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Research and Design of Fire Alarm Systems using Virtual Reality Technology Enhance Safety Training in the Maritime

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ABSTRACT

Today, water transportation plays a vital role in transporting goods and international trade. Therefore, maritime safety and fire prevention on ships are urgent issues that are being deployed quickly. There are many methods of training and fire-fighting skills for crew members and fire alarm devices installed on ships. This article develops the hardware design of a fire alarm system on ships incorporating virtual reality simulation technology. Next, build a successful connection between HMI hardware devices and simulation software, such as fire alarms. Therefore, the Seafarer can practice, detect fire areas and have basic fire-fighting skills on ships. Build and simulate virtual space on ships, fires, and fire point spaces in Unity 3D software. The system helps save training costs and human life safety, improving the ability to operate equipment before a real-life situation occurs and rescue scenarios onboard a ship.

1. Introduction.

Ship fire accidents account for many marine disasters and are vital to a ship's ability to operate. Recent ship fire damage has prompted research related to fire training on ships. Many fire alarms, fire-fighting equipment and fire simulation technology on ships have exploded rapidly. In recent years, many fires on ships have caused severe consequences. In October 2021, the Malta-flagged MV Zim Kingston transporting 52 tons of xanthates caught fire and released toxic gases into the environment, causing harm to marine life (MV Zim Kingston, 2021). In 2022, the Singapore container ship APL CAIRO caught fire in Vung Tau waters, causing damage to property and people.

Some fires, such as the fire on the cargo ship Xpress Pearl in 2021, lasted 13 days, causing substantial economic losses and was one of the worst ecological disasters in Sri Lanka's history (X-Press Pearl, 2021). In 2021, the Felicity Ace ship carrying many luxury cars and supercars caught fire in the middle of the Atlantic Ocean; more than 4000 cars must have been destroyed and left on the ship.

In the world, there are many studies on fire alarm systems on ships and VR simulations in some areas on ships for training purposes. Several fire training principles were established by the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW, 1978) and adopted by the International Maritime Organization (IMO), which also issued Evacuation Analysis Instructions for passengers in case of fire.

Some research related to the history and emergencies on ships, or some experiments that simulate fires at dangerous levels for students to practice (Chu, B.; Chang, D., 2017). The research has built a virtual reality building environment to train children, staff and teachers to collect their behaviours and attitudes towards the fire and assess the advantages and disadvantages of using virtual reality glasses (David Oliva. et al.,

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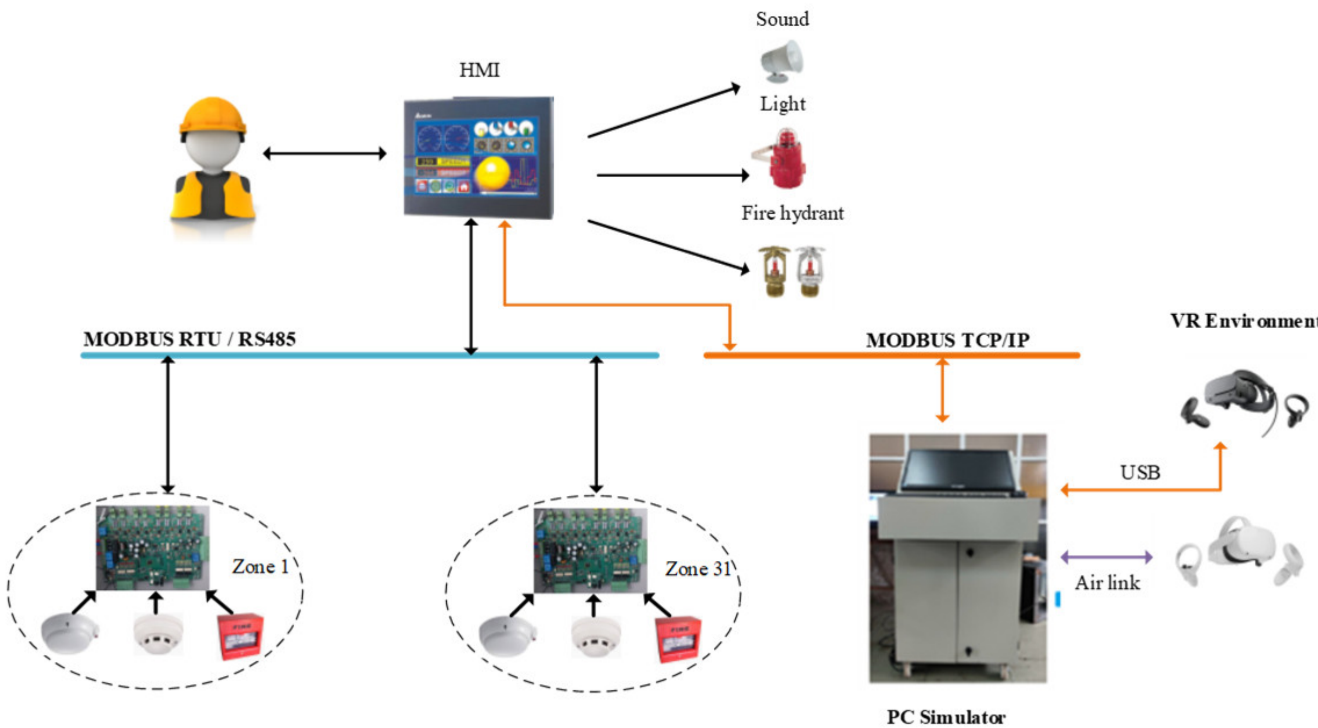
Figure 1: Fire alarm functional block diagram.



