Computer Life (CPL) ISSN: 1819-4818
DELIVERING QUALITY SCIENCE TO THE WORLD

Design and Development of Helicopter Maritime SAR Drill Simulation Platform

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Abstract: Helicopter plays an important role in maritime search and rescue (SAR), but professional helicopter SAR forces are relatively weak in most countries and regions in the world. In modern pilot training, virtual reality (VR) technology can improve the training quality and save cost. A helicopter maritime SAR drill simulation platform is introduced in this paper. The overall architecture of the platform is briefly introduced, and the design scheme of the simulation cabin and the surround screen projection visual system is explained. The modularization design ensures the good maintainability and scalability of the VR software system. The functional modules of the software system are described in detail. The VR software system is integrated based on the Unity3D environment. The experimental results show that the platform can meet the basic helicopter maritime SAR drill teaching and demonstration, and can provide friendly human-computer interaction and good sense of immersion.
Keywords: Maritime SAR; helicopter SAR; drill simulation; virtual reality; Unity3D.

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1. INTRODUCTION

With the development of world shipping, maritime activities are increasing, and frequent maritime accidents have caused huge losses to relevant countries in the political, economic, and military fields. For example, 239 people were killed in the loss of Malaysia Airlines passenger plane, and 294 people were killed in the sinking of South Korea's "years" ship, etc., The maritime search and rescue (SAR) capabilities of countries around the world are facing increasingly severe challenges, and the requirements for the efficiency of maritime SAR are also higher and higher. Maritime SAR is the process of searching for and rescuing known or unknown targets at sea (shipwrecked ship or person at sea).

Helicopter maritime SAR can play the following roles, such as guiding surface rescue ship; lowering lifeguards to rescue people in distress on the surface or onboard; rescuing people in distress with life-saving baskets, stretchers, or lifting belts; transferring people in distress or rescuing people, etc. [1], which has the characteristics of rapid mobility, wide-coverage, high search efficiency and good rescue effect, so it is of great practical significance to research this area [2]. There are two main ways to train helicopter maritime SAR personnel: practical drill and simulation drill. However, there are problems such as high cost, low efficiency and poor safety of the actual SAR drills, therefore, the use of virtual reality (VR) technology for simulation training is a better choice, and its biggest advantage is that the equipment can be reused once invested, and software system can be upgraded with the upgrading of the actual aircraft type. The concept of VR was proposed in the 1980s by Jaron Lanier, the founder of VPL Company, and includes a 3D environment, system simulation, multimedia, sensor technology, computer network technology, etc. It is an emerging interdisciplinary discipline.

Corresponding research institutions and companies in some developed countries have developed simulation modeling software with practical value, such as POSSE used by the US Coast Guard for military use, HACSALV, GHS-Salvage and ChiefMate, etc., which is for civilian use [3]. China has also begun to develop simulated flight systems in the early 1970s and has made many technological breakthroughs. However, these simulation systems are not specifically developed for maritime SAR, and cannot meet the application requirements for training helicopter maritime SAR personnel.

In this paper, a physical model of a helicopter cabin is established, VR technology is used to create a virtual shipwreck scenario and add perfect SAR guidance information, and a helicopter maritime SAR drill simulation platform is constructed through the perfect integration of real and virtual scenarios to complete the demonstration and teaching for maritime rescue personnel.

2. OVERALL ARCHITECTURE DESIGN OF THE PLATFORM

According to the performance standard 2.14 of the highest level of fully functional ship maneuvering simulator proposed by Det Norske Veritas (DVC, Det Norske Veritas) [4, 5], the performance evaluation of a navigation simulator can be assessed mainly from three aspects: action realism, physical realism and environmental realism, where physical realism depends on the adopted simulated driving platform and the supporting instrumentation, while the behavioral and environmental realism depends on the system software module.

