The Simulation System of Ship Fixed Water Extinguishing Training Based on Virtual Reality Technique

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ABSTRACT

Because it is rough to teach and train students in real environment, the ship fixed water extinguishing simulation training system is built, which can not only restore the environment but also reduce the training cost. The modeling software (3D Max) is used to establish fixed water fire-fighting equipment models. Meanwhile, the HTC VIVE helmet is used to enhance the sense of reality and the Unity3D engine is used to set up the virtual scene of the ship. The students’ movement is realized by Bezier curve. The operation to virtual equipment is realized by the collision detection. The route of the virtual crew is realized by the A* algorithm. The examination result illustrates that the training system can be applied to the fire-fighting training.

INTRODUCTION

The ship fire is a hidden danger which threatens the safety of ship's operation. It can not only cause loss of property, but also threaten the lives on the ship. It is necessary to conduct fire drills in order to examine the crew's ability to respond to fire hazards in various parts of the ship, familiarity with individual contingency tasks, and mutual support and coordination among the crew during the emergency [1]. At present, the ship fire drills are mostly carried out in the real environment. It not only causes pollution and a waste of money, but also has high risks.

In recent years, with the rapid development of computer virtual reality technology, the application of virtual reality in ship fire has drawn wide attention [2]. The VR of fire fighting in the ship itself aims to simulate the real world and restore the real fire environment as much as possible. Especially for very complex
scenes or high risk environments, it has many advantages [3]. Fixed water fire extinguishing system is not only the system that all ships must be equipped with, but also the most basic and effective extinguishing system.

The key technologies of 3D scene roaming, interaction of virtual device and planning path of virtual assistant crew are studied in this paper. Based on the HTC VIVE virtual reality helmet and the Unity 3D engine, we developed a simulation training system of ship fixed water fire extinguishing.

DESIGN OF SYSTEM SCHEME

Overall Design

The fixed water fire extinguishing system is an important part of the ship fire fighting system, which is composed of fire pump, fire hydrant, fire hose, and international shore connection. To achieve the purpose of extinguishing fire, the fire pump intakes the seawater outside the ship through the valve of seawater inlet firstly. Then the water is sprayed to anywhere in the ship through fire hose and fire hydrant. According to the requirements of the SOLAS Convention on the content of fire prevention, the training of the fixed water fire extinguishing system should be completed by a number of people. The specific training contents include the switch operation of the fire pump, the use of the fire gun, the laying and recovery of the fire hose, the use of the fire hydrant and so on. The training process of the ship's fixed water fire extinguishing system is shown in Figure 1.

![Training process diagram]

Figure 1. Training process.
Cooperative Work

It needs two or four people to work together to accomplish the training of fixed water extinguishing system. In the process of fire-fighting training, the main points examined are the degree of familiarity with the use of the equipment and the ability of cooperation among students. According to the needs of actual operation and the division of labor, we set three roles: sailor A, sailor B, and sailor C. A is responsible for opening fire pump, the fire pump intakes the seawater outside the ship through the valve of seawater inlet firstly. Then the water is sprayed to anywhere in the ship through fire hose and fire hydrant. B takes the fire hose to lay on the designated place and connect it with the fire hydrant. C takes out the fire gun to connect with the fire hose. When the connection is finished, B opens the fire hydrant valve. Because the fast velocity of water flow cause that the water belt is not easy to control, B needs to run quickly to the side of C and help him to spray water.

In order to increase the flexibility of the system, two cooperation methods are designed in this paper: one is the cooperation between the student and the virtual assistant crew, the other being the coordination among the students. The cooperation between the student and the virtual assistant crew is that the student chooses one role and the other two roles are virtual assistant crew. The student can command the crew to operate the equipment through the auxiliary menu provided by the system. The student cooperates with the virtual assistant crew to complete the training. Multiplayer collaboration refers to the three trainees logging into the system with the roles of three sailors respectively. And students can work together through the LAN. In the virtual scenario, one of the students can see the operation of the other two students. Then the three students work together to complete the training.

