

# VRLANE: A DESKTOP VIRTUAL NAVIGATION AND SAFETY MONITORING PROGRAM FOR UNDERGROUND COAL MINE

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## ABSTRACT:

Many coal mine companies have established underground safety monitor and control systems. However, the safety management information can only be displayed on the 2D maps or as reports. In this paper, a new method that combines the VR technologies with underground mine safety monitoring technologies was explored. A desktop virtual reality program for underground coal mine, called VRLane, was developed. As far as supervisors, visitors or trainees are concerned, they do not need to go the dangerous underground mining sites. On the contrary, they can investigate underground safety information on a PC or a remote console. It is one of the most attractive features of VRLane. Safety monitoring data obtained from underground mine equipments can be accessed by “clicking” the relevant piece of equipment model when walking or roaming in the virtual laneway. The paper mainly concerned about the current research advance in VR, system design, key techniques and system application. Several important techniques were introduced in the paper. Firstly, an algorithm was designed and implemented, with which the 3D laneway models and equipment models can be built on the basis of the latest mine 2D drawings automatically. Secondly, VRLane realized system integration with underground industrial automation. The system, with advantages of cheap, dynamic, easy to maintenance, provided a useful tool for safety production management in coal mine.

## 1. INTRODUCTION

With the development of computer science and spatial information technologies, new technologies, such as GIS, visualization, virtual reality and augment reality, turn to be the promising research fields for coal mine industrial informationization. Especially, VR technologies, which provide effective, simple and realistic ways for mine safety, mine worker training, accident investigation and equipment simulation, would improve the technology foundation of “Digital Mine” strategy greatly (Wu Lixin, 2004). Nowadays, many international research organizations in Australia, U.S.A., Germany, South Africa and U.K. are engaging into employing VR for mining. Also in China, Peking University (PKU), China University of Mining and Technology (CUMT) and other research institutes begin to introduce VR technologies into mining research field. However, unlike its application in urban planning, machine design, medicine and other fields, big technological gaps held application back in mining industry. There were still many bottlenecks waiting for solutions, such as 3D underground environment reconstruction automatically, 3D spatial geometric data organization, and man-machine dynamic operation.

In a two-year research period, a research group in Peking University has explored a new way to solve these technical problems. We tried to apply VR technologies into mine safety

monitoring and controlling, and developed a desktop virtual safety management program for underground coal mine from the bottom layer, called VRLane. The paper explained system design, key techniques and system application of VRLane.

## 2. CURRENT STATUS

Virtual reality offers great promise to the mining industry. During several decades, researchers in universities and other research organizations are seeking ways to help the industry capitalize on its potential. Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) has developed techniques for providing data in real-time from an underground longwall system on the web. One result will be a better description of the status of the mining process as it proceeds. Another is a training system that enhances the operator's understanding of his or her role in the longwall mining process. Research group of University of New South Wales used three large-screen projection units to create an underground coal mine. Their program is scenario-based and requires trainees to answer various safety-related questions as they “move” through the mine and thereby the story. University of Queensland created VR applications to address a number of mining industry issues such as safety training, mining engineering education, accident reconstruction, data visualization, mine planning, and environmental hazard assessment. University of Nottingham

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develops some software package, such as SafeVR, VRoom and so on. SafetVR allows a trainee to experience a “real accident” and the virtual environment can be modified to assess potential prevention strategies. The National Institute for Occupational Safety and Health (NIOSH) of America had used a game engine to create a portion of an underground coal mine. In this virtual mine, trainees have a first person vantage point as they walk or ride through the mine.

Beihang University, Zhejiang University and Harbin Institute of Technology are the earliest research institute in VR technologies in China. The most research achievements have been applied into medicine, military, education, manufacture and much else. In mining industry, researchers of CUMT used to develop a Mine Fire and Gas Blast VR System based on MultiGen Creator and Vega(Wang Bing-jian, 2004). The system can simulate the real mining operation environment, and realistically display the dynamic process of fire or gas blast with the results of grid analysis and CFD simulation. Pingdingshan Industry Vocational and Technical Colleges developed a mining VR training system to help the miners learning the ordinary regulations in underground environment. The system was developed secondly based on Virtools 3D engine. The users must answer the various safety questions to move to the next scene.

Although Chinese researchers have done much works to introduce VR into mine field, they are striving for breakthrough in technological innovation. Many coal mine enterprises have been looking forward the VR systems to help them manage mine safety production. Nowadays, various home-made 3D systems, developed for requirement of mining production, need to extend practicability of their functions. There are some problems needed to be resolved, shown as follows:

1) During the mining process, the 3D spatial data are real-time and dynamic. The automatic and quick modeling of strata and laneways are very important for 3D visualization. Most VR systems, depended on statically pre-editing models, cannot create 3D underground laneway models and equipment dynamically and accurately.

2) Most home-made 3D mining system provides simply and narrow functions such as geological modeling, reserve computation and 3D visualization. Actually, mine safety production needs more practical 3D functions. For example, applying VR in mine safety production can give supervisors more clearly decision-making information as well as provide vivid and strong feeling on underground virtual environment.

