POLISH MARITIME RESEARCH 2 (118) 2023 Vol. 30; pp. 114-120
10.2478/pomr-2023-0027

IMAGE PROCESSING METHOD FOR CARGO CONTAINER IDENTIFICATION IN A STACK WITHIN THE CARGO TEMPERATURE CONTROL AND FIRE SAFETY SYSTEM ON CONTAINER SHIPS

Vladyslav Konon *
National University „Odessa Maritime Academy", Odesa, Ukraine

* Corresponding author: *science.est@hotmail.com*

ABSTRACT

The current research is focused on the identification of cargo containers in a stack from their images in the infrared and visible spectra, in order to locate the container-origin of ignition within the cargo temperature control and fire safety system. The relevance of the topic is reinforced by the functional requirements for shipboard safety, which are embodied in Chapter II-2 of the Safety of Life at Sea (SOLAS) Convention, and demanded by the necessity of enhancing safety measures during cargo transportation by the world container fleet. The thermal imager's field of view (FOV) and the coordinate dependencies between the object and its image have been studied and modelled, and an algorithm for fire detection has been defined within the scope of the current research in connection with the containers within the camera's FOV. A corresponding verification has been carried out by means of simulation modelling using the Unity and C# programming language capabilities.

Keywords: shipboard safety, cargo transportation, cargo temperature control, image processing, fire detection

ABBREVIATIONS

SOLAS – Safety of Life at Sea
FSS Code – International Code on Fire Safety Systems
TEU – twenty-foot equivalent unit
IMDG – International Maritime Dangerous Goods
MFAG – Medical First Aid Guide for use in accidents involving dangerous goods
EmS – Emergency response procedures for ships carrying dangerous goods
ULCS – ultra-large container ship
PIR – passive infrared
RoPax – roll-on/roll-off passenger ship/ferry
RGB – red, green and blue
CCFSS – cargo temperature control and fire safety system
FOV – field of view
IDE – integrated development environment
ROI – region of interest
UI – user interface

INTRODUCTION

The occurrence of high-profile incidents, such as the cases of the MSC Zoe and X-Press Pearl, with the loss of almost 350 containers at sea or the fire, respectively, have emphasised the following two issues in the consideration of safety tasks on container ships: loss of containers at sea and fires associated with cargo ignition [1]. The constant increase in the size of ships of this type in the last decade is related to an effect of scale in the world trade of containerised cargoes. This trend brings additional design variables and operational factors into the analysis of the abovementioned safety challenges. Between 2011 and 2019, the volume of the container fleet increased by about 15%, while the share of vessels larger than 10,000 TEU increased by approximately 500%.

Thus, the excessive number and density of containers on deck and in holds, the limited space between the stacks and the ship's configuration, which, despite a significant increase in size, has generally remained unchanged, means that a fire or explosion in a container can be very difficult to detect, control and extinguish at an early stage. At the same time, particular attention needs to be paid to the transportation of special cargoes, namely dangerous goods. Although such IMDG cargoes should be stowed in accordance with the relevant regulations and ship's certificates (e.g., the Document of Compliance for the Carriage of Dangerous Goods), in practice, there are cases of undeclared or incorrectly declared dangerous goods [2]. Thus, the Master and crew become more vulnerable to the associated risks and cannot take the appropriate actions and measures required by the relevant instructions and documents (Cargo Securing Manual, MFAG, EmS guide, etc.). In accordance with Regulation 3 of Chapter VII of the SOLAS Convention, the transportation of dangerous goods in containers must comply with the provisions of the IMDG Code.

According to the information provided in [3], 58% of the 36 contributing factors in twelve fire/explosion reports were related to emergency actions on board during the emergency response, equipment failure, its installation/design and incorrectly declared or missing information regarding IMDG cargoes.

