Journal of
Marine Science and Technology

Volume 32 | Issue 2 Article 4

Research and Design a Lifeboat Virtual Reality Simulation System for Maritime Safety Training in Vietnam

Nguyen Dinh Thach
Faculty of Navigation – Vietnam Maritime University, Haiphong, Vietnam

Nguyen Van Hung
Faculty of Electrical - Electronics Engineering - Vietnam Maritime University Haiphong, Vietnam,
hung.ddt@vimaru.edu.vn

Recommended Citation
Thach, Nguyen Dinh and Hung, Nguyen Van (2024) "Research and Design a Lifeboat Virtual Reality Simulation System for Maritime Safety Training in Vietnam," *Journal of Marine Science and Technology*: Vol. 32: Iss. 2, Article 4.
DOI: 10.51400/2709-6998.2739
Available at: https://jmstt.ntou.edu.tw/journal/vol32/iss2/4

Research and Design a Lifeboat Virtual Reality Simulation System for Maritime Safety Training in Vietnam

Acknowledgements

The authors would like to thank their colleagues at Vietnam Maritime University, Vietnam Register, the Institute of Marine Environment and Resources, and the shipping companies for assisting in this work. We are also thankful for the constructive suggestions from the anonymous reviewers, which were invaluable in improving the quality of the manuscript.

RESEARCH ARTICLE

Research and Design a Lifeboat Virtual Reality Simulation System for Maritime Safety Training in Viet Nam

Nguyen Dinh Thach [a], Nguyen Van Hung [b,*]

[a] Faculty of Navigation, Vietnam Maritime University, Haiphong, Viet Nam
[b] Faculty of Electrical, Electronics Engineering, Vietnam Maritime University Haiphong, Viet Nam

Abstract

Ensuring maritime safety and security is crucial for all nations. Training trainees and operational officers in this field aims to enhance their professional skills and ability to manage and resolve incidents at sea. This article outlines the development of a lifeboat simulation system that integrates Virtual Reality (VR) technology in accordance with international maritime regulations. It describes the creation of an algorithm designed to optimize data transmission between simulation systems using the ant colony optimization technique in conjunction with intelligent control algorithms on UNITY 3D software for human interaction. In particular, the system combines training with a maritime simulation framework to comprehensively assess the trainee's progress and closely mirrors real-world scenarios. The application of the algorithm demonstrates that the speed and quality of the simulation increased substantially, effectively meeting the complex demands of the training process. The development of this virtual reality simulation system aims to facilitate seafarers' access to advanced maritime safety training technology in the future.

Keywords: Maritime safety, Lifeboat simulation, UNITY 3D virtual reality, Lifesaving skills

1. Introduction

The marine industry must ensure maritime safety and search and rescue operations. Vietnam, bordered on three sides by the sea, particularly faces the East Sea. This sea covers nearly 3.5 million square kilometers, which makes it one of the six largest seas in the world and a critical junction connecting the Pacific and Atlantic oceans. It is a strategic route for international trade, with 5/10 of the most significant maritime routes passing through. Having an important geographical location and a high density of ships passing through, which increases the chance of accidents, Vietnam has been taking responsibility for search and rescue operations. In addition, domestic shipping companies are rapidly developing regarding service quality and the number of fleets and crew. Therefore, modernizing equipment and crew safety training is essential to meet these requirements.

Many cases of accidents at sea have occurred In the country, causing involving heavy substantial damage to property and harm to human lives. In 2014, the container ship “The Pacific Express”, ship with more than 1110 tons of cargo, collided with the Saigon Princess ship, causing which led to seven people to deaths being dead (some fell into the sea) and fall into the sea. In 2022, a boat carrying 39 people capsized at Cua Dai Beach, killing 13 people [1]. In October 2023, a ship carrying cars from Korea to Singapore encountered a fire 18 km from Vung Tau City. Previously, the Panama-flagged ship AHH SHIN, with 21 sailors, on the voyage from Korea to Singapore, caught fire in Binh Thuan waterscaught

---

Received 23 October 2023; revised 8 May 2024; accepted 9 May 2024.

* Corresponding author.
E-mail addresses: thachnd.ddt@vimaru.edu.vn (N.D. Thach), hung.ddt@vimaru.edu.vn (N.V. Hung).

https://doi.org/10.51400/2709-6998.2739

fire in Binh Thuan waters on a voyage from Korea to Singapore.

In the world, on board the St. Malo, which hit a rock off the Jersey coast carrying just 300 passengers, individuals described levels of confusion and lack of instructions and advice regarding the evacuation process, recalling that many crew members gave conflicting orders (Lee et al., 2003). In April 2014, the Korean ship MV Sewol, carrying 476 people, capsized and sank in the sea about 2.7 km off Byungpoog Island (South Korea), killing at least 300 people, mainly students and teachers. In June 2015, the Chinese ship Eastern Star capsized and sank in the Yangtze River, killing 434 people [2]. In 2023, a car-carrying ship caught fire in the North Sea and had to be towed to the Dutch port for salvage.

The above example highlights why maritime safety training at sea is receiving increasing attention, driving the development and application of modern technology in life-rescue training. Devices such as marine simulation systems using virtual reality technology have been explored. While the STCW enables the basic training required to obtain the certification and licensing necessary for employment on commercial vessels, the conduct and management of drills vary greatly between ships. In ref. [3], the author used software to simulate lifeboats and complete training situations according to IMO standards. Ref. [4] reported VR simulation steps in an industrial environment to help provide labor safety training for workers. Based on theories and practice data, positive results were obtained. In ref. [5], the author compared training methods on ships with the help of virtual reality technology. The results indicate that VR can make lessons richer and more relevant to the maritime and shipbuilding industry. Yin J et al. [6] built a virtual reality simulation of the entire ship, which included the engine room and navigation areas, enabling thorough training via VR methods. However, this approach requires significant effort in constructing an actual ship and necessitates the participation of manufacturing experts. This software [7] utilizes virtual map-building techniques that integrate GPS data from the target ships.

