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Virtual Reality Simulation System for Underground Mining Project

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1. Introduction

Underground mining has the characteristics such as complex mining technology, poor visibility and sightlines, bad work condition and frequent geological disasters. It is the inevitable trend for the development of mining to innovate traditional mining industry by using modern high technologies to mitigate the deficiency. Virtual mine is the main part of digital mine, it is a new expression of mine and plays an important role in the construction of mine informatization. Virtual reality (VR for short) technology is considered as one of the three most promising technologies in the 21st century, and it has three characteristics: immersion, interactivity and imagination. Virtual reality technology can provide users with lively virtual mining environment in three-dimension, allowing users to not only immerse in the virtual mine scene but also interact with the mining equipment real-timely, which the traditional CAD design and pre-rendering three-dimensional animation can't achieve. Virtual reality technology has been got a wild range of applications and made remarkable achievements in many areas, such as virtual city, military simulation, aerospace simulation etc. It is a kind of innovation to support mine planning, mining design, disaster warning and disaster inversion by using VR technology in the field of mine.

Currently, the application research of mine VR simulation system has got rapid development at home and abroad, but only has little research on underground mining project VR simulation system. VR simulation system for underground mining project will enable users to get all-around perspective and real–time activity interaction in a virtual mine. At the main time, it has a positive meaning for virtual mining design, mine safety education and training, mining technology projects demonstration, mine production visualization management, disaster simulation and inversion etc. In this paper, Kafang polymetallic ore deposit in YunNan province of china was taken as the research object, the development process of VR simulation system for underground mining project was discussed in detail.

2. System general design

2.1 System analysis

According to the characteristics of virtual reality technology and currently needs of Kafang polymetallic ore deposit, the VR simulation system is used to realize deep immersion and achieve real-time interaction with objects in virtual mine, allowing users to roam arbitrary in

the virtual scene and interact with the mining equipments. So, VR simulation system is designed for two parts.

1.   Construct virtual mine scene

Virtual scene is the core of the whole virtual reality simulation system. So, not only the terrain and surface industry field but also the orebody, development and transportation system under the surface should be displayed. According to the development system form and mining method of Kafang polymetallic ore deposit, the virtual mine scene must have mine's terrain, mining equipments, orebody, shaft, tunnel, adit, ramp and other objects. The virtual scene should be lively, and users can feel that they are just like in the real mine. Virtual scene of Kafang mine is shown in fig.1.

2.   Simulate mining process

The mining method of Kafang mine is "reconstruct mining environment and continuous caving afterwards filling mining method". It is a new continuous caving method by reconstructing the mining environment. That is, using high efficiency, high recovery rate mining technology, and high performance for trackless mining equipments. The procedure is to construct new mining environment using backfill body framework constructed by cemented stone by grouting since the stope is finished for the purpose of the creation of mining technology on continuous mining. The process of drilling, blasting, ore removal and filling should be displayed, and the most important is that users can interact with mining equipments real-timely.
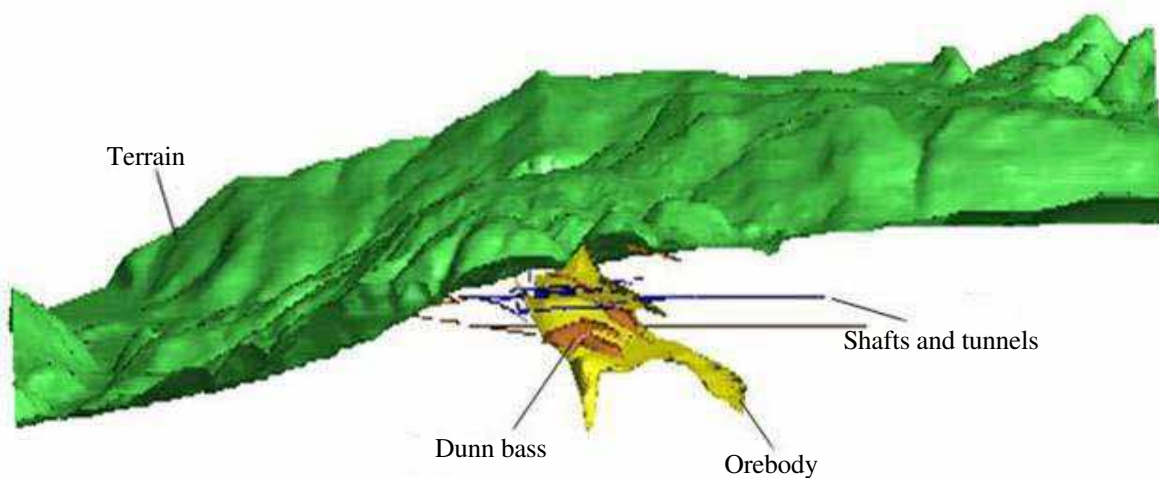

Fig. 1. Virtual scene of Kafang mine

2.2 System development environment

1.   Hardware environment : Graphics workstations, three-channel 120 degree passive 3D display system, single-channel active 3D display system and stereos.

2.   Software environment : Windows XP Professional sp2, 3DMine, Surpac Vision V5.2, OpenSceneGraph (OSG for short) and VS 2005.

      OSG is a cross-platform C++ API built on OpenGL for scene management and graphics rendering optimization, and most important is that it is open source multi-threaded and multi-display. However, OSG has nothing to do with the window system, providing no interaction way and interface management, so, the VR simulation system is take the VS

2005 as the development platform, and call the OSG library functions to realize the system function.

3. Network environment: Gigabit LAN.

2.3 System module analysis

Mining project VR simulation system is divided into five modules:

1. Display modes module: it is used to control the model's appearance. For example, to clearly see the polygonal structure of a model, go to wireframe mode, and disable texture mapping and lighting. Some of the commonly used commands are listed below:
   - Polygon mode—cycle between wireframe, point, and filled polygon rendering mode.
   - Texture mapping—toggle between textured and nontextured.
   - Lighting—disable and enable lighting.
   - Backface culling—toggle backface culling.
   - Fullscreen mode—toggle between fullscreen and windowed rendering.