The requirements for providing ships with fire safety systems are stipulated by the SOLAS Convention [4] and the International Code on Fire Safety Systems (FSS Code) [5] in accordance with Chapter II-2 of the mentioned Convention. Notwithstanding the other requirements for the transportation of IMDG cargoes, such fire systems must ensure the protection of the ship from the dangers associated with the carriage of dangerous goods in accordance with Regulation 19 of Part G of Chapter II-2 of the SOLAS Convention.

In order to achieve the fire safety goals set by the SOLAS Convention, the following functional requirements are listed in Chapter II-2 [6]:

- division of the ship into main vertical and horizontal zones by thermal and structural boundaries;
- separation of living quarters from the rest of the ship's premises by thermal and structural boundaries;
- restrictions on the use of flammable materials;
- detection of fire in the area of origin;
- provision of means of evacuation and access to fire-fighting equipment;
- availability of fire-fighting appliances and minimisation of the risk of ignition of flammable cargo vapour.

However, the opinion has been expressed that "...the legal requirements prescribed by SOLAS were originally developed for fires on board general cargo vessels, and these ships are structurally very different to a container vessel, and cargo is stored differently. We believe the mode of fire-fighting set out in SOLAS is not suitable for a modern container ship...", as stated by the chairman of the International Union of Marine Insurance forum [7].

On the other hand, there have been a number of studies aimed at improving the fire safety on board ships of different types and applying a wide variety of methods and approaches.

The research in [8] is focused on the issue of engine room fires, highlighting the inherent dangers and defining fire safety management as an important factor in efficient fire prevention. In this regard, a survey on fire safety in the engine room was carried out, resulting in proposals for the improvement of engine room fire safety management.

The study [9] presents a comparison between the predictions of three different fire models and the experimental results of a model-scale fire test as a fire scenario on a vehicle deck on board a RoPax ship. The results obtained from this research may be useful for ship design and engineering in order to reduce the risks of accidents occurring.

Paying particular attention to the subject of cruise ship fires, an attention–backpropagation neural network model is proposed in [10]. The model designed can provide a decision-making reference for subsequent fire-fighting measures and personnel evacuation. The results obtained showed the effective and early fire warning generation.

However, it should also be noted that commercial and safety concerns are usually opposed to each other. This problem is no less relevant for the container fleet too. In practice, the crews on board ULCS may differ slightly from those on vessels of smaller sizes. Consequently, safety issues become more susceptible to the negative influence of the human factor, inter alia. In this context, the need to develop new methods and systems of firefighting and fire-detection, as well as to improve the existing ones, is further justified. Since firefighting is much simpler at the early stages of fire detection, the current research is focused in the direction of temperature control of containerised cargoes.

Generally, conventional fire-detection systems consist of a central module and a monitoring panel (additional repeater panels are possible); combinations of heat detectors, smoke and flame sensors, etc.; manual fire detectors; and sound and light alarm signalling devices. They can be both fairly simple and more complex to implement. According to the principle used to determine ignition, the following types of fire sensors can be distinguished [6]: thermal sensors, ionisation smoke sensors, optical smoke sensors, photo-thermal sensors, flame sensors, beam sensors, linear thermal sensors, and intrinsically safe systems.

At the same time, a number of studies have been devoted to the problem of the development and improvement of fire-detection systems for various applications.

The study [11] presents a differential passive infrared (PIR) sensor and a method based on deep neural networks for real-time fire detection. The developed method uses a one-dimensional continuous wavelet transform to process the signals received from the sensor, with subsequent conversion of the resulting coefficients into RGB spectrum images and processing by a convolutional neural network. However, despite the declared effectiveness of the proposed system, its implementation on board a container ship with the purpose of cargo monitoring raises several issues that require further research. These include, but are not limited to, the following: the ability to detect unopened flames, such as ignition inside a cargo container; the number of sensors required since, based on the calculation of one sensor per container, a 3,000 TEU container ship may need 3,000 sensors, which raises subsequent issues of their placement and further maintenance.