Research on virtual reality technology in the maritime industry remains underexplored. In their study [8], Van et al. studied and simulated ship fire alarm systems using VR technology. This method allows a fire simulation. Simulating lifeboats for maritime safety training with accurate models is expensive and can harm crew members' lives. Realistic situations such as ship fires, collisions, or sinking in harsh weather conditions have not been tested in reality. However, applying virtual reality technology to maritime teaching at maritime universities is not yet common.

For the above reasons, the authors propose to build a lifeboat simulation system that combines virtual reality to facilitate crew training and apply algorithms to optimize transmitting and receiving data based on the ACO algorithm in real-time. In addition, the development of algorithms to control human interaction in virtual environments has become more intelligent and accessible. The outcome is a test model that supports research related to the virtual reality simulation of ships in Vietnam.

The remainder of the paper is organized as follows: Section 2 discusses the dynamic equations and external forces acting on a ship, Section 3 proposes constructing 3D lifeboat models using UNITY 3D software, and Section 4 explores virtual reality technology. The simulation results are presented in section 5. The conclusions and future work are summarised in Section 6.

2. Ship dynamics and environmental effects

2.1. Ship dynamics

To perform a realistic 3D simulation of the ship's kinematics, the designer needs all mathematical equations to model a ship. According to documents [9,10], with the selection of coordinates shown in Fig. 1 and the appropriate coordinates of the center of gravity C, we have a system of equations with 6° of freedom describing the kinematics of the ship as follows (1):

$$
\begin{aligned}
& m\left[\dot{u} - vr + wq - x_G\left(q^2 + r^2\right) + y_G\left(pq - \dot{r}\right) + z_G\left(pr + \dot{q}\right)\right] = X \\
& m\left[\dot{v} - wp + ur - y_G\left(r^2 + p^2\right) + z_G\left(qr - \dot{p}\right) + x_G\left(qp + \dot{r}\right)\right] = Y \\
& m\left[\dot{w} - uq + vp - z_G\left(p^2 + q^2\right) + x_G\left(rp - \dot{q}\right) + y_G\left(rq + \dot{p}\right)\right] = Z \\
& I_x\dot{p} + \left(I_z - I_y\right)qr + m\left[y_G\left(\dot{w} - uq + vp\right) - z_G\left(\dot{v} - wp + ur\right)\right] = K \\
& I_y\dot{q} + \left(I_x - I_z\right)rp + m\left[z_G\left(\dot{u} - vr + wq\right) - x_G\left(\dot{w} - uq + vp\right)\right] = M \\
& I_z\dot{r} + \left(I_y - I_x\right)pq + m\left[x_G\left(\dot{v} - wp + ur\right) - y_G\left(\dot{u} - vr + wq\right)\right] = N
\end{aligned}
\qquad (1)
$$

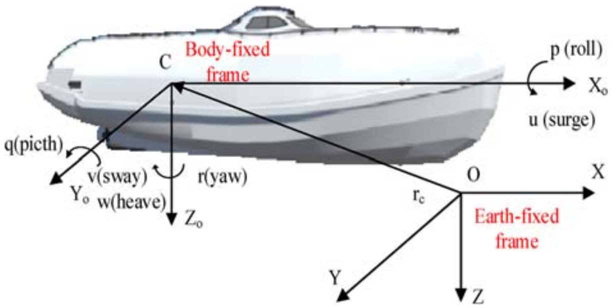


Fig. 1. Coordinate system of the ship.

The above parameters are defined in Table 1:

By separating the forces and moments of equation (1) into two parts, one describes the effects of external boundary disturbance factors, and the other represents the control signal. Another represents the thrust generated by the propulsion devices. Then, according to [9–12], we can rewrite the equation as follows:

$$\begin{aligned}&M_{RB}\dot{v}+C_{RB}(v)v=\tau_{RB};\underline{J}(\underline{\eta_2})\underline{v}\\&\Leftrightarrow M\dot{v}+C(v)v+D(v)v+g(\eta)=g_o+w+\tau\end{aligned}\tag{2}$$

where $M=M_{RB}+M_A$ signifies the inertial matrix, $C(v)=C_{RB}(v)+C_A(v)$ is the Coriolis matrix.

2.2. Forces and moments

In this section, the authors will focus on the components that are affected by the environment [10,11]. The following disturbances must be considered for ships: waves, wind, and ocean currents. The superposition principle assumes that the turbulence (waves and wind) is added to the right-hand side of the definition:

$$w=\tau_{wave}+\tau_{wind}+\tau_{current}\tag{3}$$

The ocean current component is characterized by fluid velocity vectors: $v_c=[u_c,v_c,w_c,0,0,0]^T$ of which three components are 0. In this section, the authors do not analyze in depth the specific forces acting on the ship.

Table 1. 6DOF component parameters.

DOF		Forces and moments	Linear and angular vel.	Positions and Euler angles
1	x- direction (surge)	X	u	x
2	y - direction (sway)	Y	v	y
3	z - direction (heave)	Z	w	z
4	rotation x- axis (roll)	K	p	ϕ
5	rotation y- axis (pitch)	M	q	θ
6	rotation z- axis (yaw)	N	r	Ψ

Ocean waves come from small waves rippling on the surface. This causes the pulling forces to increase and allows the short waves to grow. The short waves continuously grow until they break and run out of energy. In this article, the authors build an ocean environment based on the above factors in simulation software.

