to software used for the monitoring and detection of forest fires (Toreyin & Cetin, 2005) which has already produced satisfactory results. Figure 4 shows a comparison of the time to smoke detection alarm by classical detectors for scenarios 1 and 2.

Table 1. Camera orientation for individual tests

Test	Video file	Camera location	
		Position	Direction
Camera 1	ch. 1 – 092442	up	back
Camera 2	ch. 2 – 091939	down	back
Camera 3	ch. 3 – 091933	up	forward
Camera 4	ch. 4 – 092342	down	forward

Camera 1

Camera 2

Camera 3

Camera 4

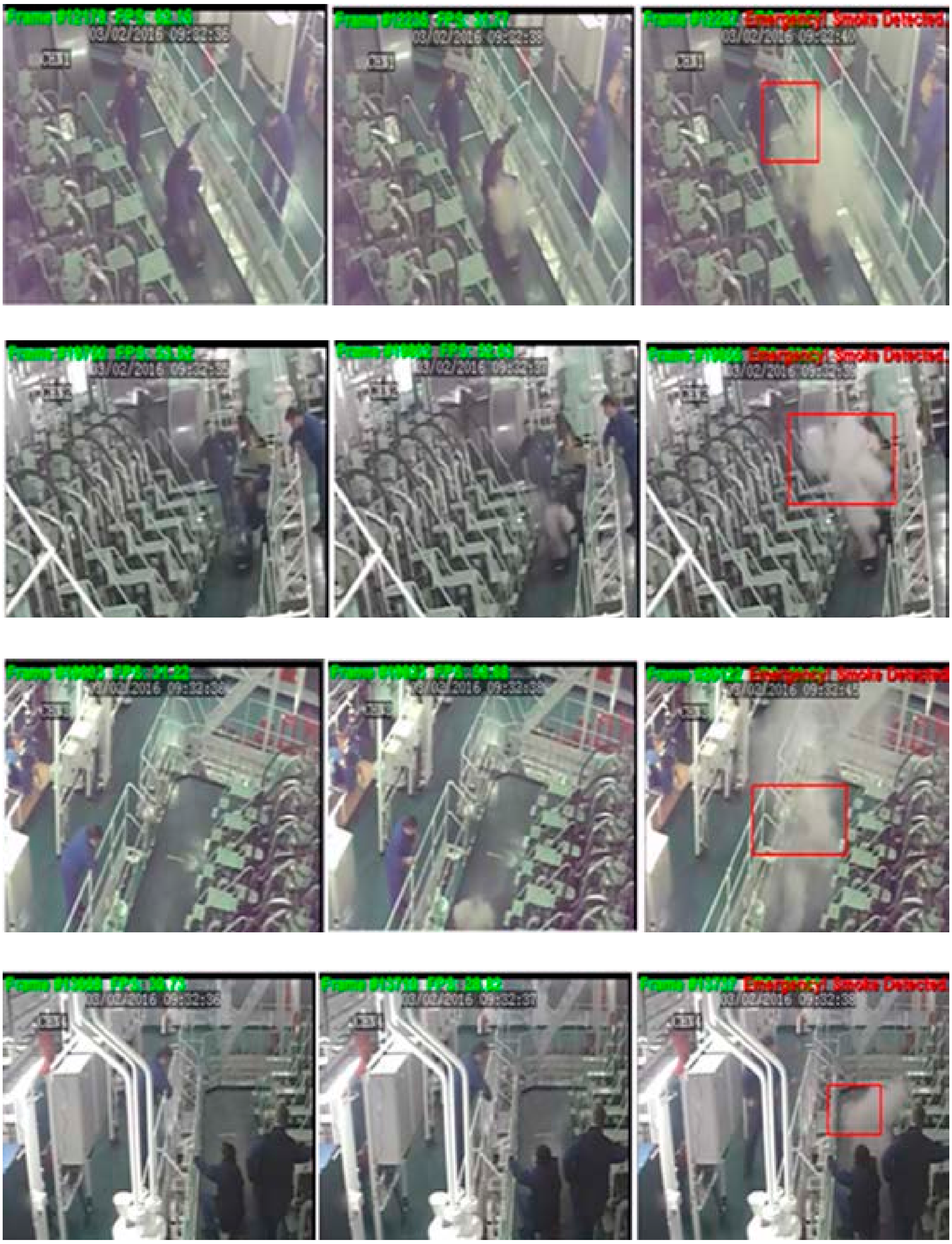

Figure 5. Video images from smoke appearance to alarm

Comparative analysis of classical and new approaches to the detection of the early stages of smoke