2. Special effect module: it is used to enhance the 3D virtual scene realism and simulate rain, fog, snow and storm by using particle system of OSG platform

3. Roaming module: it includes manual roaming and automatic roaming. Manual roaming means that users can use mouth and keyboard to adjust the location and direction of viewpoint. Automatic roaming supplies the function of recording and replaying men-roaming paths.

4. Mining process simulation module: it is used to simulate the Kafang polymetallic ore deposit mining process which consists of development, cutting, stoping, filling and ventilation.

5. Stereoscopic display module: this module is to display the mine scene in 3D way, inputting it with "three-channel passive 3D display +3D stereo" mode and "single-channel active 3D display +3D stereo" mode. At the mean time, it can be used to increase or decrease the parallax to ensure the visual comfort of roaming process.

3. System development process

The development process of mining project VR simulation system in underground mine is shown in Fig.2.

3.1 Data management

Data management which is prepared for the total virtual scene is the foundation of VR simulation system. There are many kinds of data, terrain data, geological data, shaft and tunnel data, equipment data are prepared to model terrain, orebody, shaft, tunnel and mining equipment. They are from CAD design paper, including contour maps, orebody section line drawings, development system blueprints, equipment structure diagrams etc.

Image data taken by digital camera and high resolution satellite is used to map the texture on mine 3D geometric model. The texture include of terrain photographs, rocks and mining equipment pictures, these pictures should be corrected by picture processing software and converted into .JPEG and .RGBA format. In order to make the virtual mine scene be more believable, it is necessary to add audio data such as mine environment stereo sound and mining equipments working sound to virtual mine scene. The sounds are recorded by

recording equipment and clipped by professional software. Attribute data includes name and geographical coordinates of development project, ore grade, location of mining equipment, size and shape of tunnel cross-section.
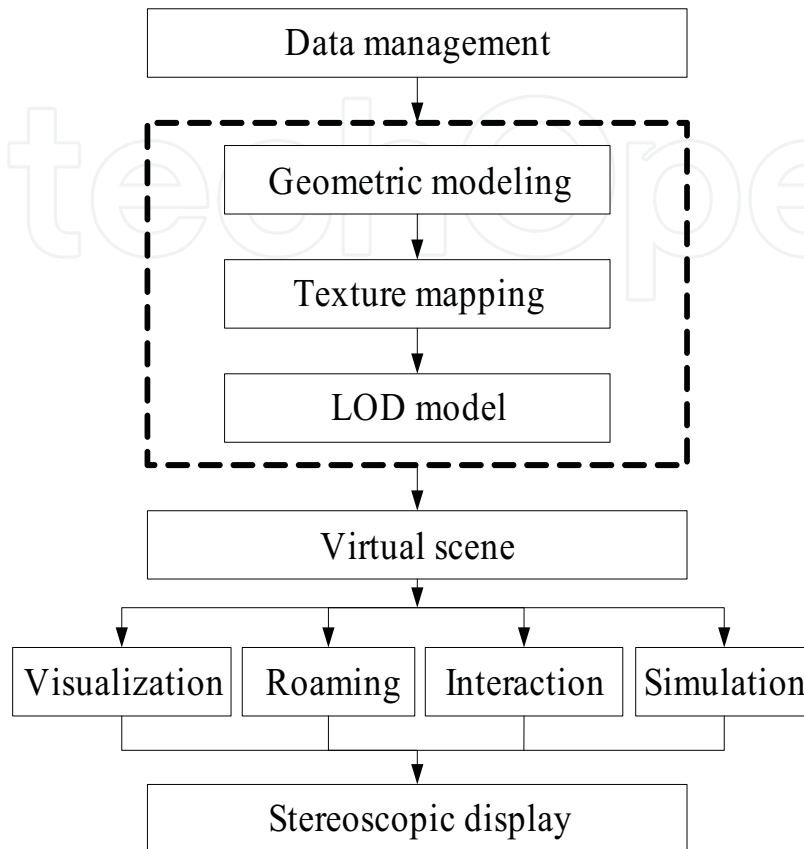
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            ┌─────────────────────────┐
            │   Stereoscopic display  │
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Fig. 2. The development process of VR simulation system

3.2 Scene modeling

Scene modelling is used to construct various models for VR simulation system. It is the key step in the establishment of the whole system and control the success of VR simulation system or not.

The characteristics of Underground mining scene modelling are in following three aspects: (a) shapes and types of the models for underground mining scene are different and opulent, and most of them are irregular. So, plenty of complex and completely different models need to be constructed. (b) The objects of virtual mine scene are divided into two categories: static objects and dynamic objects. In underground mining project VR simulation system, there are terrain models, orebody models, shaft models, tunnel models and ramp models etc, these irregular models belong to static objects. The main dynamic objects are mining equipment models such as tramcars models, LHD models and jumbo models. (c) The data of terrain model and shaft, tunnel models are too big. So, under the premise of meeting the requirements of project and visual sense, models should to be simplified properly to increase models display speed in VR system.