3. Designing a model for a ship

3.1. Building ship models in blender

Many software support 3D object modelling, such as Blender and 3ds Max, with open tools that help programmers easily manipulate and edit. To build a 3D lifeboat model, the authors surveyed several actual ships with layouts, as shown in Fig. 2.

To build detailed objects, the authors designed areas such as the cockpit and living room of the ship model to be as similar to reality as possible. Each object includes its the properties in each layer of the model. From there, you can make it possible to control and influence manipulate things in UNITY 3D software. The ship model of the ship after design is shown in Fig. 3.

3.2. Simulation of lifeboat dynamics

In order to perform a 3D simulation of the lifeboat dynamics, all equations in Sections 2 and 3 must be programmed to produce the ship's motion. In Fig. 4, three program modules, in particular, are responsible for the creation of waves in the water plane:

- WaveType.cs: used to create wave types (sinus, FFT – fast Fourier transform algorithm,…).
- EndlessWaterSquare.cs: used to create an endless ocean.
- WaterSquare.cs: used to create a square wave.

To fulfil the requirements for the speed and thrust of the ship, Equations (1) and (2) are used as follows:

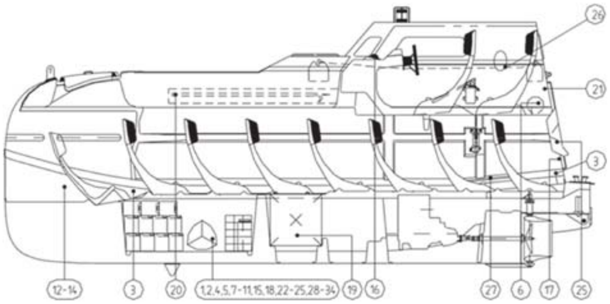


Fig. 2. Structural arrangement inside the lifeboat.

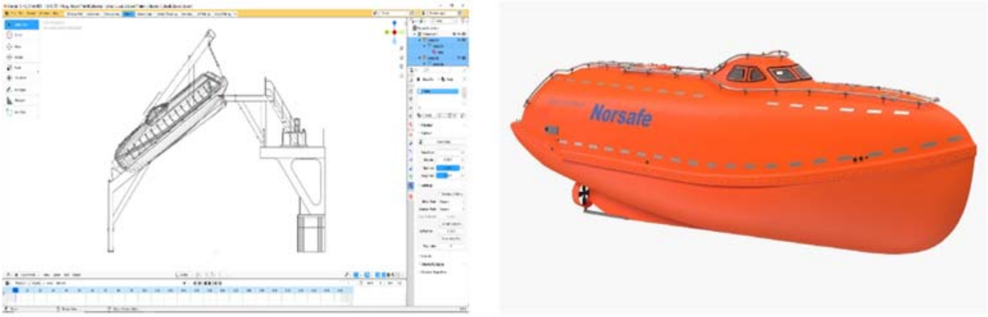


Fig. 3. A model of a lifeboat was designed using Blender.

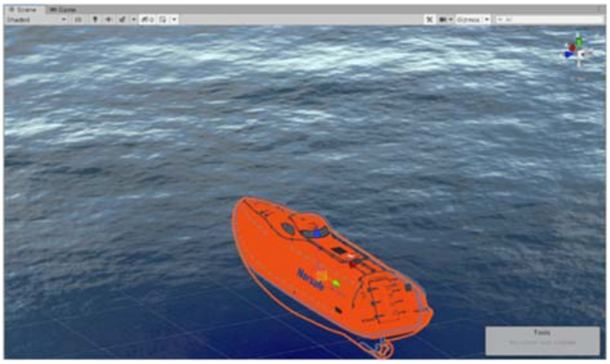


Fig. 4. The ship in a virtual environment in UNITY 3D.

- BoatPhysics.cs: used to simulate the kinematics of Equation (1).
- Boatphysicsmath. cs: used to perform calculations of force components.
- TriangleData.cs: used to divide the volume of the ship's hull in the water into triangular elements.

4. Virtual reality technology

4.1. Virtual reality technology in UNITY 3D

VR is a technology that simulates an environment where we can walk and interact with simulated objects and people. Virtual reality is utilized for education and training across various fields, including medicine, aerospace, entertainment, and education. This technology enables the exploration of inaccessible locations by creating a realistic world tailored to specific topics of study or entertainment. It presents minimal risk compared to other methods, such as physical models or theoretical studies. Virtual reality exposes students to diverse skills in the educational sector and allows them to train in a controlled environment. This setup enables learners and instructors to confidently engage in processes, techniques, and repeated experiences and safely simulate experiments or hazardous situations. Depending on different training scenarios, virtual reality significantly reduces training costs while increasing the number of training scenarios. These scenarios are built using computers to enable construction and training. This approach improves student performance, i.e., the overall quality of the training program. VR simulates a virtual environment where students can operate or test scenarios that would be dangerous if they were used in real life. This is particularly useful in hazardous industries where training is often costly and complex. In the maritime field, VR simulation methods are already used for teaching, especially for maritime safety training of crew members before disembarking [13,14]. Students acquire skills and confidence to work on real ships through realistic training scenarios.

However, there are also disadvantages to using VR. These include the potential for users to become addicted to the virtual world, reduced interaction between individuals, and health problems such as motion sickness and eyestrain. Virtual reality can also sometimes ignore fundamental laws of physics, which might lead to unrealistic scenarios. In addition, the initial investment cost is high, and simulating real devices can be time-consuming.