Trying to solve the problem of false positives, [12] describes a method for quick detection of fire by smoke. The proposed algorithm relies on the colour and diffusion characteristics of smoke and counts the number of pixels in each potential smoke region by processing its video image. However, as noted by the authors, this model has a drawback that requires further study, expressed in the independent generation of false signals due to the features of the algorithm.

The authors of [13] propose to use video images in order to detect flames, providing regular monitoring, and saving the received image at the time of the fire alarm, which may also be used for investigations. However, the implementation of such a system for cargo control on board a container vessel also raises additional issues. Besides, its effectiveness in the case of smoke or flames located inside a cargo container requires a separate study.

In [14], a cargo temperature control and fire safety system (CCFSS) is proposed and its relevance is outlined. CCFSS is based on the implementation of thermographic tools, such as thermal imagers, for efficient and early-stage fire detection in a real-time mode on board container ships. However, the proposed concept still requires solutions for a number of sub-tasks, such as:

- definition of the most efficient layout of the thermal cameras to cover the area monitored;
- development of an algorithm that is able to predict and assess the potential hazardous situation at an early stage;
- development of a method for identifying the container that is the ignition source in a stack by its images in both the thermal and visible spectra.

The first two of these sub-tasks are discussed in [15]. It was therefore decided to conduct further research on the described system in relation to a cargo identification method.

The purpose of the current research is to propose a method for the identification of cargo containers within the stack from images in both the thermal and visible spectra within the CCFSS. Such a method may contribute to the identification of the heat/ignition origin at an early stage, namely to define its exact position. The relevance of this study is reinforced by the functional requirements listed in the SOLAS Convention, namely, determination of the fire in the area of origin and minimisation of the ignition risk of flammable cargo.

THERMAL IMAGER’S FIELD OF VIEW

In order to solve this task, the general idea of an installation pattern, the minimum number of thermal cameras required, the corresponding algorithm for data processing within the CCFSS, an instrument’s field of view (FOV) and other parameters/limitations are considered, as well as the vessel’s configuration in the area where the system is installed. The parameters of the thermal camera used during the on-site observations are shown in Table 1.

Tab. 1. Specifications of the thermal camera module

Camera module	
Thermal sensor	17 µm pixel size
Thermal resolution	80x60
Visual resolution	640x480
Horizontal / vertical FOV	46° ± 1° / 35° ± 1°
Focus	Fixed 15 cm – infinity
Radiometry	
Scene dynamic range	-20°C – 120°C
Accuracy	± 5°C or ± 5% of the difference between the ambient and scene temperature. Applicable 60s after start-up when the unit is within 15°C – 35°C and the scene is within 10°C – 120°C
Thermal image analytics	– Movable spot meters – Whole image region of interest (ROI) – Editable in saved images
Palettes	Iron, Black hot, White hot, Rainbow, Contrast, Arctic, Lava, Coldest, Hottest

As installation within, for example, a cargo hold may encounter some difficulties such as bulkheads or other configuration features that may obscure the view of the sensor, it is proposed to install cameras in accordance with such configurations in order to cover all the objects of interest through the common FOV of several thermal imagers. In this way, one camera can monitor a determined number of containers.

As a first approximation, a camera’s FOV can be presented as a pyramid with a rectangle at the base. Thus, the FOV can be determined by the pyramid’s height and the angles at its vertex. In the context of the set task, the angles at the pyramid’s vertex are the horizontal and vertical angles of the FOV, given from the imager’s specifications.

Fig. 1 schematically shows the thermal camera in relation to the cargo containers: the thermal camera is located within the cross-deck (3) of the ship’s cargo area in such a way that the pyramid of its FOV (2), rotated by an angle α, covers a predetermined number of containers (1). Thus, the height of the pyramid will depend on the distance from the camera to measurable objects.