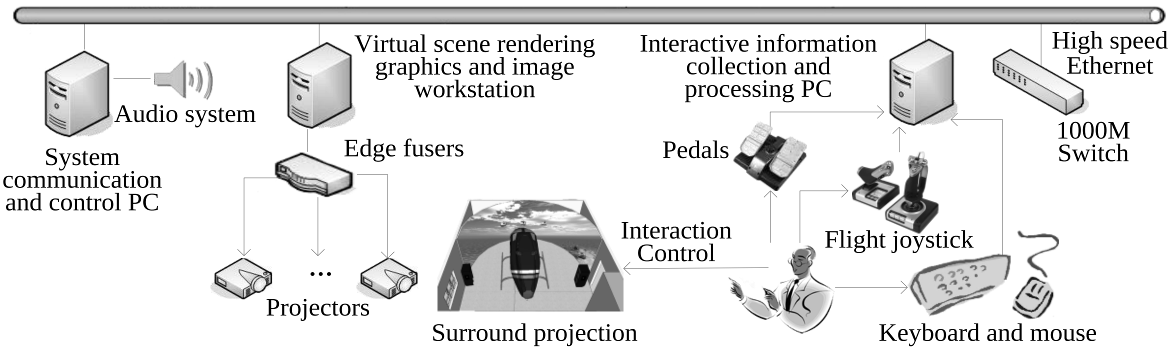


Figure 1 System hardware structure diagram

The platform in this paper is implemented by a set of closely linked hardware components working in real-time and the associated VR software system in concert, and its overall architecture is shown in Figure 1. All computers are connected via high-speed Ethernet and communicate with each other. Among them, the system communication and control PC serves as the control center of the whole simulation system, completing the functions of system initialization, progress control of scene script, user viewpoint switching, and audio system control, and is responsible for the communication between the PCs of the system. The virtual scene rendering graphic image workstation is mainly used to simulate the virtual environment, draw a largescale maritime disaster scene with 4096*1536 resolution in real-time, and output through the edge fusion, and project on the 180 °surround screen by 8 projectors. Interactive information collection and processing PC collects user input for maneuvering with flight joystick, foot pedal, keyboard and mouse, and other equipment, and accordingly calculates key movement data such as helicopter ascent, descent, forward, backward, left, right, pitch and tilt.

3. SIMULATED CABIN MODEL AND SURROUND PROJECTION VISION SYSTEM

3.1 Simulated cabin model

The simulation cabin mainly provides a realistic helicopter cabin piloting environment for the trainees. The model is built on the S-76C++ helicopter [6] produced by Sikorsky, USA, as shown in Figure 2.

Figure 2. S-75C++ helicopter[7]

(b)

Figure 3. Saitek flight joystick: (a) Saitek X52PRO Falcon flight joystick, (b) Flying foot rudder.

The simulation control module is the main functional part of the system to realize human-computer interaction. Through force feedback, it can make the pilot feel the maneuvering force directly. For helicopters, the module simulates pilot stick forces, throttle pitch stick forces and foot pedal forces. The simulation effect and realism of the maneuvering simulation module is an important indicator of the quality of the helicopter flight simulator. The system uses Saitek X52PRO Falcon flight joystick and flight rudder to complete the interactive data collection and control in the VR software system to simulate the real control of the helicopter, as shown in Figure 3.

3.2 Surround Projection Vision System

The view display module is a hardware device mainly used to display the simulated view. The training tasks of SAR helicopters mainly include takeoff, landing, basic flight and low-altitude maritime SAR, etc. Different training tasks have different performance requirements for the view display module, and Table 1 lists the performance requirements of the view display module for different training tasks.

Table 1 Performance requirements of the view display module for the training task

	Ground details	Vision change	Depth of field	Field of view angle	
Take off and landing	Medium	High	High	H>75 °	V>30 °
Basic flight	Low	Medium	High	H>120 °	V>60 °
Low altitude maritime SAR	High	Medium	Medium	H>300 °	V>135 °

From Table 1, we can see that the helicopter pilot field of view is relatively large, the existing display technology of surround screen projection and helmet type display can meet the performance requirements, however, considering that the system is used for training presentations and teaching, the cost will rise sharply with more users using helmet-based displays, so the platform uses cylindrical screens and ground screen projection to display the output view images of the VR system.

