A Virtual Reality Simulation System for Coal Safety Based on Cloud Rendering and AI Technology

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Abstract. Coal mining, regarded as a high-risk industry, has strongly demand on Virtual Reality (VR) training environment for safety mining and emergency rescue. In order to solve the problems of the current VR platform of lack of immersive experience and interest, a Browser/Client VR simulation system are designed and realized. Three key techniques are studies, including cloud rendering, AI behavior tree and mining disaster animation. Unlike WebGL and HTML5, cloud rendering provides photo-realistic quality. 2 AI characters are designed to guide users to have an overall understanding of the mine and experience the effect mine disasters. The system has been successfully applied in the Virtual Reality Teaching and Experiment Laboratory for undergraduate in China University of Mining & Technology-Beijing. The research, as a new tool for miner training and disaster drilling, has a signification meaning of the work safety IT construction.

Keywords: Coal mine safety · Virtual reality · Game artificial intelligence · Behavior tree · Cloud rendering

1 Introduction

Coal mine, with dangerous working environment and complex production system, has a strong demand for the virtual reality (VR) simulation and drills. Virtual Reality (VR) has its unique advantage for high-risk mining industry, such as miner safety training, emergency rescue drilling, longwall mining and drifting production processes simulation, disaster scenario simulation, mechanical operation training and so on. 5G communication, cloud computing and big data will become IT fundamental infrastructure in the Intelligent Mine construction in the future 3–5 years. A shift from desktop VR to Cloud VR is inevitable, as it becomes the best choice for VR. Research and application on the cloud-based VR simulation system for mine safety are very important in recently year.

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In this article, a Browser/Client VR simulation system for coal mine safety is designed and developed base on the cloud rending technology and game AI technology to solve the problems of the current VR platform, such as lack of immersive experience and interest, high requirement of the client devices performance. Section 2 introduces the related research on virtual reality training of coal mine. Section 3 introduces the system architecture design with cloud rending technology. Section 4 focuses on the Game AI design for general learning and disaster experience. Section 5 introduces the techniques of disaster animation producing. Section 6 shows some system outcome. Finally, Sect. 7 gives some conclusions.

2 Related Works

Developed mining countries such as United States, Australia, and UK have implemented VR as training environment for mining simulation, accident reconstruction and investigation, education and safety training in two decades [1–7].

Commonwealth Scientific and Industrial Research Organization (CSRIO) developed a drilling system for coal mine equipment operation. Artificial Intelligence, Computer Graphics and Virtual Reality (AIMS) in University of Nottingham, UK has a long history of developing and applying VR technology for coal mine safety training. The VR products SafeVR and VRoom are very famous for open pit truck operation training. Researchers at The National Institute for Occupational Safety and Health (NIOSH) are exploring how the mining industry can effectively use "serious games" for mine training. They have used a game engine to create a portion of an underground coal mine. In this virtual mine, trainees have a first-person point as they walk or ride through the mine. The first training package in this virtual mine instructs new miners in how to read mine maps. Marshall University used Unity3D to develop an Interactive Virtual Underground Mine Platform (IVUMP), which can record the messages, information and actions of mine rescue team members. The platform used VFIRE to enhance the ventilation interactive simulation to provide a safety training exercise for emergency response.

In China, some large mining groups and State Administration of Work Safety have been applying the VR hardware and software to safety training and emergency rescue training. For example, two national VR training centers had been established in Shendong Mining Group and Ningxia Mining Group, each of which cost more than 200 million US dollar. Those systems provided the high fidelity for users with the functions of single user, stand-alone version and "Q and A" work safety training. The VR hardware were composed of projection-based panoramic display system, infrared tracking stereoscopic glasses, VR headset display, Pad, touch screens and other devices. Moreover, desktop 3D visualization system are popular in coal mine with the functions of 3D geological model, ventilation simulation, real-time data monitoring [8–11].

There VR applications still have some shortcomings need to improve.

Lack of the Immersive Experience and the Learning Interest. Those coal mine training system have teaching and learning functions with single-player mode and ask-answer pattern, lack of the immersive experience and the learning interest. Most of them did not design AI man-machine interaction functions so that the advantages of immersion, interactivity and imagination of virtual reality could not been fully used.