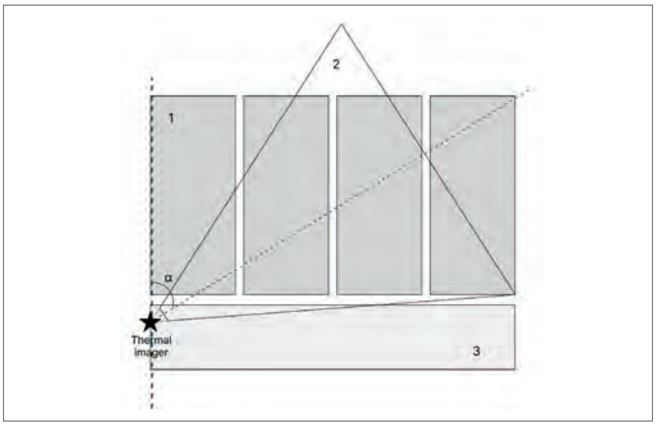

Fig. 1. Schematic representation of thermal imager’s location in relation to cargo containers (top view)

During the on-site observations, it was determined that the distance from the camera to the observable object, which is more than about 12 m, is practically inexpedient within the framework of the set task. Thus, based on the initial data available and trigonometric transformations, a pyramid's edge can be obtained by the formula:

$$a = \sqrt{h^2 \cdot \tan^2 \frac{H_{fov}}{2} + \frac{h^2}{\cos^2 \frac{V_{fov}}{2}}}, \qquad (1)$$

where:

a – side edge of the pyramid with a rectangle at the base;
h – height of the pyramid;
H_{fov} – horizontal angle of the FOV;
V_{fov} – vertical angle of the FOV.

Thus, the FOV pyramid, considering the camera specifications from Table 1, namely, H_{fov} = 46° and V_{fov} = 35° for a maximum object distance of 12 m and a camera's focus of 15 cm, becomes the frustum [16] at the value of the focus, as plotted in Fig. 2.

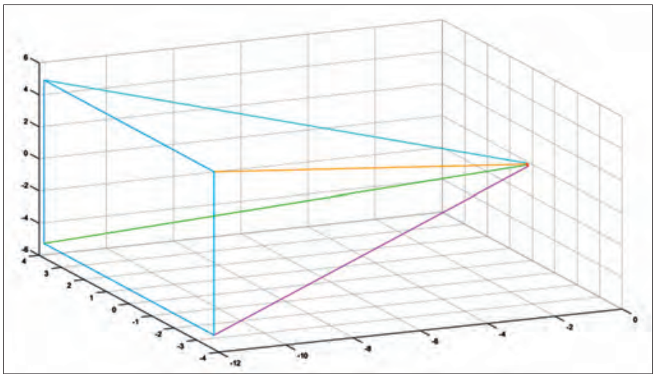

Fig. 2. Plot of the view frustum for thermal camera used during the on-site observations

DEPENDENCY BETWEEN THE COORDINATE SYSTEMS OF AN OBJECT AND ITS IMAGE

The position of the image at the time of photographing is determined by three elements of the interior and six elements of the exterior orientations (Fig. 3). The interior elements include: a camera's focus f and coordinates x_0, y_0 of a main point o. At the same time, the exterior elements are: the coordinates of a projection centre S – XS, YS, ZS, and the longitudinal, transverse and rotation angles ω, α and κ, respectively [17]. $OXYZ$ is the coordinate system of the object M; oxyz – the coordinate system of the image; m is the projection (image) of the object M in the plane of the image. Vector $\vec{R}$ determines the position of the object M in relation to the coordinate system of the image. Vector $\vec{R_S}$ determines the position of the projection centre S in the object's coordinate system. Vector $\vec{R_M}$ determines the position of the object M in relation to the coordinate system of the object. Vector $\vec{r'}$ determines the position of the image m in the coordinate system of the image. Thus, the elements of the internal orientation are defined by the internal geometry of the camera at the time of data collection and can be obtained from the instrument's specifications and through its calibration. The elements of the external orientation are determined by the position and angular orientation of the camera in relation to the measurable object's coordinate system [18].