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2019). The study calculated the prediction of the time the fire started and the temperature sensor was impacted, built a fire model, and made a relationship between time and smoke propagation speed. (Wang, J. et al., 2018). In some recent studies, virtual reality simulation technology has brought better results than traditional video-watching methods. VR training helps increase students' ability to perceive fire hazards (Lovreglio et al., 2020). In addition, when VR training with fire extinguishers, employees have better skills than those who start using real fire extinguishers (Melo. et al., 2016). As such, there is no study investigating the effectiveness of VR training for fire mitigation in terms of knowledge acquirement and retention. On the other hand, there is no comparison of possible VR training solutions with traditional training solutions focusing on using a fire extinguisher (Feng Z, et. al., 2018).

In Vietnam, several projects are related to fire alarm system design on ships. Author L. K. Thanh has researched and designed an automatic fire alarm system on vessels based on the (actuator-sensor-interface) network technology (Thanh, L . K and Thanh, N . K, 2007). In addition, Khanh et al. have built an intelligent fire alarm system for the building using IOT technology. The fire area warning system with sound and display helps people escape easily when there is a fire (Khanh, Đ. H. et al. 2018). Research on building fire alarms and fire fighting software on ships has created scenarios in virtual reality. However, the interaction with the device is still limited, and some models are simple (Van, Tuan and Hung, 2022).

To prevent unfortunate fires occurring on ships, in addition to raising awareness and equipping crew with fire prevention and fighting skills, a fire alarm system works stably, reliably and promptly. Timely giving fire warnings and the location of the fire has a significant meaning to minimize the damage to people and property.

The rest of the paper is described in Section 2, design of Fire alarm system hardware, and Section 3 proposes to build 3D models in Unity 3D software. Section 4 analyses the testing of some fire scenarios on ships. The conclusions and future work are summarised in Section 5.

2. Fire Alarm System Design.

2.1. Functional block diagram design.

The authors built the functional block diagram for the system, as shown in Figure 1. The diagram includes a Delta Dop-100 HMI touchscreen as a central control. On the other hand, this screen also plays a role in monitoring the entire system, such as displaying the fire area, displaying the alarm list, saving alarm history, and some other interactions with the user, such as editing the name of the fire area to convenient for monitoring.

Figure 1 depicts a Delta Dop-100 HMI screen that not only acts as a central control but on the other hand, this screen also plays the role of monitoring the entire system, such as displaying the fire area and the list, alarm books, saving alarm history;... and some other interactions with users, such as editing the name of the fire area to facilitate monitoring.

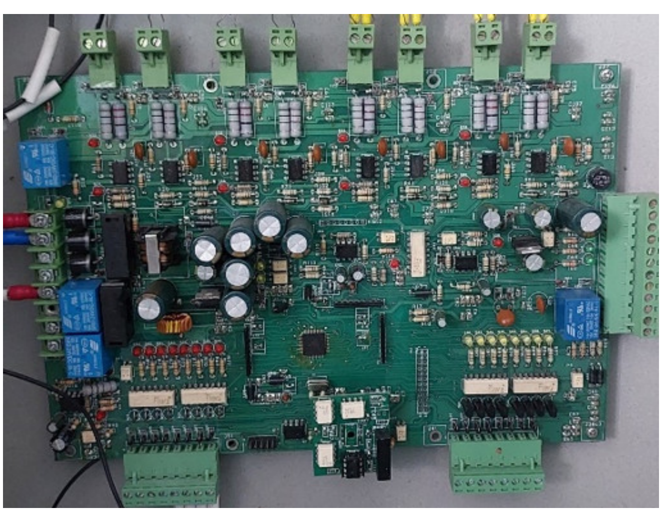
The system is designed to support a maximum connection of up to 31 fire alarm panels for fire monitoring corresponding to a Modbus RTU network that can support 32 devices. The author designs each fire alarm blister to include eight zones, but it supports stacking two blisters on top of each other to keep a maximum of 16 zones. Each zone can connect up to 16 sensors or fire alarm buttons. These zones are all defined with Modbus addresses so the central controller can determine the exact location of the fire when there is a problem (Khanh, Đ. H. et al., 2018).