Tools of Development and Equipment Selection

UNITY3D

Unity3D is a high-performance 3D virtual reality development platform. It regards the graphical development environment as the primary working way, and the interface is friendly. Besides, it has a very powerful capability of computer program compilation compared with other virtual reality developing platforms; the most distinguished feature of Unity is the multi-platform development. Now it supports many platforms such as Windows, Mac OS, Android and other platforms. Therefore, Unity3D is selected for the system as a development tool.

HTC VIVE HELMET

The keyboard and two degrees of freedom of the mouse are generally used in the traditional simulation training system as the input device, and two-dimensional
display or projection screen as the output display device. Considering that the real world is a three-dimensional space, people learn a lot of skills in manipulating three-dimensional objects and moving in three-dimensional space, so they can understand the relationship well in the three-dimensional spaces [4]. HTC Vive is the latest virtual reality helmet on the market, which offers immersive experience to users in three segments: a head mounted display, two single-hand-held controls, and the GPS system that can track the display and controller simultaneously. Therefore, HTC VIVE virtual reality helmet is applied to develop simulation training system. The three-dimensional scene presented by the head-mounted display gives the user a stronger sense of immersion and makes the human-computer interaction more natural and harmonious by using the three-dimensional interactive manner.

**SYSTEM DEVELOPMENT AND KEY TECHNOLOGIES**

The main development process of the ship fixed water fire simulation training system is shown in Figure 2.
Building of System Scene and Interface

MODELING OF 3D SCENE

The establishment of the realistic three-dimensional model of ship fire equipment is the basis of the simulation training system. In this paper, “Panamax” bulk carrier is taken as the mother ship, to establish the model of the fire control room and fire equipment. According to the provisions of the STCW convention, at least two separate fire pumps are needed to be placed in the fire control room. In addition, fire hoses and fire hydrants are placed throughout the ship as required.

In the early stage, we take photos and make video in the round of CSH. Then we collect relevant information and make rules of model making and naming. On this basis, we make the model of the ship fire equipment geometry and the material and texture of model. Then we set the light position and intensity to render the model[5]. Finally, we integrate all the rendered models into the entire ship. The figure below is part of the three-dimensional model of fire-fighting equipment and the scene picture of CSH ship three-dimensional.

DEVELOPMENT OF THREE-DIMENSIONAL INTERFACE

The traditional UI of HUD style has two characteristics [6]: first, HUD screen is the closest object to the camera lens, and other objects will be blocked by the HUD; second, the position of HUD is fixed in the screen, and many components are at the edge of the screen. And these two points are hard to be accepted in VR. First of all, if the distance between UI and students is too close, the students’ eyes cannot focus on the UI. Second, the screen in the VR is not rectangular, the edges are generally vague, and so the UI on the edge will not be seen clearly. And if the location is still fixed, out of view, it's less natural.

In this paper, we take "stereoscopic" UI instead of "HUD" UI. UI is no longer focused on a plane. We float the interface above the VIVE handle. When the operator needs to operate the interface, he simply needs to bow or get the handle to the field of view.
The system's three-dimensional interface includes: scene settings, LAN networking, navigation menu, assist order menu and suggestive information of device and other functions. The fire position, the size of the fire, select roles, etc. can be set in Scene settings menu (Figure 5); Navigation menu which is located in the upper left of the main interface and allow students to telegraph a position to the entire ship, can facilitate trainee training (Figure 6); The assist order menu is also located in the upper left of the main interface, which is mutually exclusive with the navigation menu. It is used by participants to communicate with the virtual crew to complete the water fire-fighting operation (Figure 7). The suggestive information menu is located at the bottom right of the main interface. When the trainee operates the device, it displays the related suggestive information of the device in the suggestive information interface, which includes name of the device, current status and operation prompt information. The overall layout of UI is shown in Figure 8.

