Fire-fighting Training System Based on Virtual Reality

Meiqi Jiang\textsuperscript{a}, Guanglu Zhou\textsuperscript{b} and Qiwei Zhang\textsuperscript{c}

School of Computer Science and Engineering, Harbin Institute of Technology, Weihai 264200, China

\textsuperscript{a}1395937231@qq.com, \textsuperscript{b}30515509@qq.com, \textsuperscript{c}1498588668@qq.com

Abstract. Applying virtual reality technique to fire-fighting training can effectively solve waste of manpower, material, money and so on. In this paper, we will combine HTC Vive and Unity3D engine to carry out the design and development of fire-fighting training system. Particle system, navigation grid, animation system and collision detection technology are applied to achieve flame flus gas diffusion simulation, non-experiencer follow, animation production, interaction functions between characters and objects respectively, to save time for rendering spent and meet the real-time demand of virtual scenes generation, this paper optimizes virtual scenes by using LOD technology and occlusion culling technique. The results show that the fire-fighting training system has a good sense of immersion, and it can meet the demand of fire-fighting training.

1. Introduction

The main cause of the fire is because people are lack of safety awareness, they do not know how to deal with the situation when fire emergencies happen [1], due to the real fire drill that was both waste of manpower, material, money and the effect is not good, therefore, it is quite necessary to develop a set of fire drill system for people to enhance fire safety training. Virtual reality technology has been widely used in military, entertainment, education, building, these fields, it has three characteristics, immersion, interactivity, and imagination. The fire drill system is developed using the HTC Vive device and Unity3D engine.

HTC Vive is a product developed by HTC and Vavle cooperatively, The hardware part includes head mounted displays, handles and Lighthouse locator [2], the visual sense take charge of 70% of the total sensing for a human being [3], the auditory sense, senses-smell sense, touch sense and taste sense take charge of 20%, 5%, 4% and 1% respectively [4], compared to the mouse, keyboard and other traditional virtual reality input devices, HTC Vive virtual device can make experiencer have more immersion in the virtual scenes, completed training operation by the visual sense, auditory sense and touch sense.

Unity3D engine has large assets store, supports windows, ios, android, mac and other platforms [5], can use c#, JavaScript, Boo as scripting language, by a lot of virtual reality and game’s developer favorite.

2. System Function Design

Here we select different virtual scenes for virtual fire-fighting training, the system simulate four virtual scenes including shopping mall, hospital, family as well as cabaret. The system possesses the
following main functions such as scene roaming function, simulated extinguishing function, function of simulating flame flue gas, non-experiencer follow function, animation playing function, function of taking the items, controlling rolling shutters and elevators, handle light spot selecting function. Scene roaming function enable the experiencer to walk, run, up and down stairs freely in the scene.

Which can be achieved mainly through the Lighthouse positioning technology. Simulated extinguishing function, whether fire extinguishing can be successfully achieved depend on judgement of conditions such as whether distance, the angle are appropriate etc., the algorithm of extinguishing is designed in this paper. Flame flue gas simulation function include the production and proliferation of flame, flue gas particles, which can be achieved through the Unity3d engine particle system technology to achieve. In order to make the flue gas diffuse more authentically in the virtual scene, this paper proposes the method of simulating the fire scene with Pyrosim software, the simulated data will serves as the main input condition of the Unity3D engine game particle system. As for Non-experiencer follow function, non-experiencer follow the experiencer to move into the scene, through the Unity3d engine navigation grid technology to achieve. Animation playing function, including characters’ walking, standing, squatting, switching the door and other animation playing, through the Unity3d engine animation system technology implementation. The function of taking the items, the experiencer can take object that they need in the scene. Rolling door control function, the experiencer can control the rise and fall of the rolling door. Elevator control function, the experiencer and non-experiencer can up and down the floor by taking the elevator. Handle light spot selecting function, include the experiencer use the handle to select open the fire hydrant door and selected in the family scene desired to enter functions module. This system possesses main functions include scene roaming, simulated extinguishing, taking the items, controlling rolling shutters and, elevator, handle light spot selecting function, they all need collision detection technology to realize interaction between the role and objects.