By analysing the functioning of the video-based smoke detection model, on the basis of the test results (charts), the following advantages of the automatic smoke detection system, based on video technology, were observed (Toreyin, Dedeoglu, Gudukbey & Cetin, 2005; Chen et al., 2006; Bugarić, 2007; Chen et al., 2012):

- smoke video detection response is much faster than in the classical fire alarm system;
- the system functions extremely well in spaces with high ceilings and large surface areas;
- airflow does not impact the video detection;
- change in temperature and humidity have no impact on detection;
- the obtained photographs or videos help in identifying the cause and location of the fire;
- assessment of damage is possible through the obtained photographs or videos;
- the system can be easily incorporated into the ship's existing fire alarm system.

By comparing the results shown in Figures 6, 7 and 8, it can be concluded that smoke detection based on video technology is much faster than smoke detection based on classical optical detectors. Considering the mean detection time in optical smoke detectors and in cameras, it can be concluded that the speed of response of the video technology is about sixty times faster than that of classical optical smoke detectors.

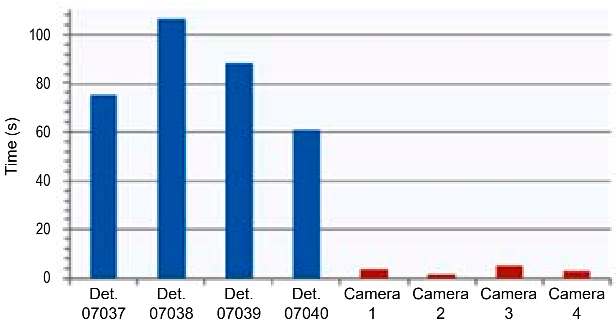

Figure 6. Comparison of the time to activation of optical smoke detectors and video detection of smoke by IP cameras without ventilation

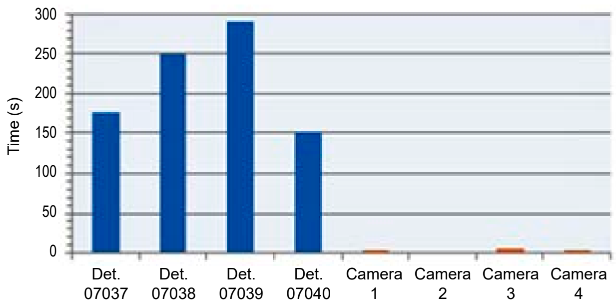

Figure 7. Comparison of the time to activation of optical smoke detectors and video detection of smoke by IP cameras with ventilation

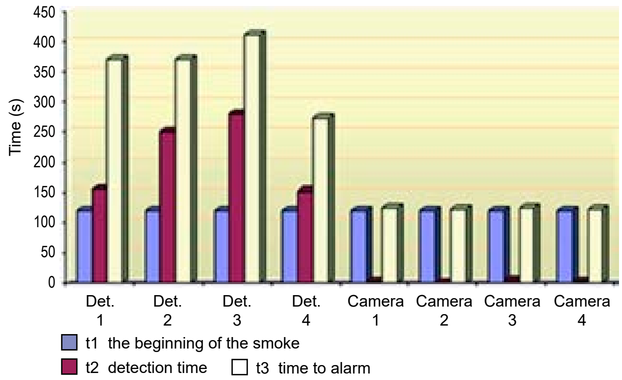

Figure 8. Time to smoke detection by optical detectors and video technology

The shortcomings of the proposed video-based smoke detection model are (Gottuk, 2008):

- the video system requires a minimum level of lighting for the monitored area of detection;
- video cameras must be in accordance with minimal technical performance;
- there is a problem of vibrations in these monitored areas which may affect the quality of images/videos;
- each camera requires parameters to be specified according to its location and surroundings;
- it is necessary to regularly clean the protective glass, otherwise the quality of the images/videos might be poor and thus adversely affect detection;
- the system still does not have permission to be used on ships.