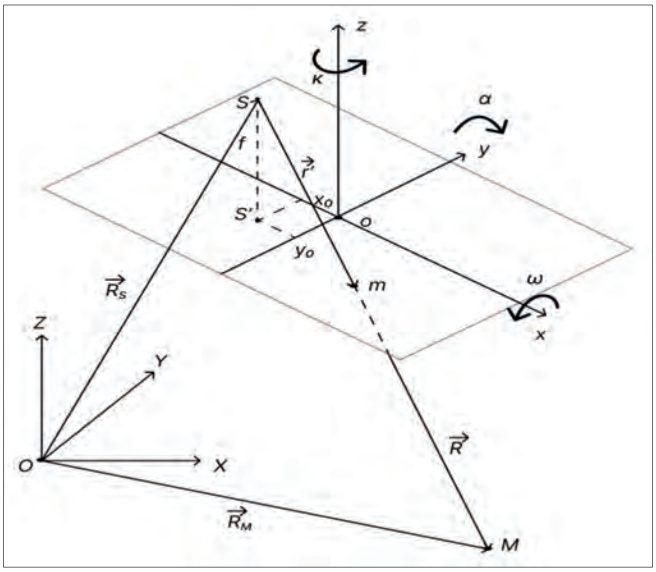

Fig. 3. Elements of the interior and exterior orientation

The coordinates of the object and its image are thus connected through the collinearity equation, which may be presented as follows:

$$\begin{cases} X = X_S + (Z-Z_S)\,\frac{X'}{Z'} \\ Y = Y_S + (Z-Z_S)\,\frac{Y'}{Z'} \end{cases}, \qquad (2)$$

where:

X, Y, Z – coordinates of the object M in the object's coordinate system;
X_S, Y_S, Z_S – coordinates of the projection centre S;
X', Y', Z' – coordinates of the vector $\vec{r'}$ in the object's coordinate system, which may be defined by the formula:

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = A \begin{bmatrix} x-x_0 \\ y-y_0 \\ -f \end{bmatrix}, \qquad (3)$$

where:

x_0, y_0, f – elements of the interior orientation;
x, y – coordinates of the image;
A – coordinate transformation matrix (direction cosine matrix), the values a_{ij} of which are determined by the values of the angle elements of the exterior orientation (ω, α, κ).

The direction cosine matrix A may be presented as follows:

$$A = \begin{bmatrix} \cos\alpha \cdot \cos\kappa - \sin\alpha \cdot \sin\omega \cdot \sin\kappa & -\cos\alpha \cdot \cos\kappa - \sin\alpha \cdot \sin\omega \cdot \cos\kappa & -\sin\alpha \cdot \cos\omega \\ \cos\omega \cdot \sin\kappa & \cos\omega \cdot \cos\kappa & -\sin\omega \\ \sin\alpha \cdot \cos\kappa + \cos\alpha \cdot \sin\omega \cdot \sin\kappa & -\sin\alpha \cdot \sin\kappa + \cos\alpha \cdot \sin\omega \cdot \cos\kappa & \cos\alpha \cdot \cos\omega \end{bmatrix} \qquad (4)$$

Considering Eq. (3), the collinearity equation Eq. (2) takes the following form:

$$\begin{cases} X = X_S + (Z - Z_S)\,\dfrac{a_{11}(x-x_0)+a_{12}(y-y_0)-a_{13}f}{a_{31}(x-x_0)+a_{32}(y-y_0)-a_{33}f} \\ Y = Y_S + (Z - Z_S)\,\dfrac{a_{21}(x-x_0)+a_{22}(y-y_0)-a_{23}f}{a_{31}(x-x_0)+a_{32}(y-y_0)-a_{33}f} \end{cases} \quad (5)$$