The SCADA computer will communicate with the simulation computer through the Modbus TCP communication protocol. From the computer simulation, images will be sent to VR glasses, bringing users into a virtual environment to perform operations and procedures in case of fire on the ship under the supervision of teachers.

2.2. Fire alarm circuit design.

The authors designed the fire alarm panel using the ATmega32 microcontroller. The manufactured fire alarm grill includes several main modules: sensor circuit module, configuration circuit module for microcontroller, communication module with touch screen, power module, alarm circuit and function test. With the design principle that the controller will inject a current value at the output of each zone, each zone will connect to a sensor or fire alarm button based on the measured current value the controller will know. It supports combining two zones on top of each other to get a 16-zone blister. Each zone is defined with a corresponding Modbus address. Figure 2 is a picture of the manufactured fire alarm panel.

Figure 2: Fire alarms have been built.

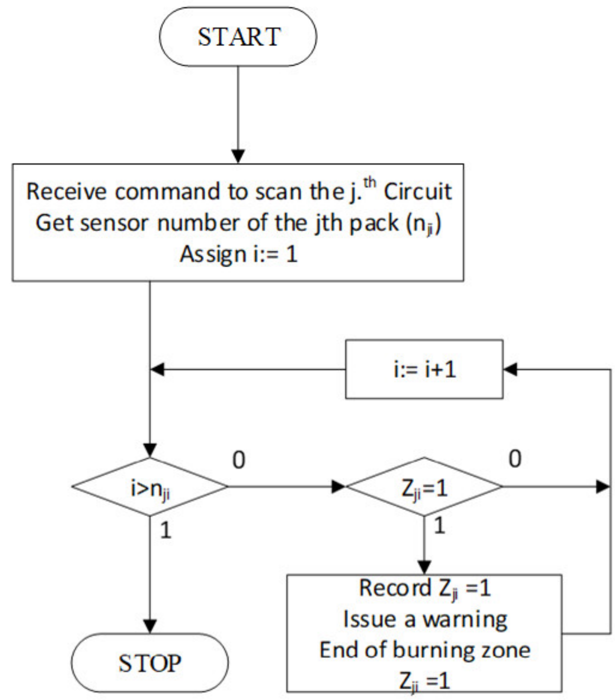


Source: Authors.

3. Control Algorithm.

After designing the circuit board hardware, the authors proceeded to build a control algorithm for the fire alarm system. Figure 3 is the control algorithm 1, which the author built for the j^{th} fire alarm.

Figure 3: Control algorithm 1 of the j^{th} fire alarm panel.



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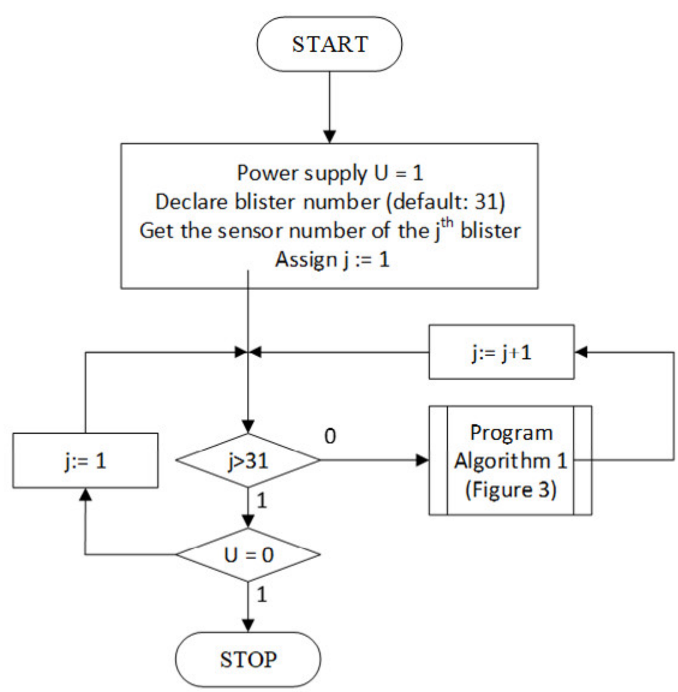
where: j - Serial number of the fire alarm in the system (max multi by default j=31); i - Serial number of sensors play in the jth round; n_{ji} - Number of sensors connected to the blister j^{th}; Z_{ji} - Burning area i^{th} of j.

Figure 4: Control algorithm 2 of fire alarm system.