3. System Key Technology

3.1. Scene Roaming Function

The scene roaming of experiencer is to control walking, running, up and down stairs and other operations by helmet and handles, the method of realization is modeling with 3dsMax for the modeling, export the format of .FBX, import into Unity3D engine, through Lighthouse positioning technology accurate locate position of helmet and handles used in the experience area by the experiencer, import the Steam VR plug-in, preset the body Camera Rig in its subfolders already contains SteamVR _Tracked Object and SteamVR _Controller Manager script, used to locate the position of helmet and handles, add Character Controller component to the created game object, this component is used for control the main role of the first person or the third person, finally, add a script to the game object to control the movement of the object, achieve roaming in the scene of the experiencer. The effect as shown in Fig. 1.

3.2. Experiencer Simulated Extinguishing Function

Taking the extinguisher is equivalent to the function of taking any objects, selected need to take the game object, add rigid body component and collider to its, write the corresponding script code, the rigid body component is dragged to the Rb parameter position of taking object codes.

To determine whether the success of fire extinguishing, the algorithm of extinguishing is designed here, find all the flame presets first, then find the flame presets closest to the experiencer, to determine whether the distance between experiencer and recently flames are less than the preset distance, whether the angle meets the requirement, whether it can be finished fire extinguishing before the preset upper limit of the number of flames, if the above conditions are met, that means the fire extinguishing was successful. The effect as shown in Fig. 2.
4. Particle System Simulated Flue Gas Diffusion

Particle system is the key technology of the Unity3D engine, which mainly uses particle system to simulate flame and flue gas diffusion, due to different flue gas diffusion regular patterns in different scenes, this paper put forward simulating flue gas diffusion according to the actual model of the scene with Pyrosim software. Pyrosim is a dynamic fire-simulation software developed by Thunderhead Engineering company in the United States, this paper selects the family scenes as the research object, simulate the fire scene with Pyrosim software, obtain the regular pattern of smoke diffusion in the real situation.

Among fire scene setting, simulate the family scenes with the length of 15m, width of 8m, height of 4m, each cell has a uniform size 0.25m x 0.25m x 0.25m, the total number of cells in each domain is 30720. The fire broke out in the bedroom, there is bed in the bedroom and a set of bedding, the material is foam. The room has been laid floors and all the partition walls are made of gypsum. The fire source is a red square has dimension of 0.5m x 0.5m, all windows for the whole scene are set to off and all doors are set to open, the family model is shown in Fig. 3, among a few green spots named Density1, Density2, Density3, Density4, Density5 represent as the smoke detectors of the master bedroom, another bedroom, kitchen, bathroom, living room respectively, which are used for detecting the concentration of the smoke, among several yellow spots stands for velocity detectors used for detecting the diffusion rate of the smoke.
Then we analysis the calculation result, set the simulation time is 300s, FDS simulation running time is 9 minutes and 36 seconds, intercept 30s, 110s, 140s, 160s smoke distribution diagram of FDS simulation running are shown in Fig. 4, it can be seen the smoke of master bedroom begin to diffusion at about 30s, the smoke of master bedroom begin to diffusion to living room at about 110s, the smoke begin to diffusion to another bedroom and kitchen at about 140s, the smoke begin to diffusion to bathroom at about 160s.

Select Density1, Density2, Density3, Density4, Density5 smoke detectors of five rooms output excel file import into origin software, can get the graph how smoke detectors change with time as shows in Fig. 5, Density in the figure stands for the flue gas concentration, it can be seen within 300s, smoke of master bedroom has the highest concentration, followed by master living room, there are not much difference between the smoke concentration of another bedroom, kitchen and bathroom.

Through the above analysis, the smoke simulation data is applied to Unity3d particle system, create several particle systems in different rooms, set some parameters of several particle systems such as

Figure 4. (a) (b) (c)( d) show 30s, 110s, 140s, 160s flue gas distribution respectively

Figure 5. How smoke detectors change with time
particle start speed, particle start lifetime, particle emission shape, particle emission direction, particle start color respectively, simulate different concentrations of smoke by control the number of particles, achieve the regular pattern of smoke diffusion by the code in Unity3D.