3) From the standpoint of VR functions, the simulation and interactive roaming of underground scene are far from the expectations. The system needs to have functions of immersive experience, interactive operation, multi-user remote cooperative work, massive data dispatch and much else.

### 3. SYSTEM DESIGN

#### 3.1 System design

VRLane has a typical COM GIS configuration. It uses Microsoft SQLServer2000 in the server to manage basic geological data and monitoring data; uses Microsoft VisualC++ 6.0 to code 2D GIS modules and 3D modeling modules; and use

Microsoft VisualC++ 2005 and ORGE engine to realize VR module.

This architecture can be divided into 3 layers, shown as Figure 1.

1) The basic layer is database management. The database stores geological, surveying, hydrological data and much else. Also, the database integrates the rock pressure data, gas monitoring data, fire monitoring data and video image from some industrial automation systems. Massive data management, multi-task transaction, multi-user concurrent control and data safety are the key technologies on the database system development. Geological model library, surveying model library, hydrological model library and equipment model library are the main contain of database management.

2) The middle layer is a 2D&3D integrated professional GIS platform. The GIS platform have both CAD and GIS functions, which not only have ability to plot all sorts of engineering maps that required in mining process, to draw geological prospecting section map and contour map automatically, to draw roadway preparing map, excavation engineering plans, roadway section map, surface and underground contrast map semi-automatically, but also realize the input, manipulation, spatial analysis and query GIS functions. The platform also integrates the 3D modeling with 2D GIS platform. It can build various models quickly, such as terrain model, geological stratum model, laneway model, equipment model and much else.

3) The top layer is VR application. The VRLane program can provide various immersive, operable and interactive VR services on the LAN or the WAN, for different user’s requirement.

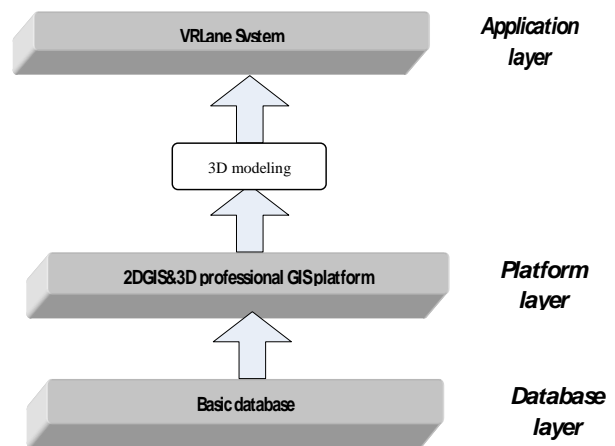


Figure 1. The frame of VRLane system structure

#### 3.2 System function

The function of VRLane can be divided into 3 parts:

1) 3D modeling functions. Those functions, cooperating with database module and 2D GIS module, can realize all sorts modeling of 3D object, mainly including ground industrial square modeling, geologic modeling, laneway modeling and mine design modeling.

Ground industrial square modeling refers to automatic modeling of buildings, trees, roads, water, pools, cooling towers, chimneys, bunkers, and arbitrarily ground construction. Geologic modeling means automatic modeling of boreholes, geological units, protecting pillars, coal heaps, strata and so on. Underground engineering modeling refers to automatic modeling of various laneways, lane junctions, shaft stations and electromechanical equipments from mine design. External model input functions include input and output from 3DSMax, OBJ, WRL.

2) VR information management functions. Those functions provide realistic and interactive virtual environment for users to walk or operate in the laneway models.

Data input function can input various models and plug-ins from user-defined format or the third-party software. Specific effects editor include light rendering, sky texturing, particle system and voice warning, and the system support render and texture special effect. Database connection provides the database link and models attribute query. Scene compilation can render and compile scene independently and pack it into an executable program for release. Role management refers that different users have different password and different privilege. Virtual roaming is a function that users can walk or roam in virtual scene from ground to underground by keyboard and mouse, and fulfill the dynamic information management.

3) Monitoring and controlling information system integration. Integrated with safety production monitoring and controlling system realize the all directional monitoring and controlling of the underground environment, facilities, disasters, and staff in 3D environment, mainly including monitoring and controlling network, ventilation with gas-proof, dust-proof and fire-proof monitoring and controlling system, mine fire bundle tube monitoring system, industrial TV monitoring system and person position system.

#### 4. KEY TECHNOLOGIES

In this section, 3 key technologies are introduced, including: 1) 3D reconstruction of underground virtual scene; 2) collision detection; 3) industrial system integration.

##### 4.1 3D reconstruction of underground virtual scene

A new algorithm of 3D laneway reconstruction from the 2D engineering plan for excavation was proposed. The engineering plan is the basic drawing for coal mining. According to this new algorithm, 3D underground laneway can be established as quadrilateral surface models or triangulated surface models according to surveying traverse points, section type of the laneway, laneway attribute and much else. And different color or texture can be set on the laneway model based on their attribute. The kernel of the algorithm is how to extract the useful information from 2D drawings and establish 3D laneway surface models automatically.