Previous studies only built an independent lifeboat simulation system that did not interact with the maritime simulation system, which made training and interaction and mutual interaction impossible. The authors synchronized data between the lifeboat and marine simulation systems in this study. Through the simulation system, students can interact with each other and help improve safety training. Fig. 5 illustrates a lifeboat simulation combined with a maritime environment simulation.

The complete simulation comprises a simulator PC, where both models and simulation software were built. Next, the images during the simulation

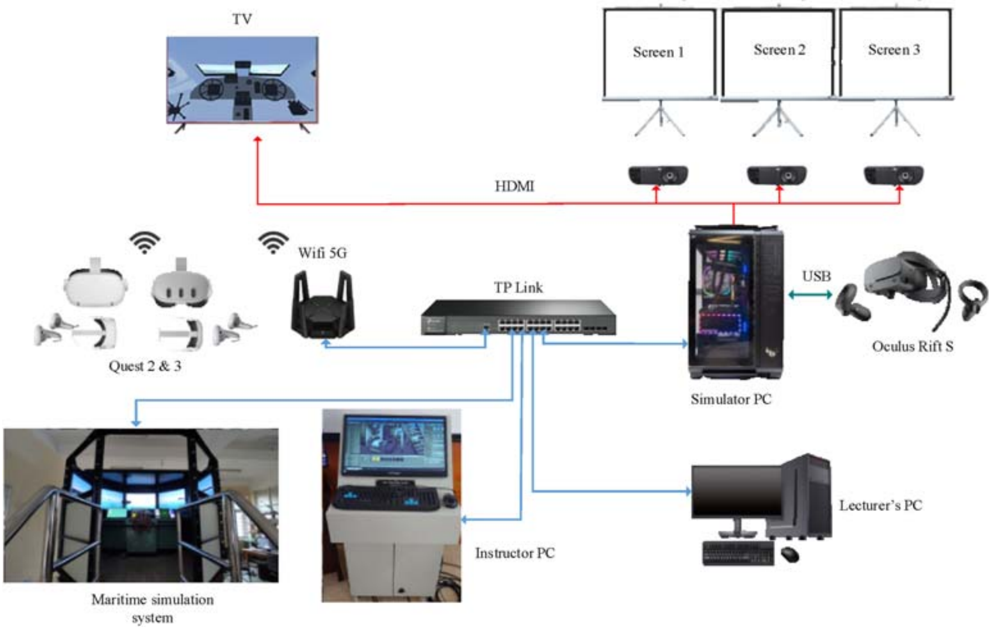


Fig. 5. Lifeboat simulation system, combined with simulation of the maritime environment.

were presented via projectors and monitors for teachers and students in the classroom to observe. Quest 2&3 and Oculus Rift S VR headsets enabled students to interact directly with each other and the software. In particular, the system was connected to the marine simulation system to facilitate mutual interaction via Ethernet and Modbus TCP/IP networks. Teachers and experts can evaluate the student's learning process via the instructor's computer.

Interacting and transmitting data between systems is complex and involves large amounts of data, so it is necessary to have a method to optimize the data transmission process to avoid data loss and local congestion during the simulation. Furthermore, the authors have built an algorithm based on the Ant Colony Optimisation (ACO) algorithm to optimize the data transmission and reception between maritime devices and systems. Many optimization algorithms, such as GA, PSO, and WOA, offer various advantages depending on the specific objectives of the problem to which they are applied.

4.2. Data transmission algorithm

Based on their behavioral characteristics, the authors use an ACO algorithm to optimize the system's data transmission and reception process. In the real world, the first ants to find their way randomly choose a path, and when finding food to return to the nest while finding their way, they leave their pheromones on the path and mark it. If other ants search for the same path, they do not move randomly but instead follow previous paths, returning and reinforcing it if they find a way to eat. This optimization method aims to find the most optimal route for retrieving and bringing back food. Similarly, in the simulation system (to avoid transmission congestion that can cause data loss), a data-based algorithm is proposed to solve the problem. Let bi(t) (i = 1, …, n) be the number of ants in town i at time t and let be the total number of ants $m = \sum_{i=1}^{n} b_i(t)$.

Let $\tau_{ij}(t+1)$ be the intensity of trail on path$_{ij}$ at time t+1, given by the formula:

$$\tau_{ij}(t+1) = \rho . \tau_{ij}(t) + \Delta\tau_{ij}(t, t+1) \tag{4}$$

where ρ is an evaporation coefficient, $\Delta\tau_{ij}(t+1) = \sum_{k=1}^{m} \Delta\tau_{ij}^{k}(t, t+1)$ is the quantity per unit of length of trail sub-stance (pheromone in real ants).

The probability p_{ij}^{k} of ant k, from currently forward the information from source sensor node *'i'* to destination sensor node *'j'* is given by (5):

$$p_{ij}^{k} = \frac{(\tau_{ij})^{\alpha} (\eta_{ij})^{\beta}}{\sum_{l \in N_i^k} (\tau_{il})^{\alpha} (\eta_{il})^{\beta}} \quad j \in N_i^k \tag{5}$$

where α, β represents two parameters which are used to determine relative neighborhood influences of pheromone trail and the heuristic information.

Therefore, in ACO quantity model:

$$\Delta\tau_{ij}^{k}(t,t+1)=\begin{cases} Q_2 \\ 0 \end{cases} \tag{6}$$

in the ANT-density model an ant going from i to j leaves Q_2 units of pheromone for every unit of length.