Source: Authors.

In algorithm 2, the controller will initially receive a scan command and the sensor number of the j^{th} blister. i will be assigned a value of 1 corresponding to the first sensor connected to grid j to be scanned. If at this first position I, a fire occurs in area i, then Z_{ji}=1 and this value will be recorded and issued a fire alarm in the Z_{ji} area.

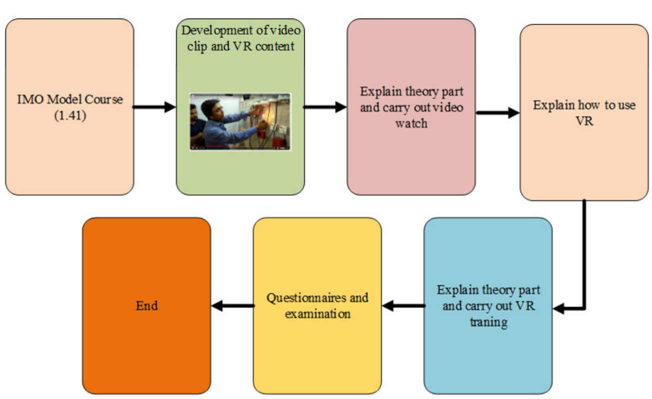
4. 3D model on Unity.

4.1. Build a simulation training process.

According to the International Standard on Training, Certification and Supervision for Seafarers (STCW 1978), as revised, several training and education courses are required to be completed by seafarers. In this study, the authors aimed to quantitatively determine the impact of VR anti-submersion fire training training by comparing it with video-based training methods. To develop video content and VR content, the content scope is defined in IMO Model Course 1.41. "Assisting passengers on exit routes" was selected from the range of the 1.41 sample course and developed into video and VR training content. The participants then watched the video and then practised on VR.

Figure 5 shows the training process of the virtual reality simulation system. In this system, based on the theory based on the IMO Model Course (1.41), the authors reconstructed video tutorials on using life-saving devices. Next, explain the idea to students and let them watch the sample video. Students will become familiar with VR glasses and function buttons. Once mastered, practice in VR glasses.

Figure 5: Fire alarm simulation system training process.



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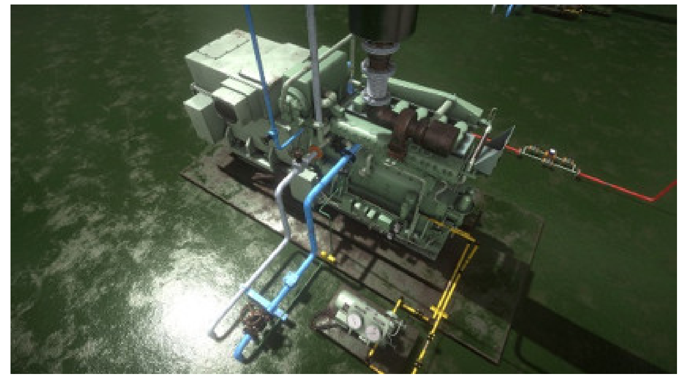
4.2. Build a model ship.

The authors built ship models with many different types of engines from several companies around the world. The container ship model has a size of 361.5m. The team uses specialized graphics software to create 3D objects. Blender software is a powerful tool to help build machine models, engine room models, cockpits and lifeboats.

Figure 6: Ship generator model.



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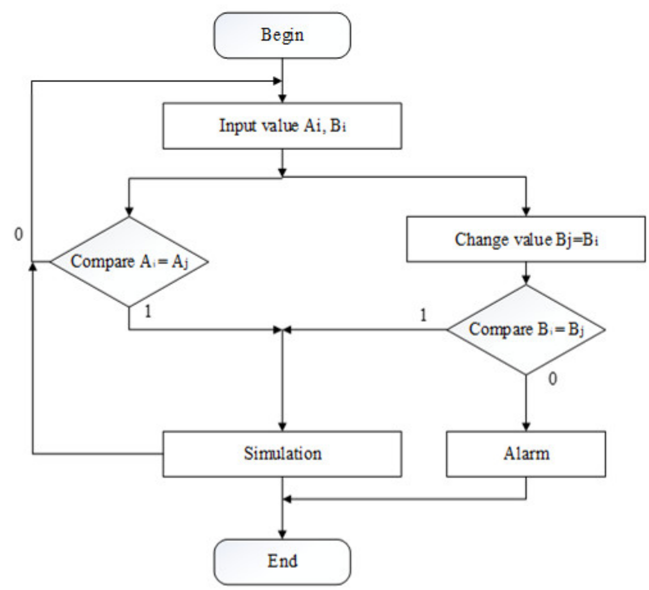
4.3. Fire simulation algorithm.