Scene modelling process contains three steps of geometric modelling, texture mapping and LOD models. The modelling process of VR simulation system is shown in fig.3.
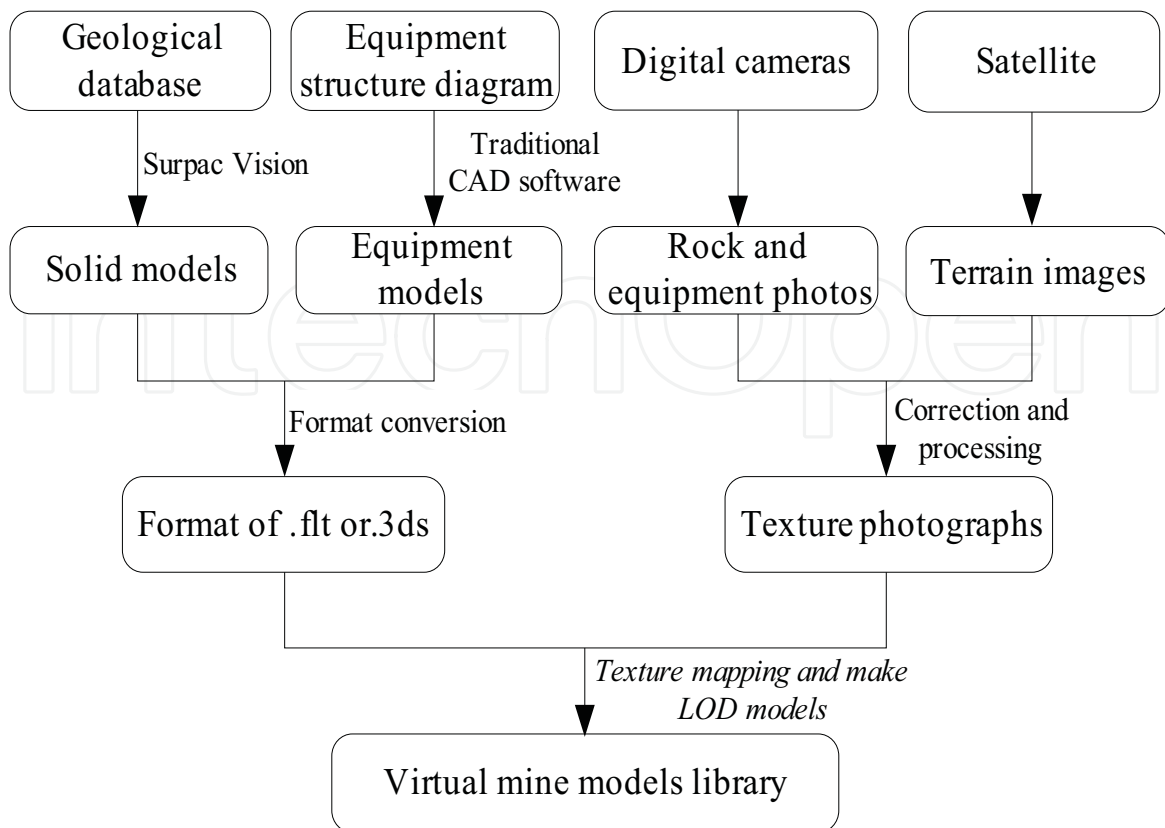
Fig. 3. The modelling process of VR simulation system

3.2.1 Geometric modelling

At present, many kinds of commercial software can meet the requirements of modeling mine models. Mine large project software (such as Surpac Vision, DataMine, Mircomine, 3DMine and DiMine) provides powerful modeling tools and modules based on geological database in the deposit modeling area. In Surpac Vision software, DTM model of terrain can be generated directly by contour, orebody model can be formed by connecting orebody section line, shaft models, tunnel models and ramp models are created by the central line and section of roadway. Fig.4 shows some solid models of Kafang polymetallic ore deposit which are created by CAD design paper.
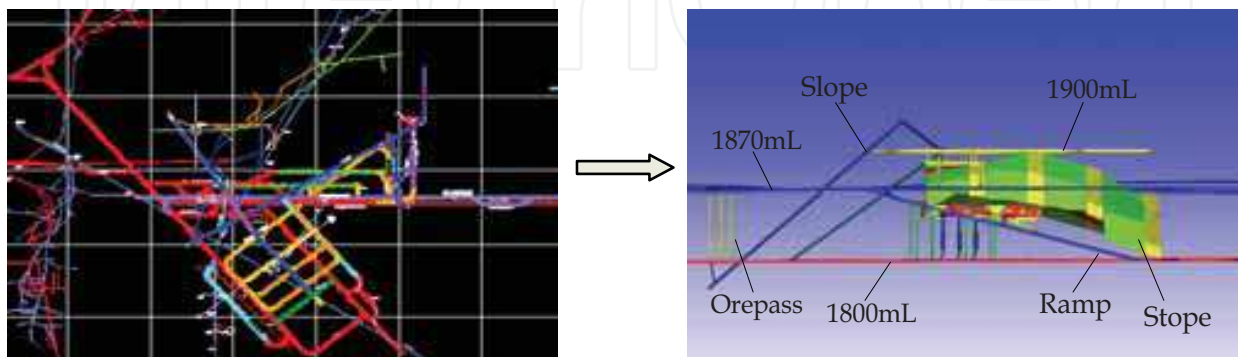
a) CAD design paper   b) solid models

Fig. 4. Some solid models of Kafang polymetallic ore deposit

The traditional CAD software (such as AutoCAD, 3DMax and Maya) has the characteristics that are easy to operate, intuitive, easy to learn, make models realistic and so on. So, it was used to produce mining equipment models which need to be sophisticated and realistic. At last, all the models should be converted into .3ds or .flt or .x data format for texture mapping and LOD models production in professional virtual reality software (such as Multigen Creator). Note that: the format should be to minimize the conversion between models so that model will have a serious distortion. Table 1 lists the common VR software and platform and the data format they support.