1. Cylinder screen design

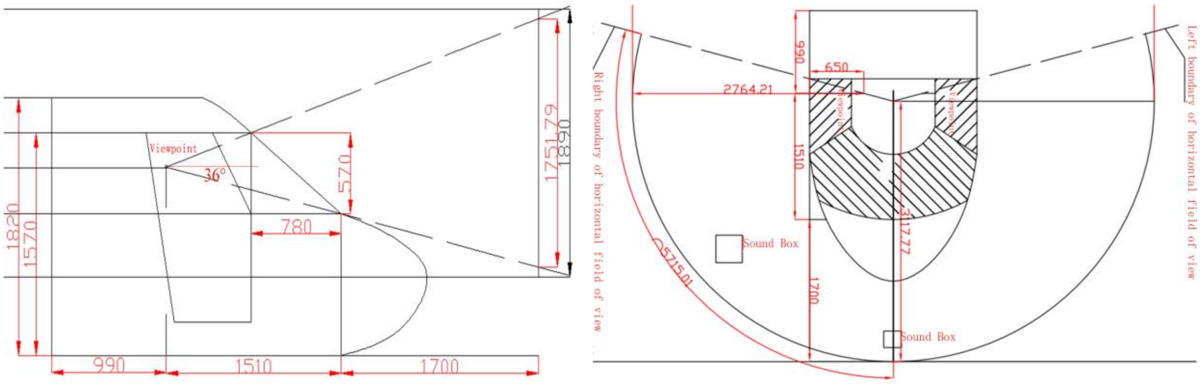


Figure 4 Cylinder screen design

According to the performance characteristics of the helicopter pilot's field of view and to ensure its immersion, the horizontal field of view angle of the surround screen is set to 180 °, the vertical field of view angle is set to 36 °above the horizontal line, and 36 °below the horizontal line, the observation point is located in the center of the cylinder screen, and the radius of the cylinder screen is designed to be 3.12 meters, the design scheme is shown in Figure 4.

2. Projection design

As shown in Figure 5, in order to achieve a horizontal field of view of 180 °and a vertical field of view of -36 °to 36 °for the helicopter pilot, six projectors were used to display the whole scene with a total final projection resolution of 7680×2160. Among them, four projectors project on the cylinder screen to display the sky view directly in front of the cabin with the output resolution of 1920×1080 for each projector. The other two projectors project to the ground screen to display the ground view during flight with the output resolution of 3840×1080 for each projector. The overlapped part of the projected image is processed by edge fusion device.

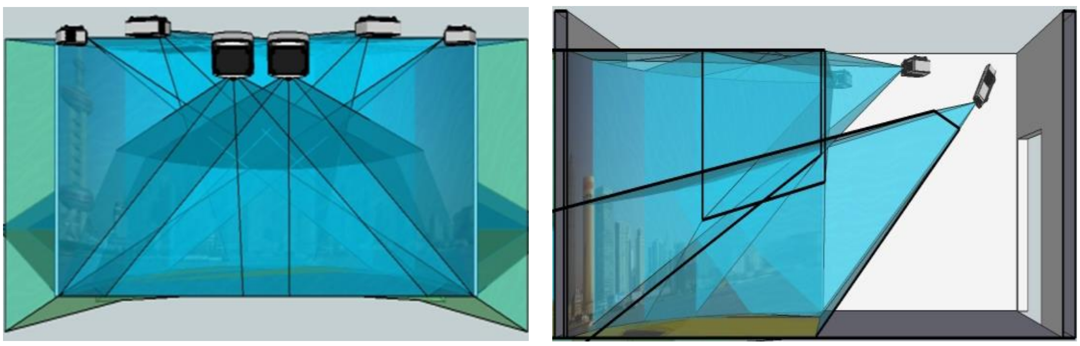


Figure 5 Projector layout

4. VR SOFTWARE SYSTEM

The VR software system was designed and developed to meet the requirements of the Performance Standard 2.14 of the highest level of fully functional ship maneuvering simulator by Det Norske Veritas (DVC) in terms of behavioral and environmental realism. This is the main program of the maritime SAR simulation platform in this paper, through the force analysis of the SAR helicopter, the mathematical model of the movement of the SAR helicopter is established, and the VR technology and CG technology are used to reproduce realistic various maritime scenes, as shown in Figure 6, the main functional modules of the VR software system include: scenery simulation, flight simulation and SAR simulation three major functional modules.