High Requirement of the Client Devices Performance. Good experiment relies on high-performance local devices. However, traditional VR training applications confront new challenges. VR applications need to support the various light terminals such as PC, mobile phone, PAD, and headset and so on, to have the abilities of mass multiplayer online (MMO), to upgrade the question-answer learning pattern into a serious multiply game experience patter. At the same time, network fluency, interaction ability, user experience and VR quality of VR also need to consider.

Lack of the Gamifying, Intelligent and Diversity. VR learning tend to be gamifying, intelligent and diversity. Non-Player Character (NPC) characters can enrich game content.AI functionalities include Sense/Think/Act cycle. With Game AI design, the VR training of answer-questions turns into interactive with NPC in 3D scenes. This will enhance the user's real experience of learning and training, strengthen their memory and safety awareness.

3 Architecture of the Virtual Reality Simulation System Based on Cloud Rendering Technology

The system is based on Unreal Engine (UE), which is one of the wildly-used engines which has a complete suite of game development tools. The system takes virtual reality visualization as the basic function, uses the NPC game AI to link the knowledgeable sites together to guide the user to experience coal mine. The system architecture is shown as Fig. 1.

A classic Browser/Client architecture of cloud rending is established. The B/S structure means each of individual player connect to the server and get 3D streaming from the server on the cloud. Cloud server handles all the events and the state of the virtual world and transfer the VR render streaming to the client.

Cloud rendering technology refers to run VR rendering program on the virtual server, taking full advantage of virtually infinite computing power to create, capture, compress high-resolution renderings, and sent to the low performance and computing power client. When bandwidth is good, users can interact with VR programs on the client through the network. In this kind of B/S architecture, the client is lightweight, without the need for expensive hardware, responsible only for decoding and displaying 3D scenes, and can both support resource-constrained platforms such as mobile devices. Users can interact with 3D scenes anywhere and anytime [12, 13].

Compared with the other popular Web3D technologies, mainly HTML5 and WebGL, cloud rendering technology has incomparable advantages, mainly because it has no special expensive requirements on the client, and no matter what kind of device can ensure 3D reality and quality. Moreover, since 5G will provide sufficient network bandwidth, online cloud rendering architecture will provide enough computing and rendering power and be a trend in the future.

In this architecture, the whole system is divided into three parts: portal server, game server and client.

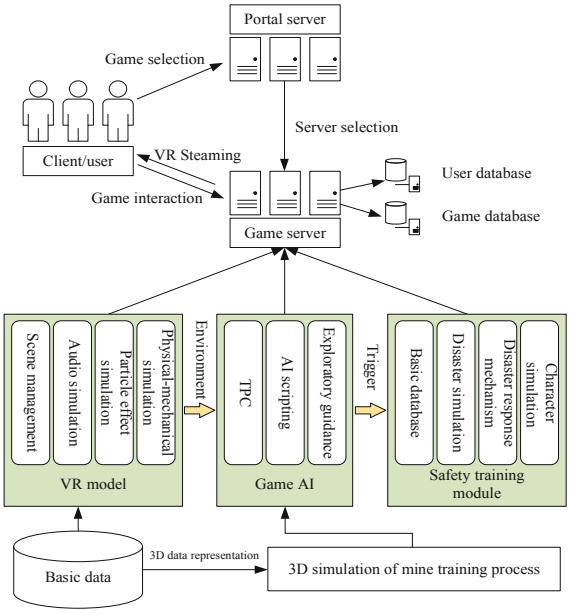

Fig. 1. The architecture of the virtual reality simulation system based on cloud rendering

Portal Server. It is responsible for user login, and according to the user's choice to find the appropriate server, control the server to start the virtual machine (game server). The client and the game server establish a connection when portal server provides the address of the virtual machine to the client, and user can run and interact the 3D program in the remote server through the network.

Game Server. It is responsible for processing the mouse and keyboard input events from the client and translating them and sending them into the interaction module of the 3D program for further parsing. The 3D scenes images are captured, encoded and sent to the client as video streaming. 3D server program includes three parts: virtual reality modeling and visualization module, AI game guidance module and safety training module.

Client. It is responsible for displaying the received 3D scene steaming and sending the user's input such as keyboard and mouse events to the server.