Sort	Name	Data format	
		Input data format	Export data format
Mine large project software	Surpac	.dwg, .dxf, .dtm, .dm	dwg, .dxf, .dm, .dtm, .wrl
	3DMine	.dwg, .dxf, .dtm, .dm, 3dm, .shp	.dwg, .dxf, .dm, 3dm, .stl
Traditional CAD software	AutoCAD	.dwg, .dxf	.dwg, .dxf
	3DMax	.3ds, .dwg, .dxf, .obj, .stl, .shp, .wrl	.3ds, .dwg, .dxf, .obj, .stl., .wrl
Professional VR software	MultiGen Creator	.3ds, .dxf, .obj, .stl	.flt, .dxf, .obj, .stl, .wrl
3D model conversion software	Deep Exploration	.3ds, .obj, .geo, .flt, .x, .stl, .wrl, .ma, .mb, .dwg, .dxf	
VR system	InTouch	.dwg, .dxf, .dtm, .dm, .x, .shp	
	CyberMaker	.3ds, .obj, .geo, .flt, .osg, .ive	
VR development platform	OSG	.3ds, .obj, .geo, .dae, .shp, .flt, .osg, .ive	

Table 1. The common VR software and platform and the data format they support

3.2.2 Texture mapping

Texture mapping is a technology that maps the pixel value of 2D image bitmaps to the corresponding peak of 3D solid models. It is used to enhance the realistic and reduce the complexity of solid models. Three kinds of texture mapping technology are used in this system.

1. Projection texture mapping: texture image is projected directly onto three-dimensional geometric model to obtain surface texture coordinates of models, mining equipment models are mapped by using this technology, texture mapping of tramcars models is shown in fig.5.
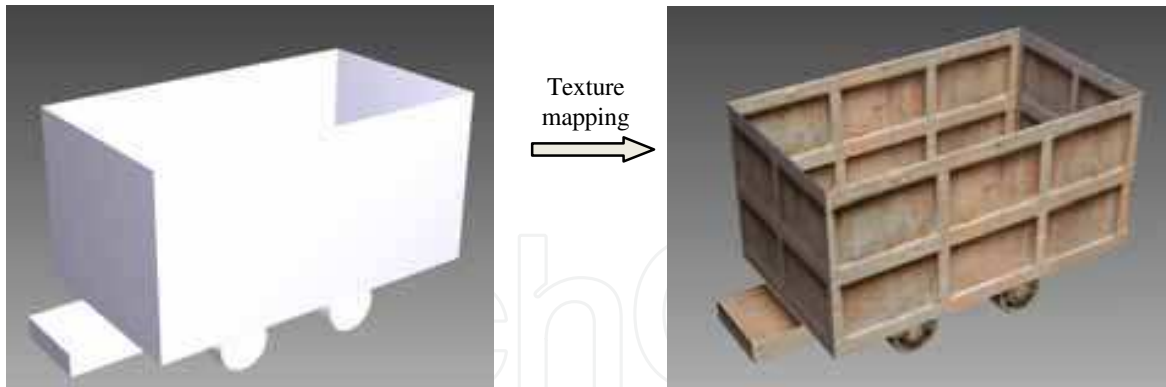
Fig. 5. Texture mapping of tramcars models

2. Transparent texture mapping: It is achieved by texture technology and integration technology. For example, the simulation of trees needs only one face. The advantage of this technology is that speed is fast and visual effects are good when you observe in the plains. Drawback is that if the rapid rotation around the bulletin board area, the surface can be seen in turn, and visual effects look bad from the high altitude. Through the bulletin board technology, roaming system allows users to add plants data in interactive way. At the main time, based on this idea, you can also increase the figure as well as that figure pictures are handled by transparent air technology and replaced by plants texture images.

3. Opaque one-sided texture mapping: it is simple and convenient, the sky ball and terrain are mainly used this method to map textures. By using satellite picture, texture mapping of Kafang polymetallic ore deposit terrain is showed in fig.6.
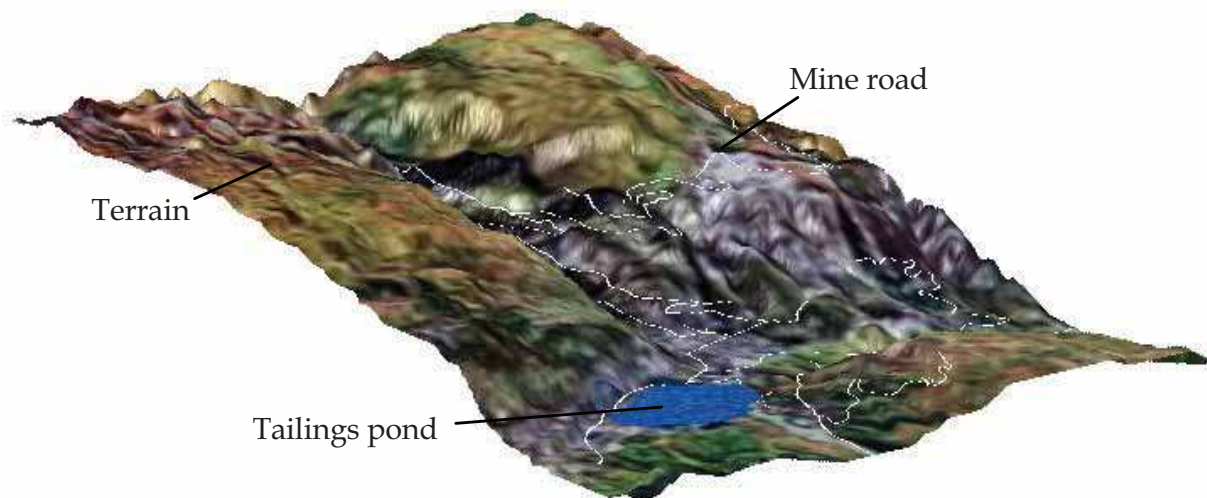
Fig. 6. Texture mapping of Kafang polymetallic ore deposit terrain

4. Texture splicing: texture is spliced continuously and repeatedly by a fundamental element splicing unit which is a small piece of representative and re-splicing texture unit. Shaft models, tunnel models and ramp models are taken in this way.