The real-time ACO algorithm is presented as follows:

RT-ACO Algorithm 1

```
1. Initialize:
   Set t:=0
   Set an initial value $\tau_{ij}(t)$ for trail intensity on every path$_{ij}$
   Set $\tau_{ij}(t+1)=0$ for every i and j
2. Repeat until the tabu list is full
   For i:=1 to n do
   For k:=1 to $b_i(t)$ do
   Choose the moving path according to $p_{ij}$ given by Equation (5), and move the k-th ant to the
   chosen location. Insert the chosen path in the tabu list of ant k; set
   $\Delta\tau_{ij}(t+1)=\Delta\tau_{ij}(t,t+1)+\Delta\tau_{ij}^{k}(t,t+1)$ according to Equation (6).
3. Memorize the shortest path found up to now and empty all tabu lists
4. If not
       Then
         Set t=t+1, 1set $\Delta\tau_{ij}(t,t+1)$:=0 for every i and j
       Goto step 2; Call algorithm 2
       Else
       Print shortest path and
    Stop
```

After receiving data from the marine simulation system, *algorithm 2* is called to test the hardware and virtual connection program in the lifeboat simulation system - see Fig. 6. In this algorithm, the variable status conditions of each function in the system are checked.

4.3. Smart human control interaction algorithm

The authors have developed scripts to facilitate interaction between users and the virtual environment. Furthermore, simulating interactions between real people and objects in virtual reality is complex and requires real-world rules. Therefore, the authors developed an algorithm to make the interaction between real and virtual people more convenient [8,15]. Fig. 7 shows the programming interface for the animation of virtual humans; the blocks represent each function, such as “move”, “swimming”, and “JumSquat”. Each of these objects includes command structures and actions that are optimized to match closely real-life requirements of human movement, such as arm force, leg force, and the effect of external forces on the human body.

This algorithm employs optimization techniques to accelerate interactions within the virtual environment, specifically enhancing the process of approaching objects. The authors initially configure the input values based on the function keys of the Oculus controller. Each button has a different function, such as holding, pushing, and moving, to resemble human actions as closely as possible. The handle part is programmed by the author as follows (Table 2):

Table 2. Function keys of Quest 2.

No.	Button	Function
1	Button A, B	Jumping and stepping over obstacles
2	Button D, E	Used to press or push objects
3	Forward and backward buttons	Move human body
4	Left right buttons	Move the human left or right
5	Button H	Grasp and grasp objects

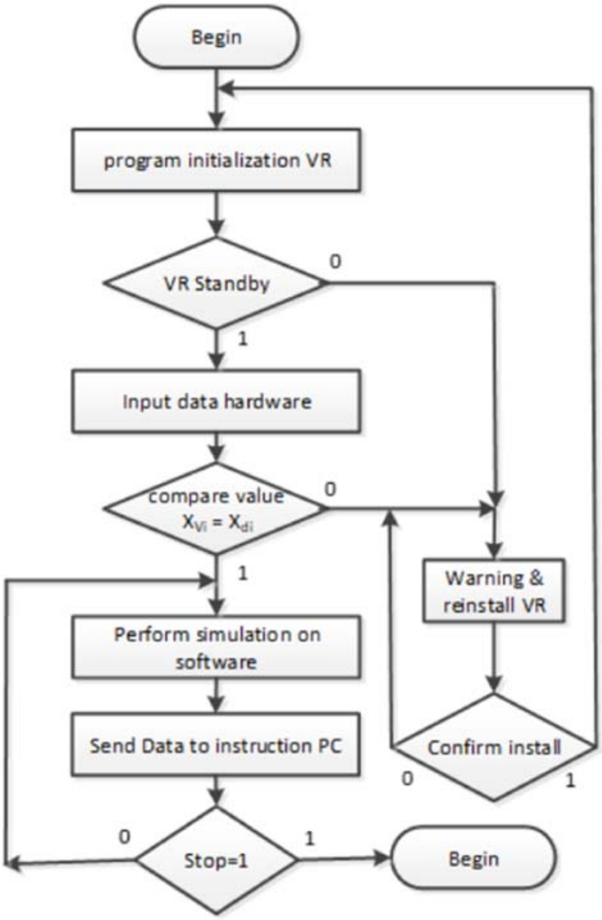


Fig. 6. *Algorithm 2 to check the simulation conditions.*

For each function, the authors create C# scripts and then assign them to every 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: function to simulate the right foot.

Then, assign each component module to each module and create interactions between them and different objects in the simulation, such as Fig. 8 [15,16].