In the case of the CCFSS, the elements of the exterior orientation can be determined at the stage of the thermal imager's installation. Also, the coordinate systems of each camera's position within the common FOV pattern can be defined individually, as they are to be synchronised by a general data processing algorithm of the CCFSS. Thus, the allocation of the object's coordinate system for each camera's position can be presented with the origin in the corresponding projection centre *S* (*XS*; *YS*; *ZS*), both rotated at the same values of ω, α, and κ. Thus, the angle elements between the respective axes of the coordinate systems acquire zero values, as also do the coordinates of the projection centre *S*. So the coordinate transformation matrix *A* from Eq. (4) becomes a third-order identity matrix, and Eq. (2) considering A as the identity matrix in Eq. (3) take the following form:

$$\begin{cases} X_M = \dfrac{Z_M \cdot (x_i - x_0)}{-f} \\ Y_M = \dfrac{Z_M \cdot (y_i - y_0)}{-f} \end{cases}, \quad (6)$$

where:

X_M, Y_M – coordinates of the object M in relation to the camera's position;

x_i, y_i – coordinates of the object's image in the plane of the image;

f – camera's focus;

Z_M – distance from the camera to the measurable object.

SIMULATION MODELLING OF CONTAINER DETECTION BY THERMAL IMAGING

A simulation environment developed by means of the Unity IDE and C# programming language capabilities, which are also described in [14, 15], was used in this research in order to perform the simulation modelling of the current task.

Ignition source identification is performed by matching the dynamic infrared data of the object from its thermal image with static coordinate dependencies using images in both the infrared and visible spectra. The data of the visible spectrum are used to distinguish containers within the FOV of the camera, namely, by defining regions of interest (ROI) on the respective image. Therefore, several ROIs can be defined in regard to the respective containers within the camera's FOV. The camera's coordinates are predetermined, based on the elements of the external and internal orientation by means of the defined dependency between the coordinate systems of an object and its image. The thermal data layer of the infrared picture, which contains the temperature information for each pixel and its corresponding palette colour, can be used in order to analyse the real-time condition of the cargo container being monitored. A colour chart or *colour palette* is required for a better match of the pixel's intensity values, which results in better detailing of the image. Moreover, these are used as an effective instrument for thermal data visualisation [19]. Thus, the container in which the ignition originates can be defined by a colour (temperature) change. When such a change is detected inside the respective ROI, the location of the origin of ignition can be identified and presented in bay/row/tier form, using data on the camera's location within the vessel's cargo area. An example of a thermal image in relation to the visible spectrum, taken during the on-site observations with the thermal imager, is presented in Fig. 4. It shows the possibility of thermal data processing by using appropriate commercial software. Spot 1, which is marked as "Sp1" in the infrared spectrum, corresponds to a temperature of 68.8°C. The instrument's calibration and evaluation of the accuracy are the subjects of a separate study and are partially reviewed in [14].

Fig. 4. Reefer-container's compressor in visible and infrared spectra

Fig. 5 presents the viewing frustum of the virtual camera, which is located inside the simulated cargo hold within the virtual environment. The camera's view is rendered as a virtual texture plane, which is equivalent to the image. Within the designed simulation, the cargo containers have a thermal layer, which changes colour depending on the temperature settings of the application. One virtual camera is set to monitor four containers, which are identified within the camera's coordinate system by numbers from left to right and from 0 to 3 (Fig. 6).

When the application is started, the colour values of the texture within the ROIs are saved to an array and used as the reference point. This is compared to the values obtained in each frame and, in the case of detecting a colour change, a warning message is issued that fire has been detected in the respective container, indicating the number from 0 to 3. In this context, each frame can be considered as an iteration of the cycle, which is stopped by a respective command from the operator.

Fig. 6 displays the above-mentioned virtual texture on the left ("Scene") for visual data analysis during the simulation process. On the right ("Game"), a general overview of the simulated cargo hold with the user interface (UI) is presented. The UI allows the user to set the temperature of a fire source and start/stop the calculations. In the bottom tab ("Console"), the warnings generated are shown in accordance with the algorithm. The monitored containers are numbered for clarity.