3.2.3 LOD model

LOD (level of detail) technology can not only ensure the visual effect of virtual scene, but also increase the frame rendering speed of scene and change the complexity of scene real-timely. When the viewpoint comes closer to objects, the object models are changed from simple to complex. At the main time, it is important to join the smoothing technology to reduce the mutation of level of detail. There are two main methods to produce LOD model in mining project virtual reality simulation system development, and one is making continuous approximation similar geometric models, and the other is reducing texture resolution. The mining equipment models and the terrain model (as the following fig.7 shows) are taken the first method, the orebody, shaft and tunnel models are used the second method.

T: 6804	T: 4862
T: 2520	T: 756
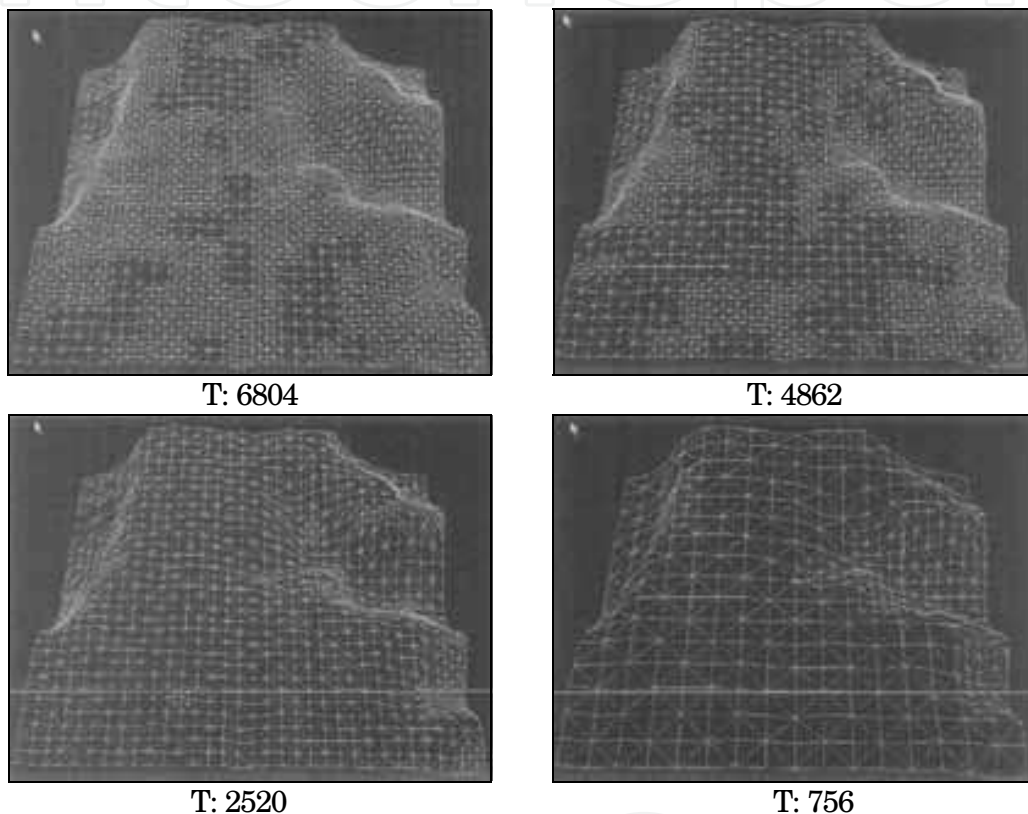
Fig. 7. LOD model of terrain ("T" means the number of the triangle)

3.3 Virtual scene

Virtual scene is the core of the whole virtual reality simulation system and collection of all visual objects in system. Under the support of virtual reality technology, scene visualization and interaction are used to build the virtual mine scene which has deep immersion and high interaction, Virtual mine is a complex system definitely, so the virtual reality simulation system is developed by object-oriented programming method based OSG and VS 2008 platform.

3.3.1 Visualization

Visualization is responsible for building a virtual mine environment of deep immersion. It is used to realize the functions, such as light, materials, geometry changes, transparent display and viewpoint attachment. Virtual scene should be set light and materials correctly.

Geometry change includes translation, rotation, scaling and other geometric operations. Transparent display can offer a way to users to observe a number of objects at the same time. For example, if the tunnels are semi-transparent, on one hand, it shows that tunnels are existent; on the other hand, it also represents the transport scheduling of mining equipments. Viewpoint attachment can make users have the feeling of driving car in the real mine when users roam in the tunnels (fig.8).

3.3.2 Scene roaming
Scene roaming can allow users to observe in virtual mine scene freely. Roaming is a process of moving viewpoints or changing sight line direction continuously to produce three-dimensional animation.

Fig. 8. Roaming in the tunnel

There are two kinds of roaming way in the virtual reality simulation.

1. Manual roaming: The location and direction of viewpoint are controlled by using the mouse and keyboard. In this virtual reality simulation, the operation "Ctrl+ left mouse button" controls the viewpoint movement of left or right, the operation "Ctrl+ right mouse button" controls the viewpoint movement of up or down, the operation "Ctrl+ middle mouse button" controls the viewpoint rotation.
2. Automatic roaming: Automatic roaming supplies a fixed roaming path to display virtual mine scene for users. The path is recorded in a notepad file where path information is interpolated, and then the path is played back. First of all, it is essential to record the initial viewpoint, rotation angle and elevation of sight line around the Z axis and so on; then, each continuous keyboard operation command is recorded with the format of "movement type, initial position, incremental movement, duration, and movement acceleration" for the purpose of interpreting the whole manual roaming process as the roaming command sequence; Thirdly, read the initial parameters from notepad files and set the system by using these parameters; At last, read the manual roaming operation command sequence and call the corresponding command processing functions for processing.