4 Design of Game AI

3D engine, like the automobile engine of the mechanical industry, determines the rendering speed, the sense of reality and immersion, and also affects the convenience and efficiency of the entire 3d application. It combines all the elements in the virtual environment together and coordinate them to work orderly in the background. A typical game engine as Unreal or Unity3D includes a rendering engine ("renderer") for 2D or 3D graphics, a physics engine or collision detection (and collision response), sound,

scripting language, animation, artificial intelligence (AI), networking, terrain, streaming, memory management, threading, localization support, and a scene graph.

Artificial intelligence in games (or 'Game AI' for short) is a module of 3D engine. There are similarities and differences between Game AI and traditional AI. Traditional AI typically demonstrate at least some of the following behaviors associated with human intelligence: planning, learning, reasoning, problem solving, knowledge representation, perception, motion, and manipulation. Game AI is emerging and become the narrow branch from traditional artificial intelligence. Game AI refers to Non-Play Characters (NPC) controlled by the computer simulate the intelligent behavior of human being or other creatures, showing a certain amount of intelligent behavior, providing users with a believable challenge to overcome [14, 15]. In our serious game, two NPC are designed to simulate the behavior of miners who guide users to understand the whole underground mine production, to experience the virtual scene and improve the relationship with the user during the process of training, conversation or other tasks.

4.1 The Principle of Game AI

By designing AI behavior, NPCs can automatically analyze and generate the game-oriented effect. When users enter the designed game scenario, they slowly become addicted to NPC's guide-feedback behavior. Compared with traditional learning, the progress of the game itself is also learning, but it is easy to grasp, which will have a positive guiding effect on the user's behavior.

They are two ways of Game AI, the finite state machine (FSM) algorithm and behavior tree algorithm. FSM is to build "state". Transitions between states are triggered by events. A "state" can represent physical conditions that the entity is in, or it can represent emotional states that the entity can exhibit. FSM is a kind of "Event triggered type" to simulate the promptly react to the human player's action with its pre-programmed behavior. An obvious drawback of FSM design is its predictability. All NPCs' behaviors are pre-programmed, the modular design and reusability is not stable when the when games get larger and more complex. A more advanced method used to enhance the personalized experience is the Behavior Tree.

A simplified flow chart of the way behavior tree can be used in such a game is shown in the Fig. 2. Figure 2 shows a sequence of actions of open/close door and open/close window. Behavior tree is mainly composed of leaf node and composite node, which is essentially a tree, that is, acyclic graph.

Leaf Tasks. They are the terminal nodes of the tree and define low level actions which describe the overall behavior. They are typically implemented by user code, maybe in the form of a script, and can be something as simple as looking up the value of a variable in the game state, executing an animation, or playing a sound effect.

Composite Tasks. They provide a standard way to describe relationships between child tasks, such as how and when they should be executed. Contrary to leaf tasks, which are defined by the user, composite nodes are predefined and provided by the behavior tree formalism. They build branches of the tree in order to organize their sub-tasks (the children). Basically, branches keep track of a collection of child tasks (conditions,

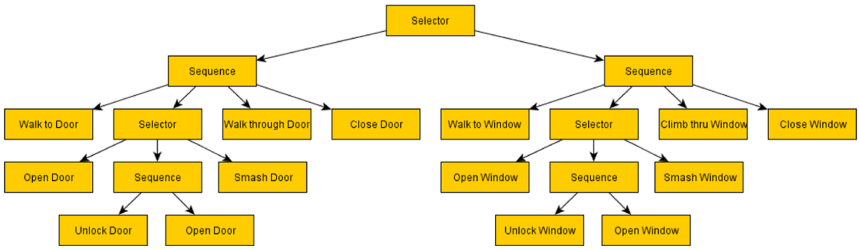

Fig. 2. The type of AI behavior tree

actions, or other composites), and their behavior is based on the behavior of their children. Composite tasks consist of selectors, sequences, parallels and decorators.

A Selector. It is a branch task that runs each of its child behaviors in turn. It will return immediately with a success status code when one of its children runs successfully.

A Sequence. It also executes the node task in turn instead. if one fails the sequence will returns, and the rest task are not executed.