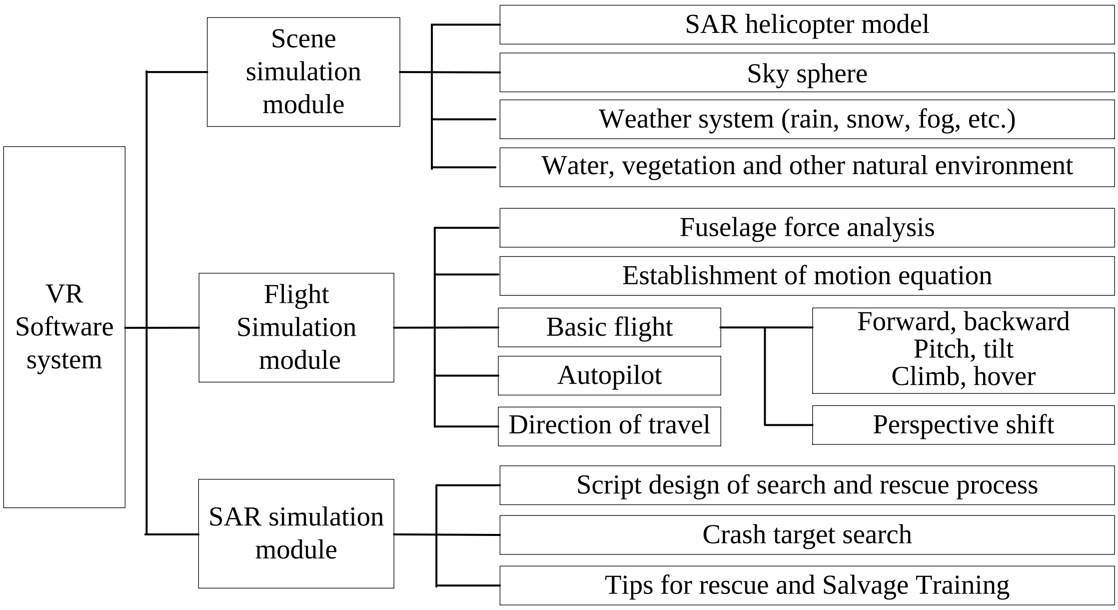


Figure 6 Main functional modules of the software system

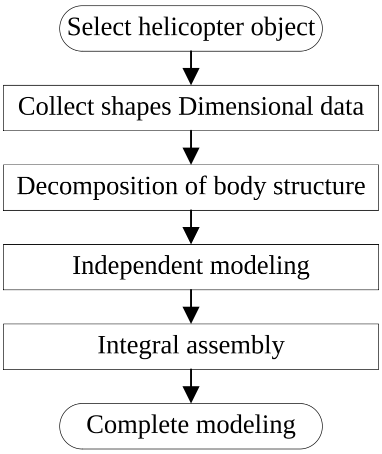


Figure 7 Helicopter modeling flow

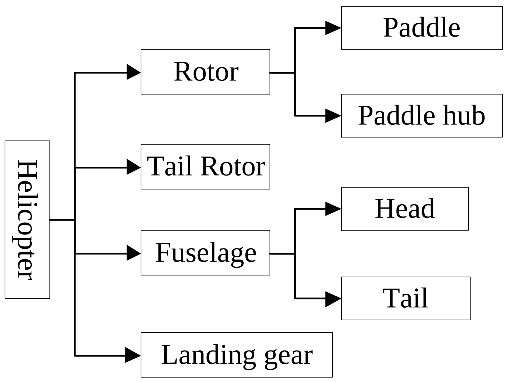


Figure 8 Helicopter structure decomposition

4.1 Scene simulation model

The scene simulation module mainly completes the drawing and rendering of the scenery seen by the pilot during the helicopter flight, which is a simulation of the real scene using VR technology and CG technology to generate the scenery environment of the East China Sea Bridge - Yangshan Port sea area, including the scenery images of the SAR helicopter, sea surface, islands, land and city buildings, vegetation, mountains, sky, fog effects, sun, rain and snow effects [8]. This section mainly introduces helicopter modeling, sky sphere modeling and weather system modeling.

1. Helicopter modeling

The complex structure of the 3D model of the helicopter, with complicated and mostly irregular fuselage surfaces, makes it difficult to build the model. Therefore, the modeled object needs to be decomposed and simplified into several simple geometric models, which are modeled independently and then assembled, and the process diagram is shown in Figure 7. The S-76C++ helicopter of the First East China Sea Rescue Flight Brigade was selected as the modeling object, and the airframe structure was decomposed by position, as shown in Figure 8.