3.3.3 Interaction operation

In the system, interaction operation is mainly controlled by using the mouse for the scheduling of mining equipments. In mining equipments models management module, the car can be selected out of right-mouse menu and interacted with suspension, opening and reverse operation. At the same time, the car objects can added in the virtual mine scene.

In addition, it is important to develop a friendly man-machine interface (fig.9). System is divided into system control program interface and mine virtual reality simulation program interface. System control program interface is used to set up single-channel and multi-channel mode, and parameters of parallax, window size, render nodes and three-dimensional mode. Mine virtual reality simulation program interface is consisted of menu
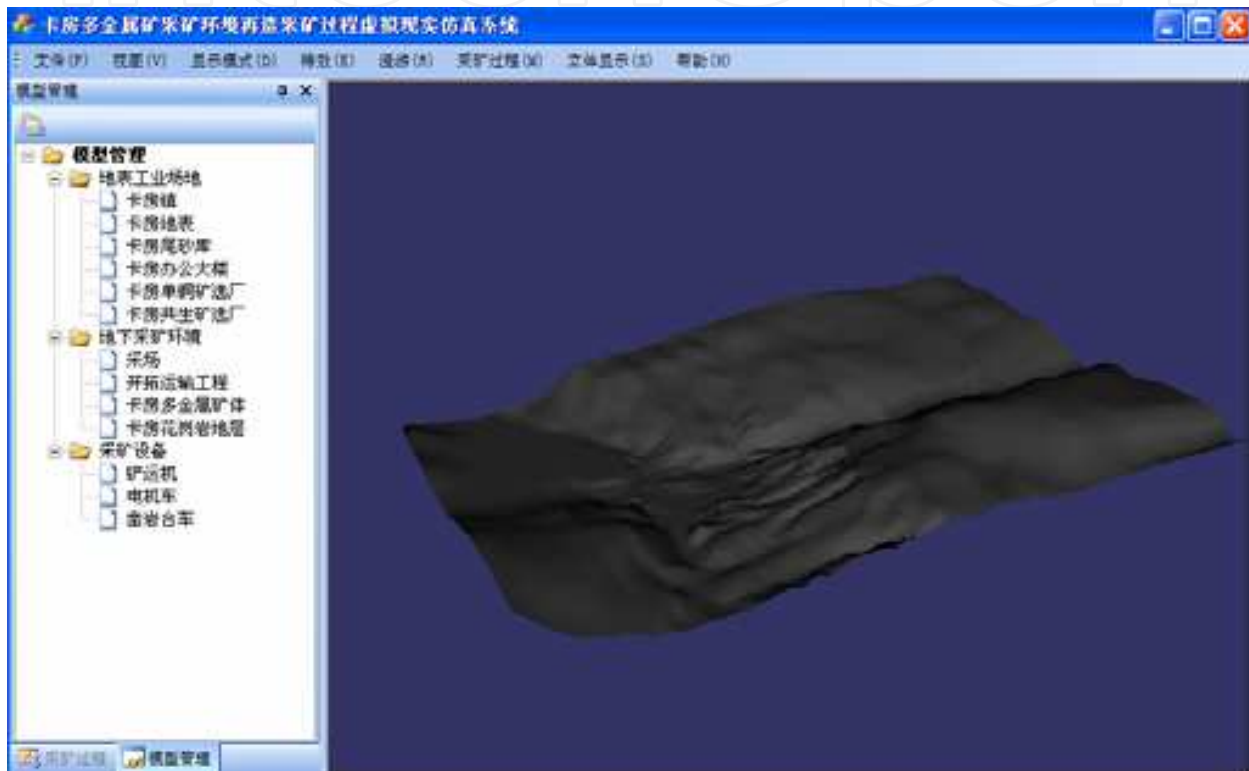
Fig. 9. One running window of VR simulation for underground mining project

and panel. Menu simulation running, roaming management, view, and help menu; panel which has the main operation function of the simulation program includes model management, viewpoint management and safety administration.

3.3.4 Simulation

Mining project simulation is not only a static scene simulation, but also a dynamic mining working environment for reproduction. There are four steps for mining technology in underground mine, such as: drilling, blasting, ore loading, ore removal and filling, so mining project simulation is mainly including the drilling simulation of drilling jumbo, the blasting simulation of rock, the ore loading process of tramcars, ore removal process of LHD, and grouting filling simulation. There are two ways to simulate the mining process, one is manual simulation, and the other is automatic demonstration. Users can drive the mining machines to control the process of drilling and ore removal in the virtual scene through manual simulation way. Automatic demonstration use the double buffer