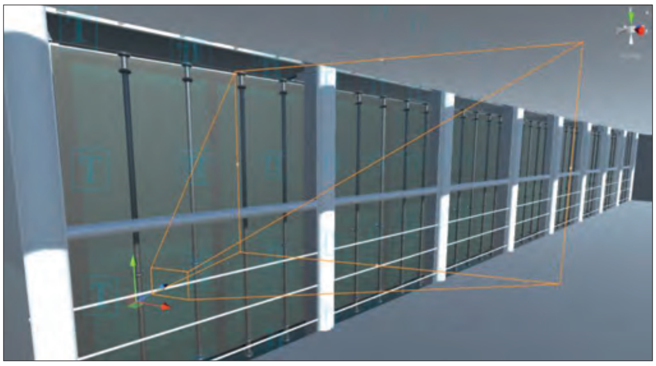

Fig. 5. Virtual camera's viewing frustum

In the presented results, colour changes have been detected only in containers 2 and 3, with the respective warning messages displayed in the "Console" tab.

The proposed algorithm is considered satisfactory within the framework of the set task. However, it still requires enhancement and further research in order to implement the use of multiple cameras, and for determination of the container with the highest temperature value within the common FOV and data synchronization arrangement.

Fig. 6. Simulation of container identification

CONCLUSIONS

The relevance of the safety issues inherent to cargo transportation by container ships has motivated research in the field, which is aimed at safety improvements through implementing a wide variety of methods and approaches. The increase in the size of container ships only reinforces the need for such improvements, particularly in the context of fire safety.

The current study proposes an image processing method to identify cargo containers in a stack within the CCFSS. This method is based on the use of thermal imagers as instruments for cargo monitoring. The algorithm developed uses images in both the thermal and visible spectra in order to detect the container that is the source of ignition and its exact position by matching the dynamic infrared data of the object from its thermal image with static coordinate dependencies. The thermal camera's FOV used during the on-site observations has been modelled during the research. The method for identifying a container's position is based on elements of its external and internal orientation, and can be implemented through the defined dependency between the coordinate systems of an object and its image. The obtained position is determined in relation to the camera's coordinate system and can potentially be transformed into a "bay/row/tier" form by comparing the placement data of the respective camera in the cargo area being monitored. The simulation modelling was carried out using the Unity and C# programming language capabilities. The results obtained, as presented in the current work, are considered satisfactory within the set task.

However, additional research should be carried out in order to implement the use of multiple cameras, enabling the determination of the container with the highest temperature value within the common FOV and data synchronization arrangements. It should be noted that, while the simulation performed was carried out for the placement of imagers in a cargo hold, the proposed image processing method may also be used on deck. Therefore, the issue of the cameras' installation pattern, as well as the other features and tasks of the CCFSS, will be the subject of further studies.

REFERENCES

1. European Maritime Safety Agency, "European Maritime Safety Report 2022," *European Maritime Safety Agency*, EMSA TN-AA-22-00, 2022. [Online]. Available: https://emsa.europa.eu/publications/item/4735-emsafe-report.html. [Accessed: Feb. 18, 2023].

2. J. Ellis, "Undeclared dangerous goods – Risk implications for maritime transport," *WMU Journal of Maritime Affairs*, vol. 9(1), pp. 5–27, 2010, doi: 10.1007/bf03195163.

3. European Maritime Safety Agency, "Safety Analysis of Data Reported in EMCIP – Analysis on Marine Casualties and Incidents involving Container Vessels," *European Maritime Safety Agency*, EMSA, 2020. [Online]. Available: https://www.emsa.europa.eu/newsroom/latest-news/item/4276-safety-analysis-of-data-reported-in-emcip-analysis-onmarine-casualties-and-incidents-involving-container-vessels.html. [Accessed: Feb. 18, 2023].