The shape and size data of the S-76C++ helicopter is shown in Figure 9. In 3ds Max, according to these multi-view data, complete the outline of the two-dimensional curve, and then use the NURBS modeling commands such as "release", "extrusion", "node-compression", "and set of Boolean operations" to complete the production of the helicopter profile, and on this basis, add the editor network modifier "mesh smoothing" modifier to make the helicopter model more realistic details.

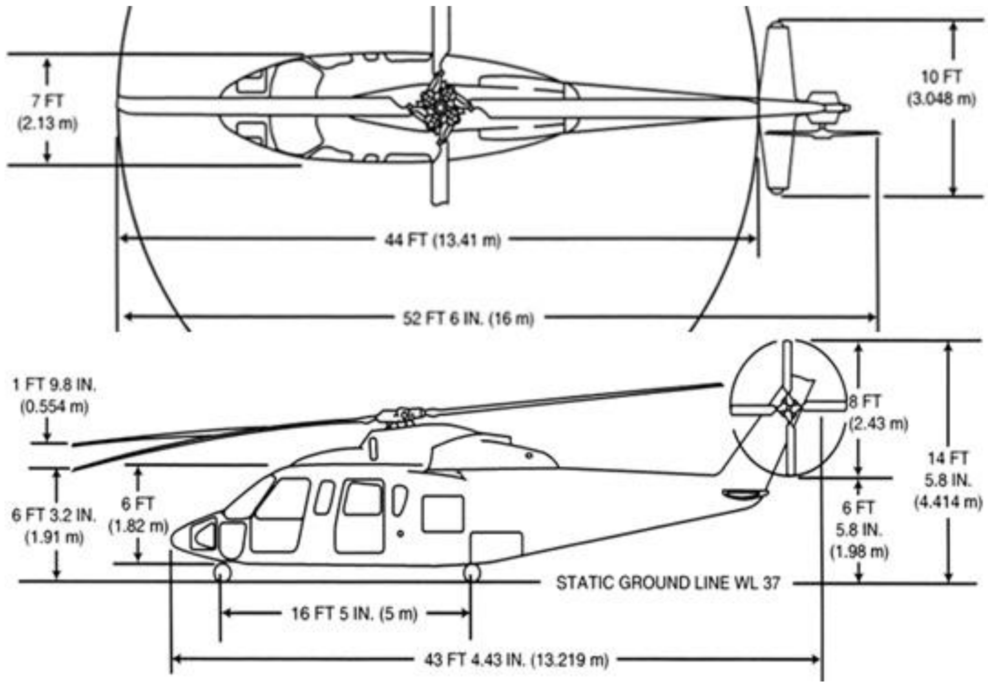


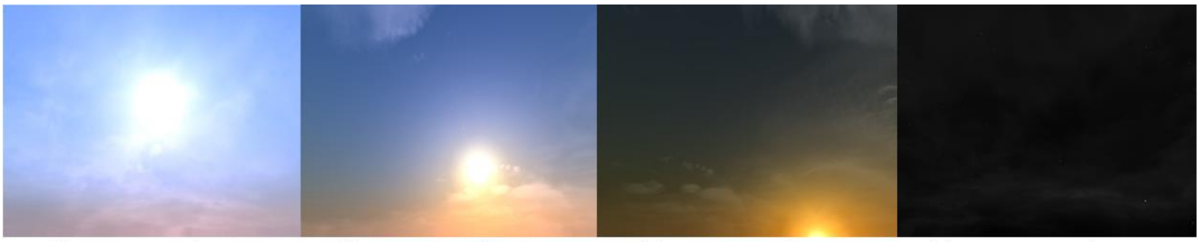
Figure 9 S-76C++ helicopter shape and dimensional data [9]

The surfaces of the helicopter model were mapped to obtain the final rendering shown in Figure 10.