Figure 7: Fire simulation algorithm.



Source: Authors.

Figure 7 describes the fire simulation program in the software. Initially, when the program receives input values from the teacher's computer, they include A_i is the fire value in the areas to be simulated. B_i is the value that can be changed during the simulation. During the simulation process, the system can be intervened to change the nature of the fire as requested by the teacher. The input values that can be changed are compared with the original setting value. If the cases are not satisfied, it will stop sending a warning signal to the teacher.

4.4. Fire and smoke in unity 3D.

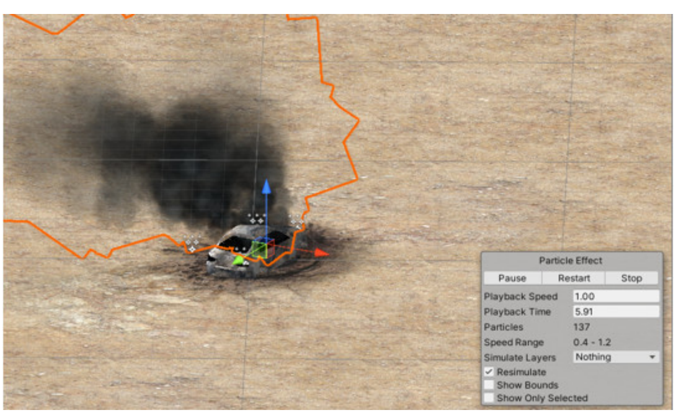
To build the fire, the authors used the Particle tool, which is a tool that helps simulate any effects. These fires have different shapes and levels depending on the burning material, space and fire area, and the fire's time until it is extinguished. The fire is simulated with its actual physical properties. We can also change these values depending on the requirements and burning materials. The duration, looping, colour and speed in the simulation will be set for each fire (Chen,2014). After creating the effect, the authors converted and programmed it based on the C# programming language platform and transferred the built algorithm into Unity. The modules are as follows:

- FireParticle.cs: contains values that create fires in each simulation area.
- FireChangeValue.cs: helps change the fire component value in the simulation.
- FireAudio.cs: Create sounds when there is a fire.

The authors then assigned scripts to each fire object in the simulation. Similar to the smoke that will appear when burning, there will be different smoke depending on the burning material. Therefore, the smoke colours and densities will be different and changed during the program. Figure 8 shows set up a fire and smoke model.Figure 8: a, Fire model; b, Smoke model.

Figure 8: a, Fire model; b, Smoke model.

a,



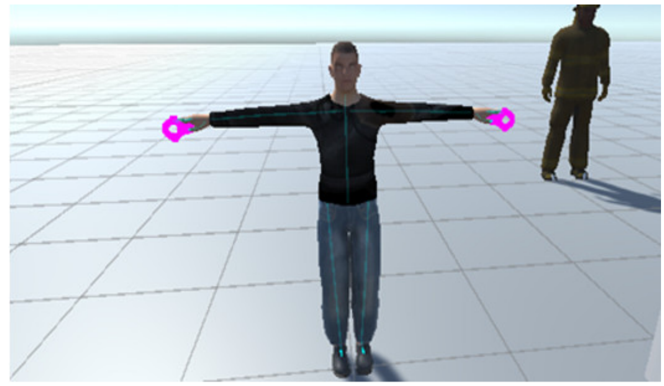
b,

Source: Authors.

4.5. VR Human Model.

The authors built the object in Unity 3D and connected it to the glasses. First, the team created the virtual human thing and the arm and leg components. A subprogram will be made to perform the function as shown in Figure 9 for each small part (Kinateder, et al., 2013).

Figure 9: VR Human model.



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For each of the above functions, C# scripts are created and assigned to each part, such as left hand and right hand.

- LeftHandTarget.cs: programming left-hand movements.
- RightHandTarget.cs: functions like the right hand.
- LeftFootTarget.cs: function to simulate left foot.
- RightFootTarget.cs: simulates proper foot functionality.

5. Simulation and result.

5.1. Simulation steps.

The system provides practice exercises that are simulated in real-life environments and meet STCW regulation VI/3, section A-VI/3 table A-VI/3-1, which describes the validation methods Demonstrate fire-fighting, search and rescue capabilities on board such as (STCW, 1978), (Lovreglio, R., Duan, X., Rahouti, A. et al. 2021):