4. IMO, *Consolidated Text of the International Convention for the Safety of Life at Sea, 1974, and its Protocol of 1988: Articles, Annexes and Certificates*. Incorporating all amendments in effect from 1 January 2020. London: IMO, 2020.

5. IMO, *International Code for Fire Safety Systems*. London: IMO, 2015.

6. *Fire Training Manual including Fire Safety Operations*, 2nd ed. Broadstone: I.C. Brindle, 2011.

7. The Maritime Executive, "Call for Better Fire Fighting Systems on Container Ships," *The Maritime Executive*, Sep. 19, 2017. [Online]. Available: https://maritime-executive.com/article/call-for-better-fire-fighting-systems-on-container-ships. [Accessed: Feb. 18, 2023].

8. W. Zeńczak and A. Krystosik-Gromadzińska, "Improvements to a fire safety management system," *Polish Maritime Research*, vol. 26, no. 4, pp. 117–123, Dec. 2019, doi: 10.2478/pomr-2019-0073.

9. A. Salem, "Vehicle-deck fires aboard Ropax ships: A comparison between numerical modelling and experimental results," *Polish Maritime Research*, vol. 26, no. 2, pp. 155–162, Jun. 2019, doi: 10.2478/pomr-2019-0035.

10. Z. Xiong, B. Xiang, Y. Chen, and B. Chen, "Research on the risk classification of cruise ship fires based on an Attention-Bp Neural Network," *Polish Maritime Research*, vol. 29, no. 3, pp. 61–68, Sep. 2022, doi: 10.2478/pomr-2022-0026.

11. K. L. B. L. Xavier and V. K. Nanayakkara, "Development of an early fire detection technique using a passive infrared sensor and deep neural networks," *Fire Technology*, vol. 58, pp. 3529–3552, 2022, doi: 10.1007/s10694-022-01319-x.

12. H. Wang, Y. Zhang, and X. Fan, "Rapid early fire smoke detection system using slope fitting in video image histogram," *Fire Technology*, vol. 56, pp. 695–714, 2020, doi: 10.1007/s10694-019-00899-5.

13. X. Cheng, J. Wu, X. Yuan, and H. Zhou, "Principles for a video fire detection system," *Fire Safety Journal*, vol. 33(1), pp. 57–69, 1999, doi: 10.1016/s0379-7112(98)00047-2.

14. V. Konon and V. Savchuk, "Infrared thermography in the context of fire safety in container transportation by sea," *Shipping & Navigation*, vol. 33, pp. 43–53, 2022, doi: 10.31653/2306-5761.33.2022.43-53.

15. V. Konon and N. Konon, "Application perspective of digital neural networks in the context of marine technologies," *TransNav, The International Journal on Marine Navigation and Safety of Sea Transportation*, vol. 16, no. 4, pp. 743–747, 2022, doi:10.12716/1001.16.04.16.

16. D. F. Rogers, *Procedural Elements of Computer Graphics*. New York: WCB/McGraw-Hill, 1997.

17. T. Szkodny, "Calculation of the Location Coordinates of an Object Observed by a Camera," in *Man-Machine Interactions 3. Advances in Intelligent Systems and Computing*, vol. 242, D. Gruca, T. Czachórski, S. Kozielski, Eds. Cham: Springer, 2014, pp. 139–151, doi: 10.1007/978-3-319-02309-0_15.

18. J. Duh, "Photogrammetry: DTM Extraction & Editing," Portland State University, 2017. [Online]. Available: https://web.pdx.edu/~jduh/courses/geog493f17/Week03.pdf [Accessed: Feb. 18, 2023].

19. A. Berg, *Detection and Tracking in Thermal Infrared Imagery*. Licentiate [Dissertation]. Linköping, Sweden: Linköping University Electronic Press, 2016. [Online]. Available: DiVA – Academic Archive Online, doi: 10.3384/lic.diva-126955.