Figure 10 Rendering effect of the helicopter model

2. Sky sphere simulation

The sky sphere is made by using a sphere model to simulate the dome, placed on top of the scene with the normal of the sphere facing inward, and the size of the sphere should be large enough to avoid the helicopter from colliding with the sphere during the flight simulation. To further enhance the realism of the scene, the effects of solar altitude angle and azimuth angle are introduced in the modeling of the sky sphere in this paper, which are calculated based on the method in the literature [10]. The user can input the time and location (latitude and longitude) of the flight training in the GUI interface, and the system will automatically perform the calculation and display the corresponding day and night mapping. Figure 11 shows the effect of the sky sphere in the Shanghai region at the corresponding time based on the calculated altitude and orientation of the sun.



(a) 2014.3.21/11:33 (b) 2014.6.21/15:50 (c) 2014.9.23/18:03 (d) 2014.12.22/20:25

Figure 11 Rendering effect of the sky sphere

3. Weather system

As maritime accidents often occur in rough sea conditions, many factors affect the efficiency of rescue, including the direction of the currents, the speed of the currents, the visibility at sea and the temperature of the water, etc. The weather has the greatest impact on rescue operations, including different weather phenomena, different wind speeds and wind directions. For example, the surface of seawater is affected by wind forces [11,12] and drifting objects at sea are subject to hydrodynamic effects [13,14]. Therefore, the weather system needs to be added to the scenario to consider the drift route of sea rescue, planning the search area, combining the weather system and rescue operations to simulate a more realistic SAR environment, making it possible for SAR personnel to conduct SAR training under various weather conditions.

Rain and snow are common weather phenomena in the natural environment and are often constructed in VR scenes using particle systems. A particle system is a collection of a large number of particles released from an emitter, each particle having a different size, rule, color, life cycle, rate, etc. The particle system is dynamically changing, i.e., new particles can be continuously generated by a controlled random process, and old particles die out with succession. To simplify the calculation, this system assumes that the particles do not collide with each other, fuse, and other inter-particle interactions during their life cycle. When the particles fall to the bottom layer that is out of the camera lens will be raised to the highest layer, recycling.

The fog scene can directly affect the visibility of the helicopter flight, so this paper uses the blending method to obtain the blur effect. Assuming that the color of the destination pixel is C_1, the color of the fog is C_f, and the fusion factor is f, the final color C after pixel fusion is expressed by Formula 1:

$$C = f \times C_1 + (1 - f) \times C_f \tag{1}$$

where the fusion factor f is a reference value for the effect of fog on the visual field, the higher the depth of the object from the viewpoint the lower its value until the visibility distance.

This paper implements a weather system that includes weather phenomena such as sunshine, rain, snow and fog. Trainees can set their training moment and location latitude and longitude, and depending on the different settings, the sky ball mapping will change accordingly. At the same time, students can set the weather conditions of the simulation training, including wind speed, wind direction rainfall (snow) amount, cloud type, thunder size, etc. The system generated rain, snow and fog effects are shown in Figure 12.

(a) rain (b) snow (c) fog

Figure 12 Rendering effect of the weather scene

4.2 Flight simulation model

1. Helicopter force and control analysis

Helicopters are subjected to a variety of external forces during the flight [15, 16]. With all external forces and moments in balance, the aircraft is in a stable flight state. The pilot uses the maneuvering mechanism in the cockpit to change the aerodynamic force on the control surface of the helicopter to achieve flight control.

The model used in this simulation platform is based on the model S-76C++ helicopter. During the flight of this type of helicopter, there are only four external forces that can be controlled by the pilot, namely the pulling force generated by the rotor, the backward force, the lateral force and the tail rotor pulling force. The pilot can also change the engine's output power by changing the engine's fuel supply, thereby controlling the rotor speed. In the simulation module of the aircraft, it is necessary to establish a model for the aerodynamics and manipulation of the aircraft to realize the simulation. The external forces and control methods of the helicopter [16] are shown in Table 2.