5. Results

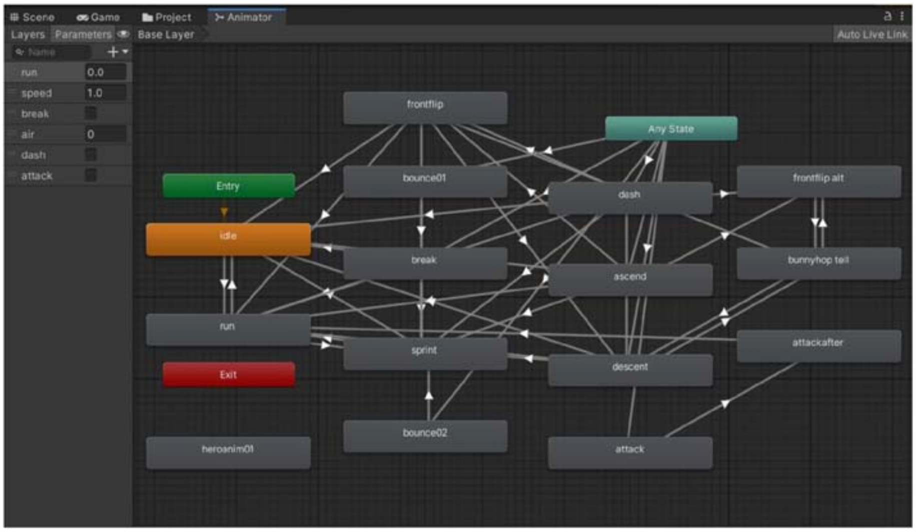
5.1. Test scenario

The system offers practice exercises that simulate real-life environments and comply with STCW regulation VI/3, section A-IV/2 table A-IV/3-1. This regulation covers organizational capabilities, abandon ship training, and knowledge concerning the operation of lifeboats, rescue boats, launching equipment, and ship arrangements [17]. Fig. 9 shows the block diagram of the training process proposed by the authors based on IMO and STCW regulations.

5.2. Result

This section presents a comparison between the IBES approach and BES algorithms. The experiments were conducted using UNITY 3D on a PC with an Intel(R) Core i7-10700 Processor clocked at 2.90 GHz and 128 GB of RAM.

The authors experimented with a ship fire scenario that included the risk of having to abandon the ship. Crew members wear glasses and conduct training with the developed systems. When the teacher's computer sends the fire signal to the



run 0.0
speed 1.0
break ☐
air 0
dash ☐
attack ☐

Fig. 7. *Dashboard of algorithms that control human interaction.*

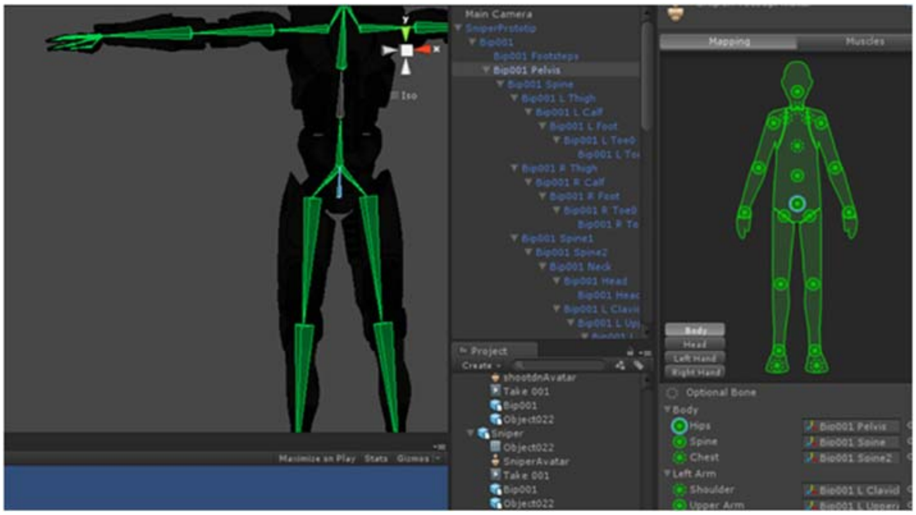
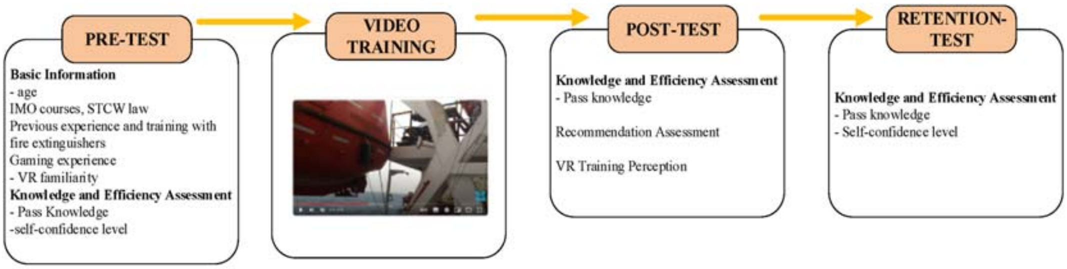
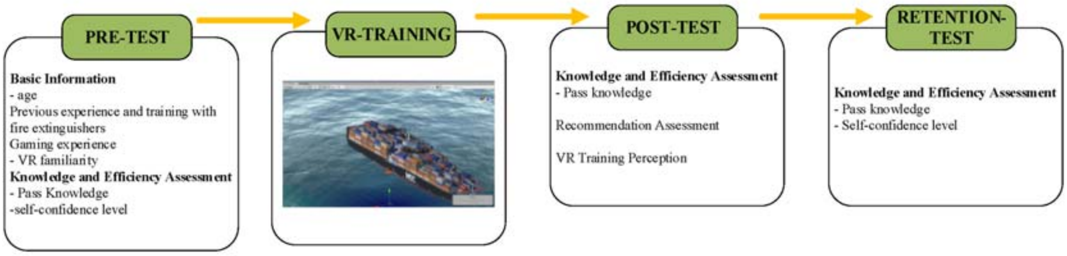


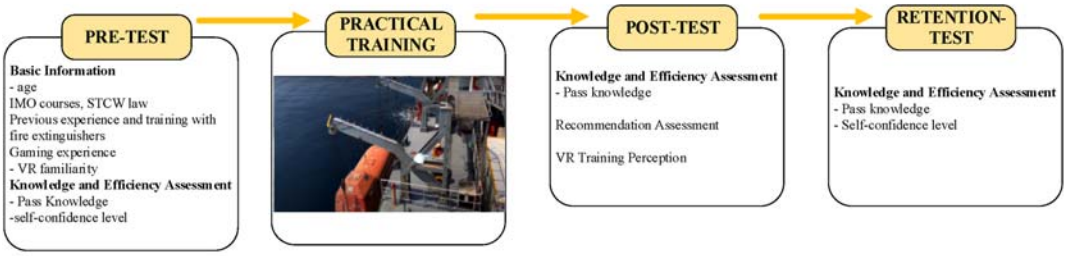
Fig. 8. Bone structure of virtual human.



a. Theoretical training procedures and videos



b. Training process combining VR technology



c. Theoretical and practical training procedures

Fig. 9. Training steps in accordance with IMO regulations.