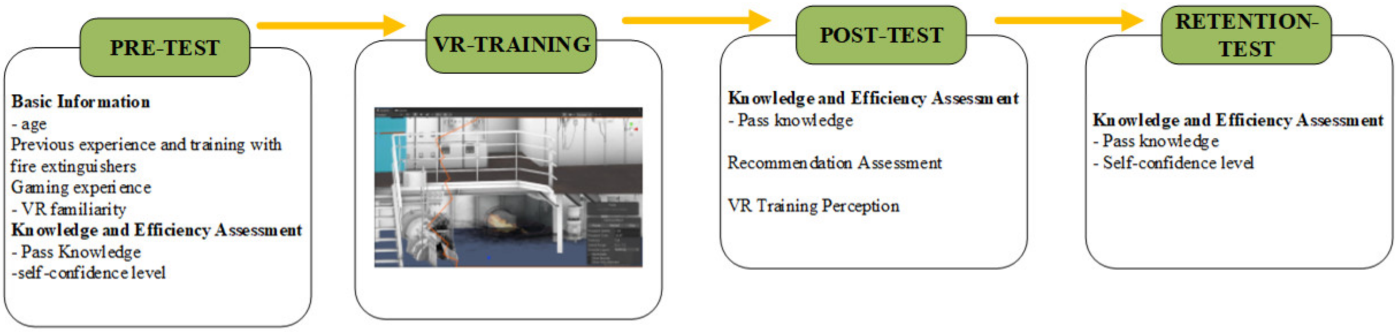
- Control fire-fighting activities on board.
- Organize and train the fire brigade.
- Check and maintain fire detection and fighting systems and equipment.

In addition, the onboard fire-fighting training system developed using virtual reality technology can fulfil various training purposes. It mainly consists of training in fire fighting skills, familiarization with all functions of fire equipment, handling of fire accidents in different positions of the ship and commanding decision-making (Smith S, Ericson E, 2009). Figure 10 describes the student assessment process through the virtual reality simulation system (Desiana, 2022).

5.2. Result.

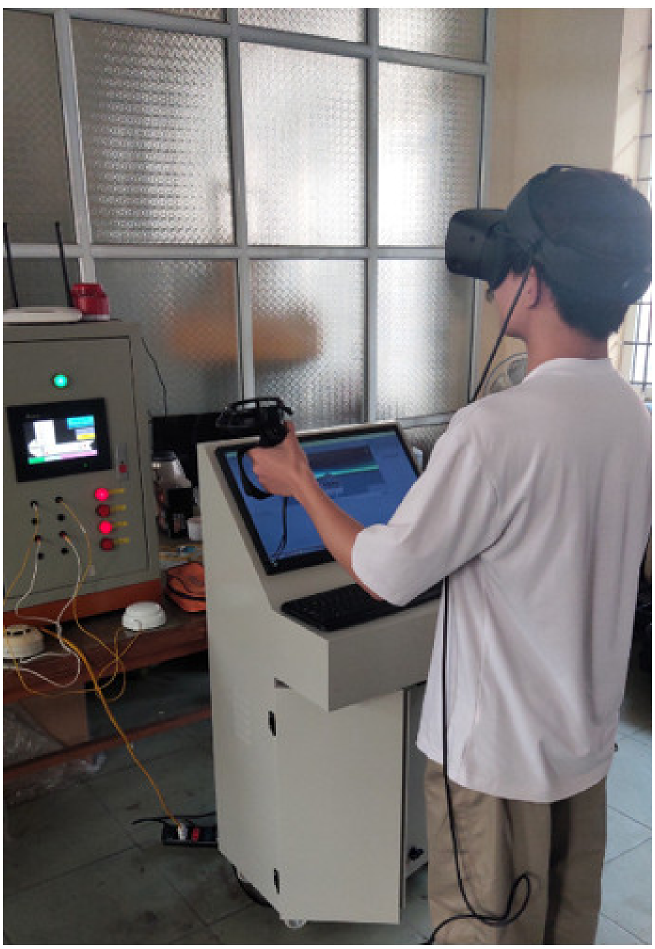
The authors put on glasses and started the simulation program. Before practising, students will watch videos and read documents related to the ship, location, fire-fighting equipment and specific fire-fighting procedures. Then, students wear VR glasses and begin the simulation, as shown in Figure 11.

Figure 10: Research simulation process.



Source: Authors.

Figure 11: Students Testing VR glasses.



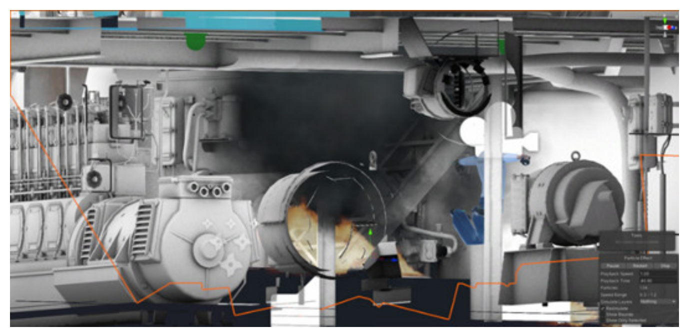
Source: Authors.