Table 2 S-76 helicopter maneuvering mode

Variance	Flight mode	Cockpit control mechanism	Aircraft handling surfaces	Aerodynamics
Horizontal	Lifting and lowering	Total pitch bar	Rotary Wing	Rotor pull
Vertical	In and out, pitch and tilt	Lever longitudinal	Rotary Wing	Backward force and hub torque
Transverse	Side shift, roll	Lever lateral	Rotary Wing	Lateral force and hub moment
Direction of travel	Steering	Pedal	Tail Rotor	Tail rotor pull

The rotor provides the maneuvering force for the horizontal traverse and vertical lift of the helicopter and is the primary maneuvering surface for helicopter flight. At the same time, the rotor blade generates the main aerodynamic force sufficient to free the helicopter from gravity and is the main lift surface of the helicopter. The propeller hub torque has a significant effect on the leveling and stability characteristics of the helicopter. This moment is derived from the centrifugal force of the rotor blades and the tilt of the rotor cone. The tail rotor is mainly used to generate the lateral force, which creates the yaw moment, to balance the rotor counter-torque, and to perform the heading maneuver. The aerodynamic force of the tail rotor is similar to that of the rotor blades.

We encapsulate an interactive data processing class, Input, to unify the input data of interactive input devices such as a mouse, keyboard, joystick and joystick used in the system. The range of input information for the flight joystick and foot pedal in this system is shown in Table 3.

Table 3 Peripheral input data

Cockpit control mechanism	Manipulation	Input range	Parameters of objects in the scene
Joystick	Push right Push left Pull forward Pull back	[0, 1] [-1, 0] [0, 1] [-1, 0]	Helicopter Z-axis Helicopter X-axis
Total pitch bar	Push forward Pull back	[0, 1] [-1, 0]	Helicopter Y-axis
Pedal	Left foot pedal forward swing Right foot pedal front swing	[-1, 0] [0, 1]	Helicopter Z-axis rotation

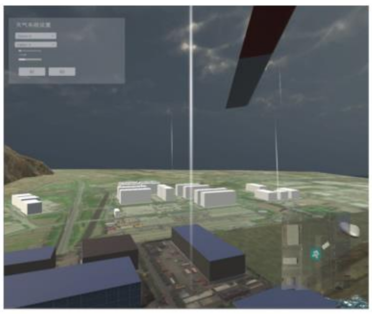
Script components are added to virtual objects in the system by writing control scripts to implement specific manipulation functions. The helicopter motion is performed by a combination of helicopter center-of-mass position movement calculation and angular deflection, using two scripts to handle position movement and rotation motion separately. Several typical poses for the virtual helicopter under system manipulation are shown in Figure 13(a), (b) and (c).

In this system, two perspectives are provided for the user: the first perspective of the driver in the cockpit and the third perspective outside the cabin, and can switch between the two freely, as shown in Figure 13(d) and (e) as shown.

(a) Side flying attitude

(b) Dive attitude

(c) Hovering attitude



(d) First-person view inside cabin

(e) Third person perspective

Figure 13 Several typical attitudes of the helicopter and the user perspective provided by the system

4.3 SAR simulation model

A complete SAR event script in the system contains several components such as the random generation of maritime accidents, instructions from the SAR center to the helicopter SAR team, SAR process prompts, and SAR animations with real-time calculations. It also integrates geographic information, searches and rescue resources, and marine meteorological and environmental databases to provide supporting information for maritime SAR services [17,18]. In this system, there are four rescuers performing tasks in the helicopter SAR operation: a pilot, a co-pilot, a winch operator, and a lifeguard.