A Decorator. It is a task that has one single child task and modifies its behavior in some way. It will return when a child task output is modified. It can be used to make decisions on whether a branch (or even a single node) in the tree can be executed.

A Parallel. It is composite task to handles "concurrent" behaviors. It's a special branch task that runs all children when stepped. The behavior tree allows parallel node tasks, which may be state machine. Multiple state machines can be executed in parallel.

4.2 Design of AI Behavior

In Unreal engine, Blueprint is used by adding and connecting a series of nodes which have some functionality attached to them to a Behavior Tree Graph. Figure 3 designs a NPC's plot of learning general knowledge and experience the mine disaster. Also, two AI characters are designed to find local navigation grid path automatically.

The First NPC is task-oriented character who explain the common knowledge about the coalmine and guide the user to visit the key underground work site such as longwall working face. Once the user completes the corresponding task and gives feedback can NPC release the next task. The tasks are preparing before entering the underground mine, looking for the entrance, entering the cage, visiting the underground working face. The behavior tree of task-oriented NPC is shown as Fig. 4.

The second NPC is disaster-oriented character who guide user to experience the typical coal mine disaster. The NPC's behavior tree is shown as Fig. 5. Selector, sequence, parallel are designed to trigger the accidents such as gas leakage, roof fall, fire and seepage. The selector firstly judges whether it is dangerous or not, then run each disaster sequence. Sequence executes the disaster animation in turn and test the user's reaction if it is correct or not. NPC also give out the run and waring to the user in parallel node.

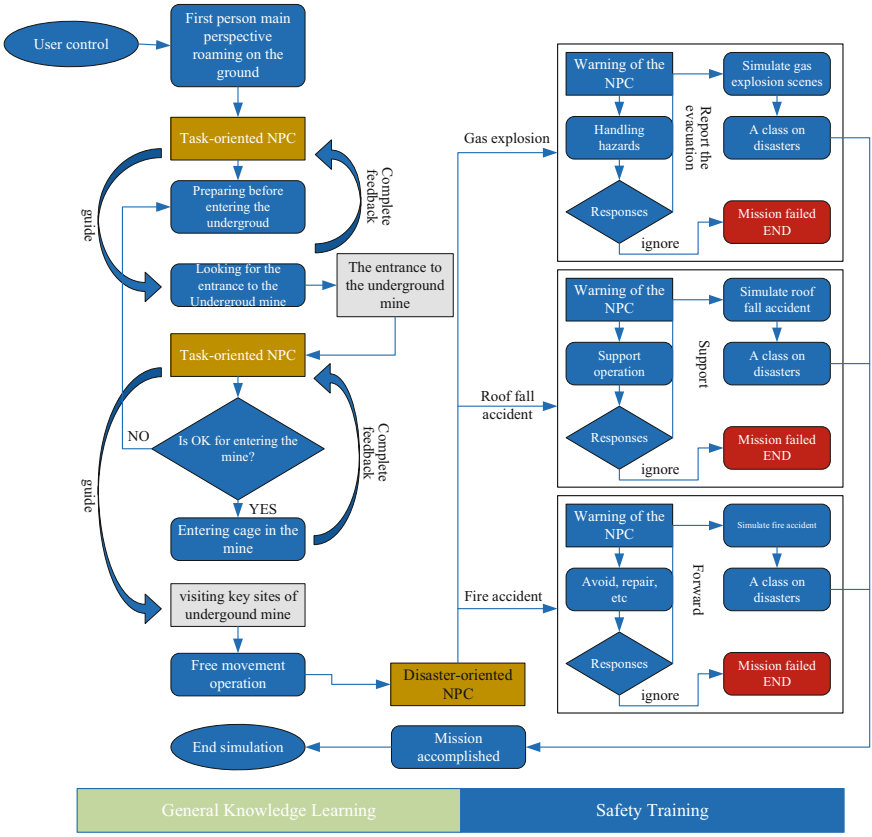

Fig. 3. The VR mission of Game AI NPC plot

5 Key Technique Typical Disaster Simulation Animation

Mining is a high-risk industry, which exist many dangerous accidents such as gas leakage, roof fall, fire and seepage. Once the corresponding animation are triggered by NPC's AI behavior, the system will randomly enter the disaster simulation and it will make the corresponding judgment according to the type of disaster and the handling method of the operator, shown as Table 1.