Fig. 10. Students participating in simulation testing training.

simulation computer, the crew's accommodation area appears to be on fire.

Typically, lifeboat simulation systems in independent operational studies are not linked to marine simulation systems, as shown in Fig. 10. Thus, there is no synchronization in training students to work on ships. This lifeboat simulation system represents a new development in the maritime industry in Vietnam, while marine simulation equipment is ordered entirely abroad. Suppose an electrical short circuit in the equipment warehouse on the ship caused the fire to spread, and the crew had to abandon the ship. The authors allowed 100 students from Vietnam Maritime University to test the system. The groups were divided as follows [17−21]:

- Case 1: Number of students learning theory and watching instructional videos: 25 students.
- Case 2: Number of students studying theory and attending practice: 25 students.
- Case 3: Number of students learning theory, watching videos, learning the virtual reality simulation system, and practicing: 25 students.

Students were trained and evaluated through tests to determine their ability to apply the system to training. Fig. 11 shows the fire scenario and personnel movement.

Fig. 12. View from the lifeboat as seen using VR glasses.

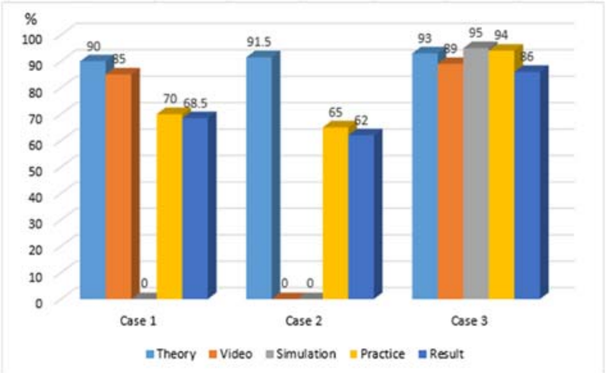
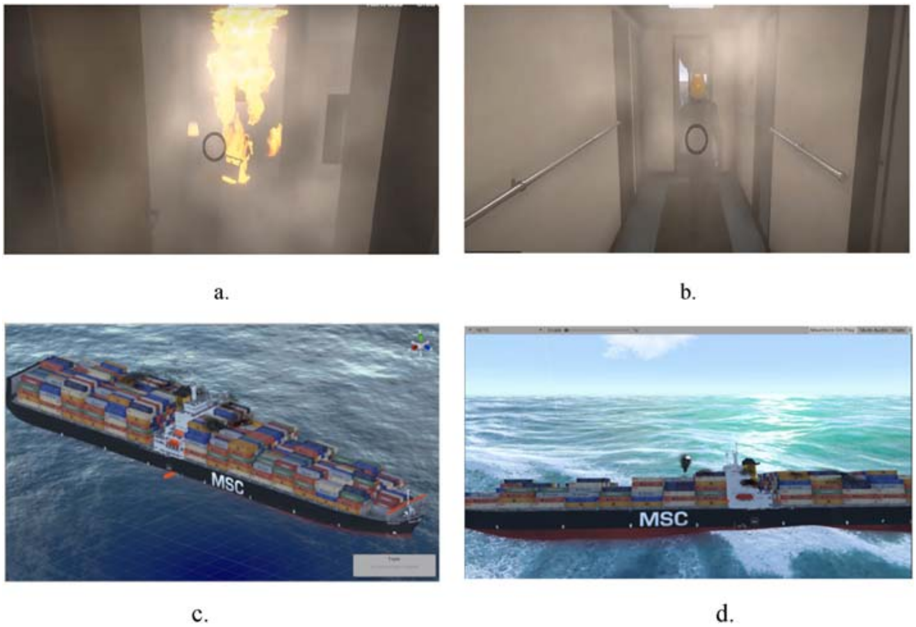


Fig. 13. Student assessment results based on cases.



a. b. c. d.

Fig. 11. a. warehouse caught fire; b. People moving into the hallway; c. the ship on fire outside; d. The ship tilts to the right.

Table 3. ACO data transmission and reception speed evaluation.

No.	Sent data (bytes)	received data (bytes)	Time (s)	Sent data with ACO (bytes)	Received data with ACO (bytes)	Time with ACO (s)
1	150	120	5.0	150	150	4.0
2	145	132	5.5	145	145	4.5
3	120	95	**4.5**	120	120	3.2
4	125	110	6.5	125	125	3.6
5	200	182	30	200	200	4.2
6	140	125	15	140	140	4.6
7	135	112	50	135	135	**3.0**
8	160	**80**	**60**	160	**150**	**30**
9	172	160	40	172	171	4.1
10	160	151	35	160	160	3.5

During the training process, crew members will move onto the lifeboat and begin the training. In each case, the authors trained ten students after they had passed the previous activity. Fig. 12 shows the lifeboat's cockpit and passenger compartment areas [20].

The test results of the student group after the training process are shown in Fig. 13. The results indicate that case 3 has the highest rate of students, achieving about 86%, while the scenario of students reading documents only reached 62%. The rate of students practicing simulation reached nearly 95%, helping the training process achieve exceptional outcomes.