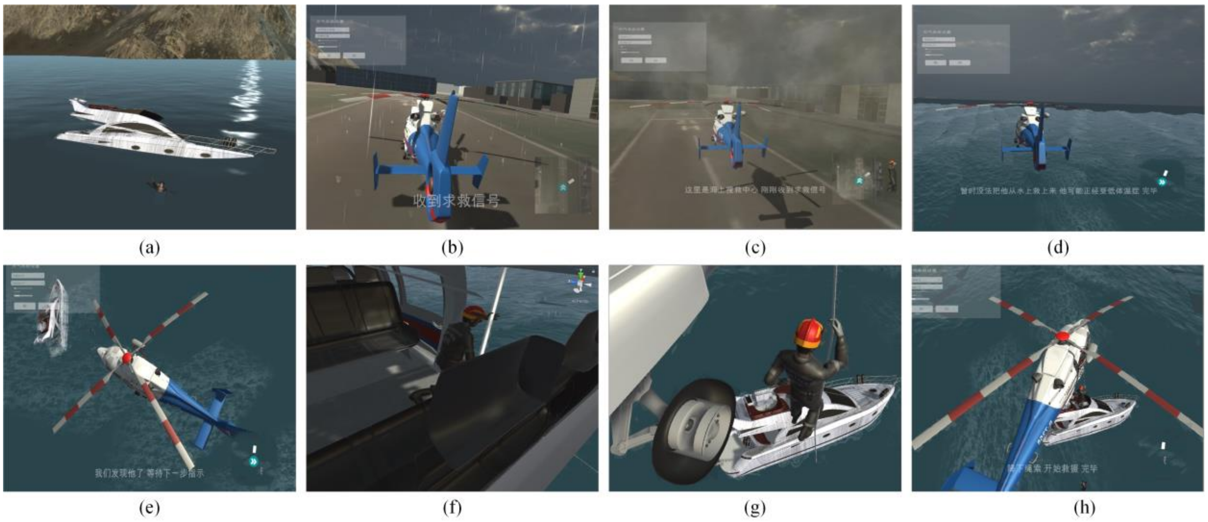


Figure 14 SAR process: (a) a maritime accident occurs; (b) the SAR center issues a SAR instruction, and the crew receives the mission; (c) the crew board and the helicopter takes off; (d) the helicopter fly to the shipwreck site; (e) Arrive at the shipwreck site, find the drowning person, and prepare for rescue; (f) with the consent of the captain, open the helicopter cabin door, hang the hook by the winch operator, and start to put the lifeguard down; (g) when the lifeguard's head leaves the cabin, request the captain to fly closer to the person waiting for rescue; (h) Carry out rescue, check the injured condition of the rescued person after confirming that he is on the plane and prepare to return.

As shown in Figure 14, the specific rescue process is as follows.

(1) Accept the task: understand the content of the task, including the object and number of rescue, the location of the incident site, the rescued person's clothing, whether they are injured, the rescued person's medical history, etc.

(2) Crew boarding: lifeguards and winch operator prepare the equipment. First aid kits and rescue slings are carried by lifeguards. Check the status of the winch by the winch operator before boarding the plane.

(3) After checking and flying to the scene, when arriving at the scene area, the winch operator asks the captain if he could open the hatch. After receiving permission, each crew member assists the captain in searching for and rescue targets.

(4) After the target is found. The command is "target found", "target position XXXXX", the captain replies "target insight", then find a suitable position, the captain will hover the aircraft upwind, generally let the target in The captain will hover the aircraft upwind, usually with the target at two o'clock in the cockpit of the helicopter. The captain then does a hover check, checking the three elements of altitude, heading and obstacles at the scene.

(5) The winch operator, lifeguards and captain discuss and communicate the rescue plan, and the final negotiated plan needs to be approved by the entire crew.
(6) The winch operator performs safety coordination to release the hooks, assists the lifeguard in hanging the numbered hooks and rescue supplies, and helps the lifeguard with safety checks.
(7) The unpiloted pilot makes a pre-winch check and informs the flight attitude, mechanical condition, engine temperature, pressure, slip oil, fuel quantity, etc. The winch operator then has the lifeguard sit by the door, asks the captain if he can release the hook, and releases the hook after the captain agrees.
(8) After the lifeguard's head leaves the cabin, the captain may be asked to maneuver the aircraft closer to the target area to rescue the survivor on board.
(9) The winch operator informs the captain to close the hatch, close the hatch, and leave the site.

5. CONCLUSION

With the increasing of maritime activities, countries all over the world pay more and more attention to the construction of maritime SAR capability. Helicopters play an important role in maritime SAR. In this paper, a simulation platform for helicopter maritime SAR drills based on VR technology is implemented. The experimental results show that the system is highly immersive, good in real-time, and friendly and efficient in human-computer interaction. By using the system, the trainees can fully understand the detailed process of helicopter maritime SAR and can complete the primary learning of SAR task. Of course, there is still room for improvement in the work of this paper. For example, the realistic simulation of the virtual sea surface, especially the simulation of rolling waves, foam and other effects, are all problems that will be solved in the subsequent research work.

ACKNOWLEDGEMENTS

This paper was financially supported by the Natural Science Foundation of Shanghai, China, grant number 14ZR1419700. The authors gratefully thank the research team of Information and Communication System Engineering Lab of College of Information Engineering, Shanghai Maritime University for their general support.

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