technology of OSG to set system clock, then order the animation together in accordance with the time to form the whole mining process. Besides, collision detection system is based on the level of AABB bounding box and blasting simulation is based on the osgParticle namespace of OSG platform. The result of mining process simulation is shown in fig.10 and explosion implementation procedures are as follows:

```
osg::Group *root= new osg::Group();
// set the speed of wind
osg::Vec3 position(0, 0, 0);
// application of explosive
osgParticle::ExplosionEffect*explosion = new osgParticle::ExplosionEffect(position, 1.0f);
// application of explosion debris
osgParticle::ExplosionDebrisEffect*explosionDebri=new
osgParticle::ExplosionDebrisEffect(position, 1.0f);
// set smoke model
osgParticle::SmokeEffect* smoke = new osgParticle::SmokeEffect(position, 0.5f);
// set fire model
osgParticle::FireEffect* fire = new osgParticle::FireEffect (position, 1.0f,5.0);
// set the wind effect
explosion->setWind(wind);
explosionDebri->setWind(wind);
smoke->setWind(wind);
fire->setWind(wind);
// join in scene node
root->addChild(explosion);
root->addChild(explosionDebri);
root->addChild(smoke);
root->addChild(fire);
```
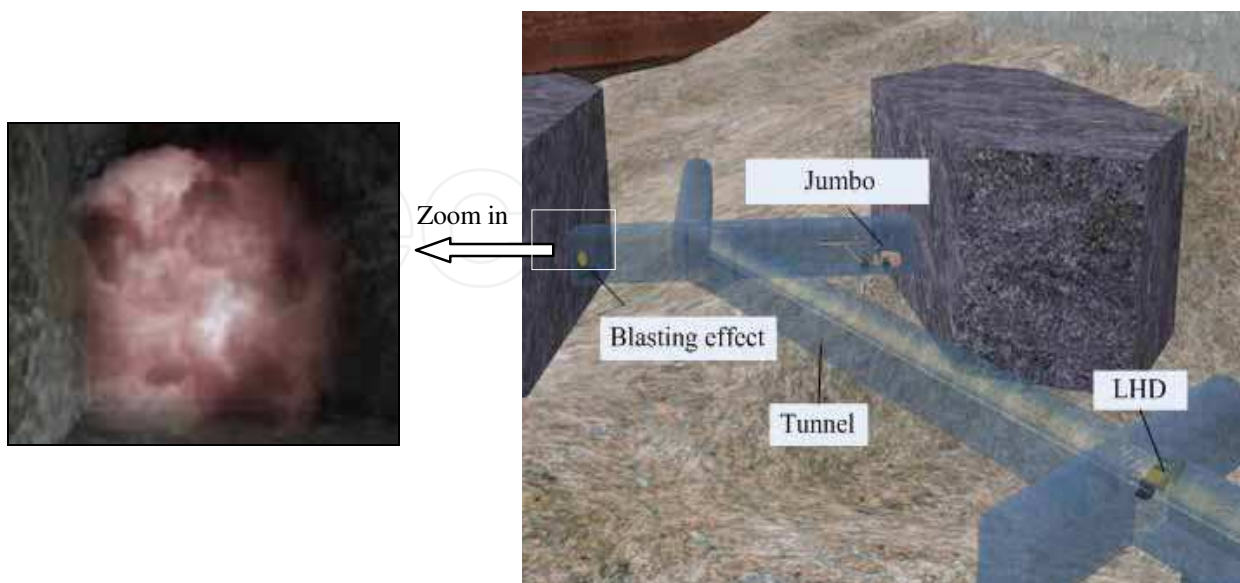

Fig. 10. Mining process simulation

3.4 Stereoscopic display

Stereoscopic display is divided into stereoscopic visual performance and stereoscopic sound performance. Stereoscopic visual performance can supply two view scenes for left eye and right eye separately by using virtual reality equipments firstly, such as professional DLP projector, receive the left eye and right eye video images through left eye and right eye respectively by drawing on three-dimensional glasses and form three-dimensional scene in users' brains finally. Stereoscopic sound performance can output stereo sound and video image through three-dimensional sound machine synchronously. In this VR simulation system, stereoscopic sound is realized by using OpenAL API in OSG platform. First of all, create a buffer. Second, load WAV data. "CreateBufferAndLoadWav" member function calls "COpenALBuffer" instance member function to create a buffer and load WAV data. In of "CreateSource" member function, source is created and buffer area is associated by calling "COpenALSource" instance member function.

The combine of stereoscopic visual performance and stereoscopic sound performance support very important deep information for virtual mine scene, and thus to improve its fidelity, reality and immersion. Three-channel passive 3D display is shown in fig.11 and single-channel active 3D display is shown in fig.12 and its implementation procedures are as follows:

```
osg::Group *root= new osg::Group();
/ / add model nodes
root->addChild( osgDB::readNodeFile("terrain.3ds"));
root->addChild( osgDB::readNodeFile("orebody.3ds"));
root->addChild ( osgDB::readNodeFile ("development. 3ds"));
viewer.setSceneData(root);
/ / set stereo
osg::DisplaySettings::instance()->setStereo(true);
/ / set eye separation
osg::DisplaySettings::instance()->setEyeSeparation (0.08);
viewer.realize();
viewer.run();
```

4. Conclusion

The virtual reality simulation system represents the mine's terrain, development and transportation system, orebody occurrence condition and underground mining process successful in 3D model, and then it can work well in three-channel passive 3D display mode and single-channel active 3D display mode. The virtual mine scene provide user with a very lively sense of immersion, and users can roam freely in the scene. At the same time, the system has a friendly man-machine interface, and users can interact with the mining equipments. All in all, the system basically meets the requirements of mining management expectation. Through the development of underground mining project VR simulation system, the system implementation method and process are studied and the result shows that this idea is reasonable and feasible.