**Key Technology and Implementation**

The ship is equipped with a large number of fire hydrants and fire dragon boxes. When the student uses the collaborative approach of trainees and virtual assistant crew, the process of operating equipment by trainee and the virtual crew is not the same completely. The trainees wander around by means of ray teleportation to operate the equipment, and the virtual crew operates the equipment throughout the path according to the real-time planning. The key technologies and implementation process are described in this paper through the following three aspects: scene roaming, virtual device interaction and path planning.
SCENE ROAMING

There are two main roaming methods in this system, one is continuous roaming, the other being fast teleport. Continuous roaming is similar to the move of role controller in the game. The student controls the movement of perspective continuously, through inputting the handle disk key and setting the fixed step. We do not introduce details here because the realization of continuous roaming is relatively simple. The basic principle of fast teleporting is that the student emits a ray from the handle and the point where the ray intersects with the deck or stair in the scene is the position to be teleported. Due to the small space on board, traditional straight line teleport has its disadvantages. When obstacles are in front of students or the target position is higher than the starting point, the intersection of the delivery point is often inaccurate by using straight line teleport. It causes that the operation cannot be completed in time. To solve this problem, we use Bezier curves instead of straight lines to achieve fast teleportation. When there is an obstacle in the front or the target point is higher than the starting point, the Bezier curve is a smooth curve, and the position of the intersection point is obtained by connecting the fixed angle and the fixed length.

Given \( n+1 \) points in space \( P_0, P_1, P_2, \ldots, P_n \), the parameter curve constructed by formula (1) is \( n \) times Bezier curve[7]. \( P_0, P_1, P_2, \ldots, P_n \) are the control vertices of \( P(t) \).

\[
P(t) = \sum_{i=0}^{n} P_{i,n}(t), \quad 0 \leq t \leq 1
\]

The key to constructing a Bezier curve is finding the right control points. In this system, we use three points to construct the quadratic parameter Bezier curve. We set XYZ as the world coordinate system of the whole scene, the coordinate system of the handle itself is UVN. And we divide objects in the scene into the teleportation areas (decks, stairs, etc.) and the non-teleportation areas (walls, cargo hatches, etc.) before constructing a Bezier curve. An example of a barrier-free object in the direction of the handle N-axis (just in front of the handle) is shown (Figure 8). When the student presses the disk key of the handle, the position of the handle in the virtual scene is regarded as point A and it emits a certain length of ray \( L_1 \) (the length can be adjusted according to the actual situation) towards the direction of the N axis of the handle. Collision detection is made at this time. If the ray does not collide with any object, the handle takes the end point of the ray as point B, and emits an infinite ray \( L_2 \) towards the opposite direction to the Y axis of the world. If the object collided by \( L_2 \) is a transient area, the collision point is the point C which can be transmitted. A, B, C three points are the control points we need. After getting the curve and changing the parameter \( u \) of the curve, we can get a series of positions of the curve. In order to realize visualization of the curve (Figure 9), we place the green spheres in each position, which marks the point can be teleported. If the object collided with \( L_2 \) is not in the teleportation region, we construct the Bezier curve...
with red ball, which marks the point cannot be teleported. The process of using Bezier curves to achieve fast teleporting is shown in Figure 10.

**DEVICE INTERACTION**

The device interaction in this system is mainly that students operate the device by handle in the virtual scene. There are two main ways to interact: one is the ray mode, and the other is the touch mode. The former needs to determine whether the ray emitted by the handle intersect with the device. The latter needs to determine whether the handle "touch" with the device, if intersection or contact exists, the students can apply concrete operation to the device.

Two kinds of interaction have their own characteristics. The ray mode is suitable for the situation that the operated equipment is dense, such as multiple buttons on the smoke detection panel. By contrast, the touch mode is more suitable for the situation that the device is dispersed, fire hydrants dispersed in multiple locations in the scene. Either way is selected, collision detection should be carried out.

Objects in the scene must be given colliders if they need to sense a collision. The Unity engine provides five types of colliders for objects: the Box Collider, the Sphere Collider, the Capsule Collider, the Mesh Collider and the Wheel Collider.
According to the characteristics of the object shape to select the collider, it can reduce the amount of calculation of the computer and improve the system fluency.

In summary, the simulation of device interaction process is as follows.
1. Choose the appropriate interaction, according to the location of the device.
2. Add appropriate colliders for each device to detect rays or touch.
3. Script. When a collision is detected, the device will move according to the edited regular to realize the simulation of device interaction.