The disaster simulation module integrates various 3D animation, audio, particle effect, and physical-mechanical models of the 3D engine. 3D model is to establish model of mines, terrain, tunnels, characters, etc. Audio focuses on creating real sound as realistic as possible from the dimension of the source, such as footsteps when walking on the grass and in the tunnel, wheezing when running, mechanical sound when the cage is opened, etc.

The particle effect is to display the dust in the mining face or the dust generated when the roof fall rises. The physical-mechanical model can enhance the virtual character's realistic sense of force, not only the downward acceleration of gravity, but also the sense of gravity when the rock wall is peeling off. Blueprint are used to create those VR effects.

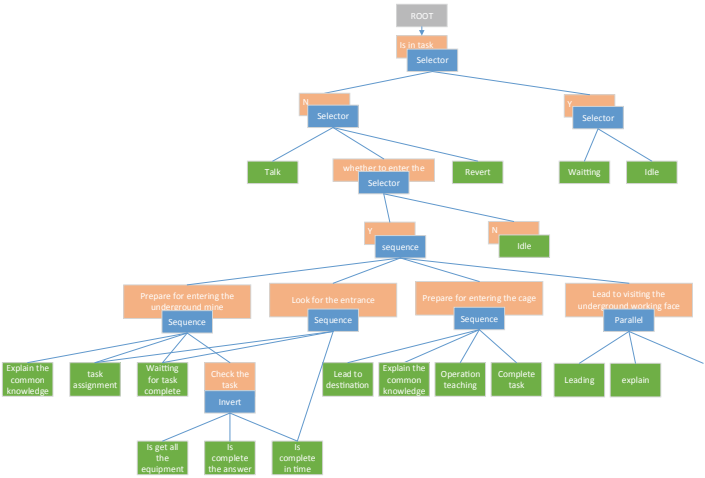

Fig. 4. Behavior tree of the task-oriented NPC

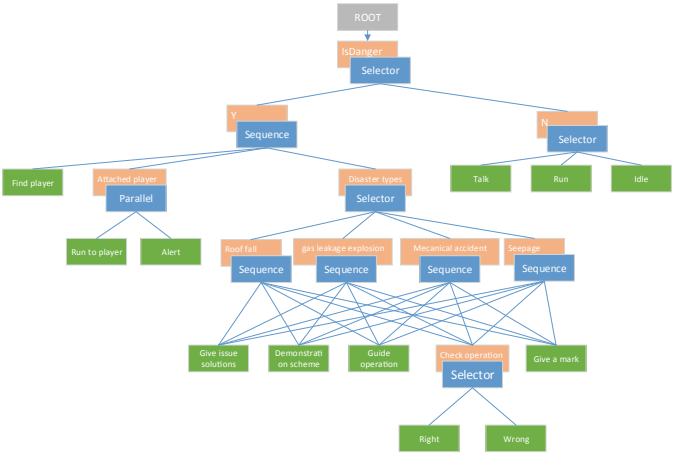

Fig. 5. Behavior tree of the disaster-oriented NPC

5.1 Gas and Coal Dust Explosions

Through this VR system, user will understand boundary conditions of gas and coal dust explosions. By animation technology, a process of coal and gas outburst are established so that user could perceive the disaster from the vision, auditory, and other aspects, and understand the movement and destruction process of the mixed wind and dust. Also, some emergency preparedness such as collaborative gas extraction can be fully displayed.

Table 1. Typical mine disaster simulation

Types of accidents	Characteristics of accidents	Treatments
Gas and dust exploration	Gas leak detector exceeds the upper limit and self-ignite	Report, escape
Roof fall and wall collapse	Rubble drop	Roadway support
Fire accident	Spontaneous combustion	Report escape etc.
Seepage	Water seeps out through a gap or coal seam	Seal

5.2 Roof Fall and Wall Collapse

Through this VR system, user will understand the main factors of roof fall and wall collapse. They can simulate the conditions of various rock burst disasters, simulate the process of ground pressure disasters so that user could understand the form of disaster, causes of these disasters, factors, and the methods of disaster prevention.