Nevertheless, the VR simulation system still has the following disadvantages for future study: firstly, the tool for human-computer interaction which merely using keyboard and mouse is not enough, further research is necessary to develop professional virtual reality
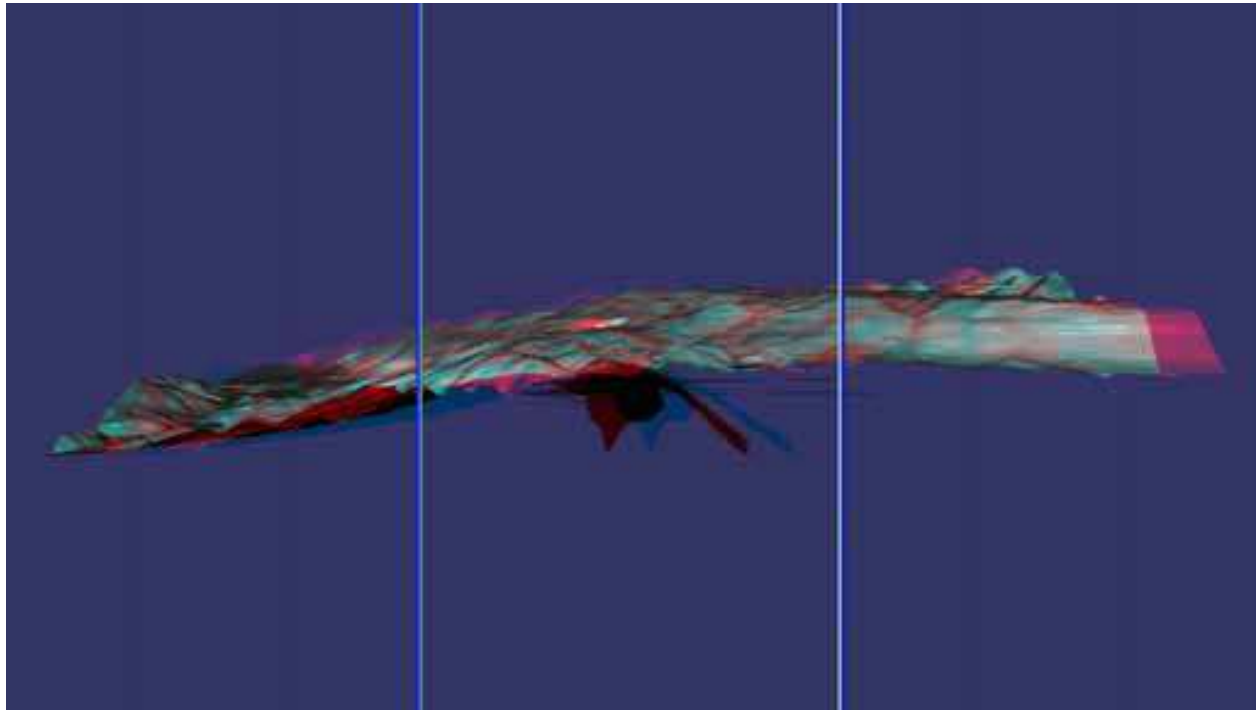
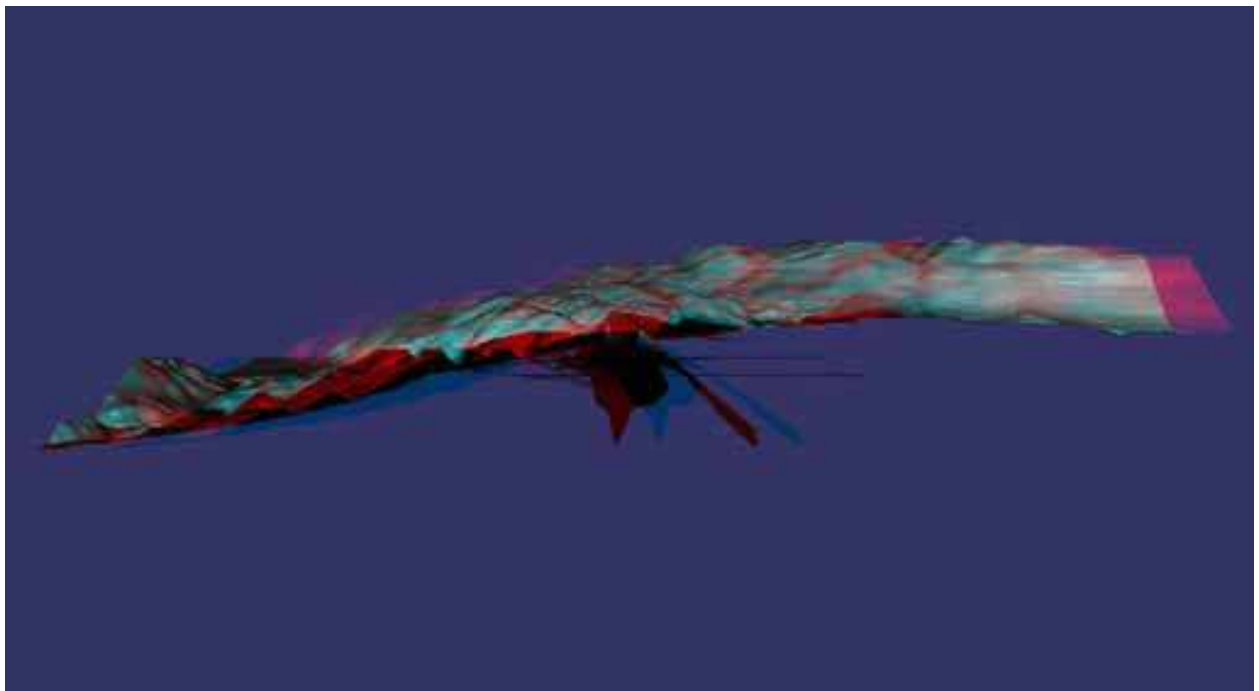Fig. 11. Three-channel passive 3D display

Fig. 12. Single-channel active 3D display

input device (3D mouse, Steering wheel, and data gloves, etc.) interface to enhance the interaction with the virtual mine scene; Secondly, the system don't have the function for data query and analysis module for 3D objects to realize the VR GIS function etc. At main time, virtual reality technology will play a greater advantage and role in mine ventilation simulation, numerical simulation and mine fire simulation etc. With the continuous

development of virtual reality technology, VR is bound to have far-reaching effect to the mine future modernization.

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Virtual Reality

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Technological advancement in graphics and other human motion tracking hardware has promoted pushing "virtual reality" closer to "reality" and thus usage of virtual reality has been extended to various fields. The most typical fields for the application of virtual reality are medicine and engineering. The reviews in this book describe the latest virtual reality-related knowledge in these two fields such as: advanced human-computer interaction and virtual reality technologies, evaluation tools for cognition and behavior, medical and surgical treatment, neuroscience and neuro-rehabilitation, assistant tools for overcoming mental illnesses, educational and industrial uses In addition, the considerations for virtual worlds in human society are discussed. This book will serve as a state-of-the-art resource for researchers who are interested in developing a beneficial technology for human society.

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