The experiments involved 100 students studying Navigation at Vietnam Maritime University for testing and training to evaluate results. After 2weeks after the training, the same participants were contacted again to complete the retention test.

However, only 50 of them completed the second evaluation test (25 for the VR group and 25 for the video group).

Figure 12 shows that the heat and smoke sensors will detect and alert the fire alarm panel when a generator catches fire. Simultaneously, the fire signal fire level and area will be simulated and displayed in VR software.

Figure 12: Fire situation in the engine room.



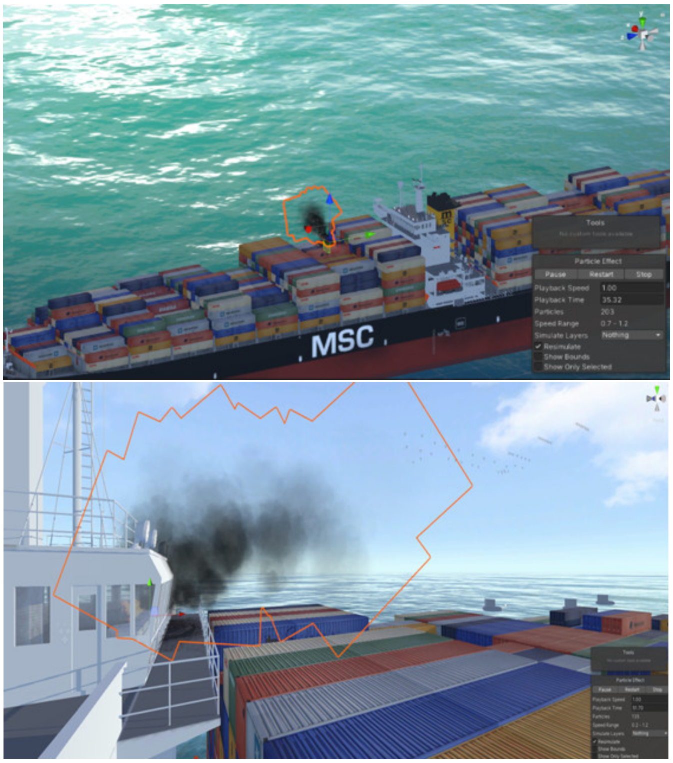
Source: Authors.

Figure 13: Fire situation in the electric room.

Source: Authors.

The spread of the fire will be simulated based on the actual characteristics of the fire. For different objects, the degree of ignition changes. Therefore, acting as a fire object will be more complex and require more detail. The fire level meets about 85% of the actual fire situation during the test. Figure 13 depicts the extent of fire spread in the engine room and the impact of the fire suppression system. At this time, the heat sensor will impact and alarm the entire ship. The crew's task is to determine the location of the fire and then wear protective clothing to extinguish the fire and save people.

Figure 14: a, Container Fire; b, Bridge room.



Source: Authors.

Figure 15: a, Hallway area; b, Seafarer room.

Source: Authors.

From the simulation process, the training evaluation results of the trainees are shown in table 1:

Table 1: Evaluation table of simulation system function.

No.	Function	Kongsberg	Simulation
1	Fire alarm in dangerous areas	100%	90%
2	Fire simulation	100%	90%
3	Skills in using protective equipment	100%	95%
4	Fire fighting	100%	85%
5	Integrated video, instruction sheet	80%	95%

Source: Authors.

Based on the table above, the authors found that the system meets 75% of basic feature requirements compared to foreign systems and IMO standards.

Conclusions.

The article has initially successfully built a fire alarm, fire fighting and anti-sink simulation system for ships. Build 3D models with specific features based on the provisions of the International Maritime Convention STCW 2010 and the IMO Model Course. Besides, build Fire alarm procedures in the simulation. In particular, the authors created a simulation system based on virtual reality technology; this is the first step to applying virtual technology in the maritime field, while Vietnam has not yet implemented it. Therefore, in the future, the authors will try to build ship models suitable for current training requirements and the current training procedures for maritime safety in education in Vietnam to meet the needs of existing training resources and high-quality human resources.

Acknowledgements.

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References.

MV Zim Kingston (2021), Canadian Coast Guard evacuates crew members from container ship off B.C. coast due to fire, Available at: https://www.cbc.ca/news/canada/british-columbia-/shipping-containers-on-fire-1.6222815. [Access: 25/08/2023].

X-Press Pearl (2021), X-Press Pearl Container Ship Fire and Sinkage: Oil Spill and Hazardous Material Release in Coastal Waters of Sri Linka. Affected still Seek Compensation. Available at: https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/x-press-pearl-loss-will-add-to-insurers-container-ship-headaches-64571553. [Access: 28/08/2023].