4.1. Navigation Grid
Navigation grid is a kind of technology in the 3d world that can achieve dynamic objects navigate automatically, can generated navigation grid automatically according to the scene content, hang up the component of navigation to the object that need to navigate, the object of navigate can find the suitable route according to the target point and arrive at the target point.

The non-experiencer serve as the firemen follow the experiencer to move into the scene rescue and extinguishing, method to realize is selecting floor item from the scene at first, clicking the top right corner of Inspector view, clicking the lower triangular button of Static, selecting Navigation Static option pop-up from the drop-down list, select menu bar Window Navigation, click the Bake button from the pop-up Navigation view, the grid in the scene will automatically generated, import the person object, add the component of Nav Mesh Agent to it, set the parameters, add a control script, set the parameters of Target is Player, achieve the non-experiencer follow the experiencer to move. The effect as shown in Fig. 6.

4.2. Animation Production
Mecanim is Unity3D's inherent animation system, function is very rich. Here are several related key concepts.

The animation controller has several functions including the integration of multiple animations, using state machine to play and switch animations, using scripts to control the animation etc. The animation state machine provides methods of looking through all the animation segments, including animation states, animation transitions and animation events. Hybrid trees can be used to mix multiple similar motions in the game animation.

This paper animation system is used to simulate characters walking, standing, squatting, door switch and other animations, here to introduce the realization of the door switch animation. Import animated doors into the engine, create Animator Controller, named it AC, open AC, create two states named open and close, select the state of open, add animations to the Motion parameter in the properties panel, on the close button right click, choose Make Transition, click on open, create a state transition line 1 from close to open, use the same method create a state transition line 2 from open to close, click on Parameters, add bool type parameter, named it sw, click on line 1, add Conditions in the properties panel and convert when sw is true, do the same operation to the line 2, but convert when sw is false, add a collider of Sphere on the door handle, add a control script, achieve the door switch.
4.3. Collision Detection Technology

The most key technology of virtual reality is collision detection technology, it is used to detect the collision between the object and the character model, can effectively avoid the phenomenon of penetrating the wall. At present, the common collision detection algorithm are divided into two categories, collision detection algorithm based on time and collision detection algorithm based on space, the latter were most widely used, the common level bounding box includes axis-aligned bounding box (AABB), sphere bounding box (Sphere) and oriented bounding box (OBB) [6].

The AABB bounding box is along the direction of coordinate axis of the three-dimensional space contains surrounded by objects six sides boxed cuboid, its advantage is simple to construction, with low complexity of intersection test and easy to implement, while the disadvantage is relatively poor of compactness. When two AABB bounding boxes are intersect on the projections of three coordinate axis, two AABB bounding boxes are intersect [7, 8].

The Sphere bounding box is sphere, the advantage is simple shape, low difficulty of construction intersection test is easier to achieve, while the disadvantage is relatively poor compactness compared with AABB bounding box. It is easy to judge the intersection of two Sphere bounding boxes, the calculation of the core and radius of two spheres are only needed, if the radius sum of two sphere are less than the core distance of two sphere, it is shown that no collision happen and there is no intersection, if the radius sum of two sphere are more than the core distance of two sphere, shown that there is intersection, the half of the maximum and minimum of all vertex coordinate on the object being detected is the center of the sphere, the half of the maximum and minimum of all fixed coordinates is radius [9].

The OBB bounding box and the AABB bounding box are similar, but there is difference, that is OBB bounding box has directionality, it can wrapped object close better along the direction of object according to the shape features, therefore, it is a kind of improved AABB bounding box, the advantage is good compactness while the disadvantage is difficult to construct, intersection test very complexity.

When system interaction occurs, because there will be a lot of objects model in the scene, some of them are simple and some are relatively complex, the Unity3D provides the mesh collider, its advantage is high accuracy while the disadvantage is enormous performance consumption, therefore, for simple objects model we can use Unity engine provides several types of colliders, such as the Box Collider, the Sphere Collider, the Capsule Collider etc. to achieve, for complex objects model, this paper can conduct rough collision detection at first, because only the situation of bounding box intersection, wrapped geometry can intersect, therefore, we can exclude the impossibility of a collision in the short term according to add an AABB bounding box to the object, then conduct careful inspection, according to add the mesh collider to complex object model, accurate to conduct collision detection of the object model where the two AABB bounding boxes have intersected.