5.3 Fire Accident

Through this VR system, user will understand the main form of mine fire such as external fires mainly caused by open flames, blasting, current short circuit, etc., as well as internal fires caused by combustion of coal or other flammable substances due to their own oxidation and heat. VR simulate the conditions of various fires, understand the severity of disasters and master the methods for preventing fires. The system also shows the fire accident treatment, including the closed grouting method and nitrogen injection method.

5.4 Water Seepage

Through the system, user will understand the main factors of mine seepage, such as fissure water, etc. The system can simulate the conditions of various seepage, simulate the process of water inrush, the causes of water inrush and various influencing factors of water inrush so that employees could understand the severity of the disaster accidents and master the methods of seepage prevention and treatment.

6 System Implement

The system has been successfully applied in the Virtual Reality Teaching and Experiment Laboratory for undergraduate in China University of Mining & Technology-Beijing. A cloud rendering cluster is composed by two virtual rendering servers with configuration of M60 8G/ CPU 4Core/32 GB RAM/bandwidth BGP 40 Mbps. A client is required as CPU Intel i7, 16 GB RAM. This hardware environment can only support 6 users at most.

According to former acquired 3D data, such as geographic data, geophysical data, and mining data, the 3D entity model are generated by different modeling method by using 3DMax or Maya. The NPC's characters are made according to the ratio of real people.

NPC Virtual Roaming: NPC will walk around buildings with the user, and enter the underground mine by auxiliary cage, visit longwall mining face or tunneling face, and introduce ventilation system, transportation system, water supply and drainage system and power supply system, etc. This function enables the new miners to have an overall understanding of the mine.

NPC Accident Guidance: Through the dialogue with the AI guider, when the user is working normally, the NPC can have a dialogue with him to judge his behavior, with the function of information prompt, illegal operation prompt. The system triggers disaster simulation according to operating conditions.

In this system, mining safety accidents is concentrated in gas explosion, roof fall, fire and seepage. By analyzing disaster reasons, accident characteristics, occurrence status, and formation impact, a specific disaster simulation knowledge library is constructed, which contains a brief description of various disasters, namely, preventive measures, suggestive prevention on pre-disaster characteristics and the popularization of post-disaster knowledge, and it can combine with system guidance to popularize the consequences of disasters (Figs. 6, 7, 8, 9, and 10).

Fig. 6. Finding entrance of underground mine with task-oriented NPC

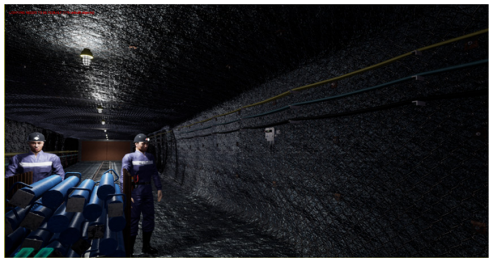

Fig. 7. Visiting working face with task-oriented NPC

Fig. 8. Gas explosion animation

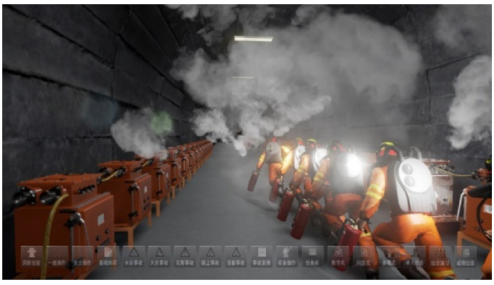

Fig. 9. Fire-extinguishing animation

Fig. 10. Roof accident animation

7 Conclusion

With the development of intelligent mine construction, the development of virtual reality in the mining industry is facing unprecedented opportunities and challenges. Cloud rendering technology will be the mainstream of 3D technology development in the future. The gamification of AI can also attract users to take actions and strengthen their cognition and learning abilities. In this paper, a serious-game virtual reality platform for mine safety training with Unreal engine is designed and developed based on the latest technology. NPC AI guidance are designed to simulate the process of underground roaming and accident experience including gas explosion, roof fall and wall collapse, fire and seepage. The results of the study will provide a new tool for coal mine work safety and training, avoiding high-risk and extreme environment underground. It provides

user with a reliable, safe and cheap software platform, which not only meets the urgent needs of the government and enterprises for mine safety training, but also promotes the development of mine safety IT construction.

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