International Maritime Organization (1978), International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW); International Maritime Organization: London, UK. Available at: https://www.imo.org/en/OurWork/HumanElement/Pages/STCW-Convention.aspx. [Accessed: 28/08/2023].

IMO (2016), Revised Guidelines on Evacuation Analysis for New and Existing Passenger Ships; IMO: London, UK. Available at: https://www.imorules.com/MSCCIRC_1533.html. [Accessed: 29/08/2023]

Chu, B.; Chang, D. (2017) 'Effect of Full-Bore Natural Gas Release on Fire and Individual Risks: A Case Study for an LNG-Fueled Ship', Journal of Natural Gas Science and Engineering, vol. 37, pp. 234–247. doi: 10.1016/j.jngse.2016.11.043.

David Oliva. et al. (2019) ' Virtual reality as a communication tool for fire safety – Experiences from the VirPa project', GamiFIN Conference 2019, pp. 241-252. doi: https://ceur-ws.org/Vol-2359/paper21.pdf. [Accessed: 31/08/2023].

Wang, J. et al. (2018) 'A Mathematical Model for Heat Detector Activation Time under Ship Fire in a Long-Narrow Space', Ocean. Engineering, vol. 159, pp. 305–314. doi: 10.1016/j.oceaneng.2018.04.012.

Lovreglio, R., Duan, X., Rahouti, A., Phipps, R., and Nilsson, D. (2020) 'Comparing the effectiveness of fire extinguisher virtual reality and video training'. Virtual Real, vol. 25, pp. 133-145. doi: 10.1007/s10055-020-00447-5.

Melo, M., Bessa, M., and Roberto Frias, R. (2016) 'The impact of body position on the usability of multisensory virtual environments: case study of a virtual bicycle', in ACM International Conference Proceeding Series, pp. 20–24. doi: 10.1145/3019943.3019947.

Desiana, R. and Prima, S. C. (2022) 'Cyber security policy in Indonesian shipping safety', Journal of Maritime Studies and National Integration, 5(2), pp. 109–117. doi: 10.14710/jmsni.v5i2.13673.

Feng Z, Gonzalez V, Amor R, 'Lovreglio R et al (2018) Immersive virtual reality serious games for evacuation training and research: a systematic literature review', Comput Educ, vol. 127, pp. 252-256. doi:10.1016/j.compedu.2018.09.002.

Chen, L.-C., Wu, C.-H., Shen, T.-S., & Chou, C.-C. (2014) 'The application of geometric network models and building information models in geospatial environments for fire-fighting simulations. Computers, Environment and Urban Systems, vol. 45, pp. 1–12. doi: 10.1016/j.compenvurbsys.2014.01.003.

Makransky, G., Terkildsen, T. S., & Mayer, R. E. (2019). 'Adding immersive virtual reality to a science lab simulation causes more presence but less learning', Learning and Instruction, vol. 60, pp. 225-236. doi:10.1016/j.learninstruc.2017.12.-007.

Thanh, L . K and Thanh, N . K (2007) 'Building the Fire Detecting and General Alarm system in the Ship by Using the AS-I (actuator-sensor-interface) network, No. 11+12, pp. 46-51. Available at: http://khcn.vimaru.edu.vn/sites/khcn.vimaru.edu.-vn/files/46_nghien_cuu_che_tao.pdf.

Khanh, Đ. H. et al. (2018) 'Designing Fire Alarm systems and Building Monitoring and Control Applications', Journal of Marine Science and Technology, No. 55, pp. 37–42.

Van, N. T, Tuan, Đ. A, Hung, N. V (2022) 'Designing Fire Alarm and Fire-Fighting ships Virtual Reality System', No. 08, pp. 144-148. doi: https://sti.vista.gov.vn/tw/Lists/TaiLieuKHC-N/Attachments/346793/CVb12S082022144.pdf.

Kinateder M, Pauli P, Müller M, Krieger J, Heimbecher F, Rönnau I, Bergerhausen U, Vollmann G, Mühlberger A (2013) 'Human behaviour in severe tunnel accidents: effects of information and behavioural training', Trans Res Part F Traffic Psychol Behav, vol. 17,pp. 20–32. doi:10.1016/j.trf.2012.09.00.

Smith S, Ericson E (2009) 'Using immersive game virtual reality to teach fire-safety skills to children'. Virtual Real, vol. 13(2), pp. 87–99. doi: 10.1007/s10055-009-0113-6.

Lovreglio, R., Duan, X., Rahouti, A. et al. (2021) 'Comparing the effectiveness of fire extinguisher virtual reality and video training'. Virtual Reality vol. 25, pp. 133–145. doi: 10.1007/s-10055-020-00447-5.