PATH PLANATION

The room in ship is narrow and it has much fire equipment. When the students command the virtual assist crew to go to somewhere to operate a device, the problem of path planation of virtual crew should be solved. At present, there are many algorithms for path planning, such as artificial potential field method[8], genetic algorithm[9] and A* algorithm[10]. Among them, A* algorithm is a path planning method which is suitable for the information of environment is known and the environment change less during path finding. Aiming at the specific environment of ship, in this paper A* algorithm is chosen for virtual crew path planning.

A* algorithm is a typical heuristic search algorithm in artificial intelligence. It uses heuristic information to find the optimal path to the destination node with minimal cost. The core of the algorithm is a valuation function:

\[ f(n) = g(n) + h(n) \]  

In Eq. (2) \( f(n) \) is the cost sum of the shortest path from the starting node to the target node, \( g(n) \) is the actual cost from the starting node to the node \( n \), \( h(n) \) is the estimated cost of the shortest path from the node \( n \) to the destination node.

There are three A* path finding grids: navigational chart based on cell, navigational chart based on view-point and navigational grids. Compared with the first two navigation maps, the advantage of the navigation grid is that it can perform the movement of point-to-point accurately. This is very suitable for the ship environment with narrow space, so in this paper the navigation grid is used. The concrete realization process is as follows:

1. Grid layout
   According to the actual situation of CSH, we identify the model by stratifying after confirming the area which needs to be navigated. The area is divided into Walking layer (Ground) and Obstacle layer (Obstacle). Then we add grid collision to the objects such as the ground and stairs in the scene. Finally, we lay the navigation grid according to the layer of the objects.

2. Role settings
In order to prevent the virtual crew from being crossed by other models during path finding, it needs to add a role controller to the virtual crew. Then we set the height of virtual crew the slope of the stairs and other parameters, and add A* path algorithm script to each crew. Finally, we create animation state machine and switch animation of standing, walking, operating equipment and other animation according to the actual situation.

(3) Process of path finding

Firstly, we define a two-dimensional array to hold all the nodes in the navigation grid and create two lists of nodes to be called by A* algorithm, which they are added by walkable and non-walkable nodes. After the student commands the virtual crew to open the fire hydrant, the virtual crew starts to seek the path from the current node. We use the valuation function to compare the value of each node around the current node, and select the less costly node to expand. It will end until we find out the destination node.

TRAINING EXAMPLE

Based on the above techniques, a simulation system of ship fixed fire extinguishing simulation is developed in this paper. We take the following cargo case to illustrate, which adopts the cooperation of students and virtual assist crew to conduct the fixed water fire extinguishing training.

First, set the location of fire, the size of fire and other environmental information (Figure 5). According to process of Figure 1, the system allocates clear tasks for students and the virtual crew.

An alarm is issued from the cab smoke detection panel (Figure 11) and the driver on duty can operate all ship alarms. When the student opens the fire pump at the fire control station, he finds fire pump power disorders. Then he commands virtual crew to open the emergency fire pump (Figure 12). After that, he roams to the cargo hold 1 to get the hose. And he lays it to the designated place and connects it with the fire hydrant, while the virtual crew takes out the fire gun (Figure 13) and connects it with the hose. Finally, open the hydrant (Figure 14) and cool the bulkhead. After the flame is extinguished, the fire-fighting equipment is recycled and the exercise is completed.

Figure 11. Smoke detection panel alarm. Figure 12. Emergency fire pump.
CONCLUSION

In this paper, a fixed water fire simulation training system based on the HTC VIVE is realized. It can provide more dimensions for students to operate and capture the location and gestures of students to complete complex interactive tasks. The system can reduce training costs and make the training subject to the site and time no longer which has great training result.

In the follow-up research process, the following areas can be carried out: establish evaluation algorithms and develop intelligent evaluation procedures. For the other fire equipment onboard the ship, the function of simulation training and building a complete functional ship fire simulation training system can be develop.

REFERENCES