Smoke detection and activation of the alarm when using video technology happens in about 2–3 seconds on average. With classical detectors, these times depend on the monitored surface, the height of the room and different air flows affecting the direction of the movement of smoke.

Economic justification for the proposed model with regards to decreasing the total costs incurred by the untimely detection of the early stages of fire in ship engine rooms

Fire is one of the top three causes of vessel loss and one of the main risks for Ro-Ro ferries and passenger ships. Timely dissemination of information regarding the location of a fire is the most important

Table 2. Approximate prices of engine room systems and individual devices for three types of ship built in the *Uljanik Shipyard* (Croatia) (in USD)

Systems and devices of the ships' engine room	Bulk carrier	Chemical tanker	Car carrier
1. Incinerators	48,807.00	48,807.00	48,807.00
2. Sanitary water system	26,606.00	26,606.00	26,606.00
3. Sewage treatment plant	25,400.00	25,400.00	25,400.00
4. Main engine	3,381,000.00	3,500,000.00	3,600,000.00
5. Compressors	32,000.00	32,000.00	35,000.00
6. Fresh water generator	23,500.00	23,500.00	23,500.00
7. Auxiliary engines	757,000.00	800,000.00	900,000.00
8. Separators	118,000.00	118,000.00	118,000.00
9. Fuel preparation unit	80,000.00	80,000.00	80,000.00
10. Pump	83,000.00	83,000.00	93,000.00
11. Coolers	34,000.00	34,000.00	40,000.00
12. Accompanying equipment	50,000.00	50,000.00	57,000.00
Total	4,659,313.00	4,821,313.00	5,047,313.00

factor in its prevention or limitation. The risk of a fire itself can never be completely eliminated, but its effects can be mitigated.

It is impossible to predict the speed at which a fire will spread. Sometimes the flames or smoke in the engine room spread so quickly that the automatic extinguisher system cannot react quickly enough and the damage is substantial. There have also been cases where a manual fire extinguisher is sufficient to combat the fire and the damage is negligible. To demonstrate the economic justification of the proposed model, with regards to increasing the safety of the ship and decreasing possible incurred costs, it is necessary to know the price of each engine room system (Table 2).

Table 2 shows the prices of the main engine room systems for three types of ship built in the *Uljanik Shipyard* (Croatia). From the table, it is possible to read the total financial loss that the late detection and untimely extinguishing of a fire could cause. The associated works such as painting, welding, pipeline installation and other works to repair an engine room are not included.

When the prices of the ship fire alarm systems (Table 3) are compared with the total price of the engine room, it can be concluded that investing in the proposed computer vision based fire alarm system, with an increase of the fire alarm system price of 20%, would quickly pay off. It is necessary to keep in mind that newer ships already have CCTV systems installed and that, with the implementation of a smoke video detection program into the existing CCTV system, the proposed model can very quickly be integrated into the overall fire alarm system.

Table 3. Prices of ship fire alarm systems and CCTV systems for three types of ship (in USD)

	Bulk carrier	Chemical tanker	Car carrier
Fire Alarm System	20,500.00	24,500.00	82,000.00
CCTV System	6,400.00	6,400.00	12,000.00

Conclusions

Despite the modern technologies used in detecting and extinguishing fires on ships, fires still pose a real threat. The growing demands of contemporary ship owners for risk mitigation and navigational safety have encouraged manufacturers of shipping equipment and the scientific community to research, develop and implement new solutions.

The fear of fires on ships is constantly present in the maritime industry, from the construction of simple wooden ships, whose material was very susceptible to fire, until today. Ship fires can have catastrophic consequences, causing enormous material damages to the ship, its systems and cargo, loss of human lives and damage to the environment. Due to this fact, the fire alarm system has played a very important role in the protection of people and ships, with reliable and quick notification of the exact location of a fire incident. There is a direct connection between the extent of damages caused by fire and the time of intervention of various ship fire alarm systems: the shorter the intervention time, the lesser the damage to the ship, as demonstrated in this paper. The main requirement of a fire alarm is a timely reaction, i.e. the quickest possible detection of a fire incident, for the purpose of minimizing the damage.

The development of technology also aims to integrate ships' systems, including fire alarm systems, and also the control of each system's functioning, which ultimately aims to achieve significantly simpler management and surveillance.

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