In addition, the authors evaluated different scenarios during the data transmission based on algorithm 1. The results are shown in Table 3:

The results of Table 3 show that in the 8th test, 160 bytes of transmitted data were used (received data were only 80 bytes). After applying the ACO algorithm, the result was 150 bytes in 30 s.

6. Conclusion

In this paper, a 3D lifeboat model was built with specific features based on the STCW 2010 International Maritime Convention regulations and the IMO Modeling Course. In addition, applying the ACO optimization algorithm helped optimize the data-transmission process in the simulation setup, and the algorithm controls the intelligent interaction between virtual humans and the environment. Moreover, this system can be combined with a maritime simulation system to help train the entire ship's incident response ability simultaneously. Our research results provide a foundational approach for Vietnam to adopt virtual reality simulation technology in maritime industry training and education. Moving forward, the authors plan to develop ship models that align with current training needs and the maritime safety training process in Vietnam. This initiative aims to fulfill the demand for high-quality human resources in the sector.

Funding

This research is funded by Vietnam Maritime University.

Conflict of interest

The authors declare no conflicts of interest associated with this manuscript.

Acknowledgment

The authors would like to thank their colleagues at Vietnam Maritime University, Vietnam Register, the Institute of Marine Environment and Resources, and the shipping companies for assisting in this work. We are also thankful for the constructive suggestions from the anonymous reviewers, which were invaluable in improving the quality of the manuscript.

References

[1] Thirteen killed as motorboat capsizes near Hoi An shore [Available online]: https://e.vnexpress.net/news/news/13-killed-as-motorboat-capsizes-near-hoi-an-shore-4432402.html.

[2] China cruise ship disaster: 434 bodies recovered; 8 still missing [Available online]: https://edition.cnn.com/2015/06/08/asia/china-ship-sinking/index.html.

[3] Spyridon Nektarios Bolierakis, Margarita Kostovasili, Lazaros Karagiannidis. Dr. Angelos Amditis. Training on LSA lifeboat operation using mixed reality. Virtual Real Intell Hardware J 2023;5(3):201−12.

[4] Rauh SF, Koller M, Schäfer P, Meixner G, Bogdan C, Viberg O. MR On-SeT. A mixed reality occupational health and safety training for world-wide distribution. Int J Emerg Technol Learn (IJET) 2021;16(5):163−85.

[5] Hunt Tim, Gordon P. Report on recommendations on alternative methods of training. Zenodo 2021. https://doi.org/10.5281/zenodo.5517612 [Available online]:.

[6] Yin J, Ren H, Zhou Y. The whole ship simulation training platform based on virtual reality. IEEE Open J Intelligent Transport Syst 2021;2:207−15.

[7] Zhang S, Zhang T, Wu Y, Yi Y. Three-dimensional waterway system for ship navigation based on integrated virtual waterway and flow simulation. J Waterw Port, Coast Ocean Eng 2017;143(1):1−14.

[8] Van NT, Tuan DA, Hung NV. Designing fire alarm and fire-fighting ships virtual reality system8; 2022. p. 144−8.

[9] Fossen Thor I. Guidance and control of ocean vehicles. Chichester NewYork: John Wiley & Sons; 1994.

[10] Fossen TI. Marine control systems – guidance and control of ship, rigs, underwater vehicles. Marine Cybernet Trondheim Norway 2002;28(3):24–36.

[11] Tuan DA, Quan DM. Ship mathematical models serve research, simulation and design of automatic steering systems. J Mar Sci Technol 2013;3:12–21.

[12] Khanh ĐH, Thao PM, Hung NV, Tung ĐX, Sơn NC. Buiding 3D simulation system of the dynamics of a marine ship. J Mar Sci Technol 2017;55:96–101.

[13] Khanh ĐH, Thuy LV, Đat BT, Thinh NX, Thao PM, Hung NV. Designing fire alarm systems and building monitoring and control applications. J Mar Sci Technol 2018;55:37–42.

[14] Lovreglio R, Duan X, Rahouti A, Phipps R, Nilsson D. Comparing the effectiveness of fire extinguisher virtual reality and video training. Virtual Real 2021;25:133–45.

[15] Rossell JM, Vicente-Rodrigo J, Rubio-Massegu J, Barcons V. An effective strategy of real-time vision-based control for a stewart platform. In: Proceedings of the 2018 IEEE International conference on Industrial technology (ICIT), 20-22 february 2018. Lyon, France: IEEE; 2018. p. 75–80.

[16] Giorgio De, Andrea, Romero Mario, Onori Mauro, Wang Lihui. Procedia Manuf 2017;11:1279–87.

[17] Adoption of amendments to the annex to the international convention on standards of training, certification and watchkeeping for seafarers (STCW). United Kingdom: International Maritime Organization (IMO); 1978.

[18] Kaplan AD, Cruit J, Endsley M, Beers SM, Sawyer BD, Hancock PA. The Effects of virtual reality, augmented reality, and mixed reality as training enhancement methods: A meta-analysis. Hum Factors 2021;63(4):706–26.

[19] Resobowo DS, Buda KA, Dinariyana AAB. Using sensitivity analysis for selecting of ship maintenance variables for improving reliability of military ship. Acad Res Int 2014;5(2):127.

[20] Nguyen Oang. The application of the ahp method in ship system risk estimation. Pol Marit Res 2009;16(1):78–82.

[21] My TC, Khanh LD, Thao PM. An artificial neural networks (ANN) approach for 3 degrees of freedom motion controlling. Int J Informatics Vis 2023;7(2):301–9. https://doi.org/10.30630/joiv.7.2.1817.