4.4. Scene Optimization

LOD technology, also called hierarchy details technology, proposed by Clark in 2017, has been widely used in virtual reality field, it determines the resource allocation of object model rendering by the location and importance of model in the scene in the display environment, that is to say the object model far from the camera in the game scene uses the low-precision model, on the contrary uses the high-precision model, using LOD technology optimize game rendering efficiency under the premise of without impacting on the screen vision, thereby solve the problem of system is not running smoothly.
Figure 8. Three different surface models

The models made in 3dsMax can be divided into 3 groups, high precision model, medium precision model and low precision model respectively, three different surface models as shown in Fig. 8 above. Export the format of .FBX and import it into Unity3D engine, choose LODGroup from Component, drag the three models of prepared different precision to the various levels in LODGroup component, LOD 0 adds the closest model to the camera, which is a high precision model, LOD 1 adds the medium precision model, keep adding to the last Culled plug-in, the model will disappear completely, we get efficient rendering calculation by selecting needed model and distance settings.

Occlusion culling technique. If the computer rendering of all objects in the scene will increase the load on the CPU, thus cause less smooth operation, complex 3D scene especially, need a large of rendering work, we can use occlusion culling technique to address this situation. Occlusion culling technique is when an object is blocked by other objects and invisible in camera’s visual scope, then it doesn't need to be rendered. Under most circumstances in the engine, camera is rendering from far to near, that is, objects away from camera will be rendered first, a short distance away from camera will be rendered, therefore occlusion culling technique in the engine cannot completed automatically, we need to achieve it by a series of operations.

Firstly, through a few operations in Unity3D, create a component of occlusion area, set an occlusion area that cameras can reach, it can also create some occlusion area to adjust the place where the object is likely to arrive. Secondly, set properties, so that it can contain all objects that need to be occlusion culling. Finally, baking the scene of need to occlusion culling.

5. Conclusion
Applying virtual reality technique to fire drill in this paper, to achieve the main functions of the system through research on particle system, collision detection, scene optimization and other technologies, the system can help experiencers learn use of fire extinguisher, know about the common fire hazard, the emergency handling of the common fire methods and how to safe escape when the fire broke out, It has the characteristics of immersion, simple operation and rich functions etc., achieve the purpose of system development, can effectively conduct people's escape training, the firemen search and rescue extinguishing training. Provide reference of technique and thinking for virtual reality technique applying in fire-fighting or other fields.

References
[1] X.I. Mingze, S.P. Smith, Reusing Simulated Evacuation Behaviour in a Game Engine, Australian Conference on Interactive Entertainment. 2014.
[2] W.F. Gong, Design and Research for Virtual Reality Sandplay Therapy Based on HTC VIVE, Harbin Institution of Technology, 2016. (in Chinese).
[3] H. Zhang, Head-mounted display - based intuitive virtual reality training system for the mining industry, International Journal of Mining Science and Technology. 27(2017) 717-722.
[4] T. Mazuryk, M. Gervautz, Virtual Reality-History, Applications, Technology and Future, CiteSeer. 1996.
[5] N. Bucher, Introducing Design Patterns and Best Practices in Unity3D, Southeast Conference. (2017) 243 - 247.

[6] H.Q. Sun, Research and Realization of Key Technology of Vehicle Virtual Assembly System, North University, 2017. (in Chinese).

[7] B.G. Sun, Study of the Key Technologies of Control and Interaction in Virtual Assembly, Hubei University of Technology, 2016. (in Chinese).

[8] W. An, Z. Cai, Collision Detection Technology based on bounding box of Virtual Reality, International Conference on E-product E-service. (2010) 1 - 4.

[9] J.J. Guo, Research on Optical Capture Data Based Virtual-Real Interaction Technology, North China University of Technology, 2017. (in Chinese).