##### 4.1.1 Geometric feature of the laneway

A laneway is composed of centerline, floor, roof, section and side face, shown as Figure 2. A complex laneway model can be divided into many single laneway models. Section type decides the shape of laneway model and the centerline determines its

spatial position. Namely, the geometric feature is decided by the section type and the centerline.

Generally, the section types are in various styles, such as U-type steel frame, three-sectional arch, round arch, one-centered arch, three-centered arch, lacking-circle arc, trapezoid arch.. Since the distance between the side face and the center line is fixed, the certain section can be loaded on the each nodes of the center line and a regular laneway model is built.

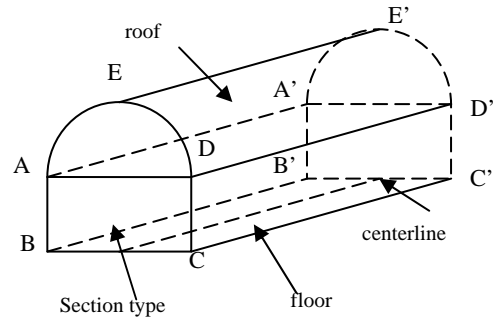


Figure 2. Configuration of a single laneway

##### 4.1.2 3D reconstruction of laneway model

The principle of the algorithm is the control points of the laneway side surface are computed by loading the section on the node and mid-vertex of the centerline. After that, the control points are connected and the regularly triangulated surface is shaped. We take the round arch as an example to explain the modeling process.

A round arch is composed of vertical wall  $h$ , width  $s$  and round roof  $r$ , shown as Figure 4. Granted that the coordinate of node  $O$  of the centerline, we can calculate coordinates of  $A, B, C, D$  according to  $s$  and  $h$ . If we break the round roof into pieces, we can calculate the coordinate of control points  $B_1, B_2, B_3, C_1, C_2$  and  $C_3$ .

During the whole modeling process, the key problem is how to calculate the surface points on a sharp bend, shown as Figure.3. Section  $A_1A_2$  is loaded at node  $A$ , and section  $A_1'A_2'$  is loaded at node  $P$ . In the same way, section  $B_1B_2$  is loaded at node  $B$ , and section  $B_1'B_2'$  is loaded at node  $P$ .  $A_1'A_2'$  and  $B_1'B_2'$  do not coincide with each other. Therefore, the surface model will be crossed partly and separated partly.

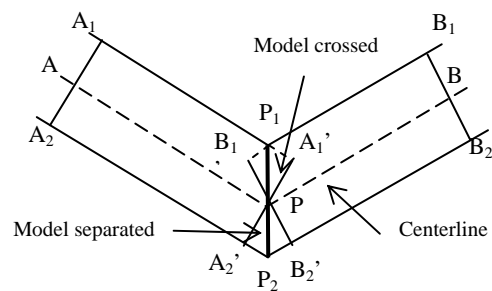


Figure 3. Sketch map of sharp bend on the center line

We give a simple method to solve this problem. As the section  $A_1'A_2'$ ,  $A_1'$  is reduced to be  $P_1$ ,  $A_2'$  is extended to  $P_2$ . In the

same way,  $B_1'$  is reduced to be  $P_1$  and  $B_2'$  is extended to  $P_2$ . So a new coincidental section  $P_1P_2$  is built. The shortage of the method is that the model at the corner is too sharp to accord with reality. We can smooth the corner model by adding smoothing curve points nearby corner.

#### 4.1.3 3D reconstruction of crossing laneway

Compared to the straight laneway, the 3D reconstruction of crossing laneway is more complicated. We present a constrained Delaunay modeling algorithm to solve the problem.

Many 3D reconstruction algorithms try to reduce the data's dimension to make computation easier. For example, 3D data for surface reconstruction will be likely projected on an orthogonal plane ( $XY$ ,  $XZ$ , or  $YZ$ ) and then triangulated as 2D data. According to this idea, we try to change control points on crossing position into  $XY$  plane and create a Delaunay triangular network with constrained boundary, shown as figure. 4. In this figure, LaneA, LaneB, LaneC and LaneD cross with each other in a shadow region. As to the shadow region, we firstly compute the surface control points according to the algorithm of section 4.1.2. Then, a TIN surface of junction is built by projecting 4 laneway's control points on  $XY$  plane. Finally, TIN of LaneA, LaneB, LaneC, LaneD and shadow region are put together into an integrated model.

As far as coal mine are concerned, the configuration of most laneways is limited style. Therefore we can use automatic creation method. This method has advantage of fitting the quick modification of data and getting the right model immediately. The disadvantage is the laneway model is rough, the visual effect is not good, and the texture mapping is uncontrollable.

Aiming to those disadvantages, the third-party modeling software should also be used to build laneway model. Much programs extrude various laneway models manual on the basis of centerline and section on the engineering map. This method has advantages of good visual effect and texture mapping. It can describe virtual scene in very great detail. The disadvantage is that the method cannot update data dynamically and the modeling is laborious and time-consuming.

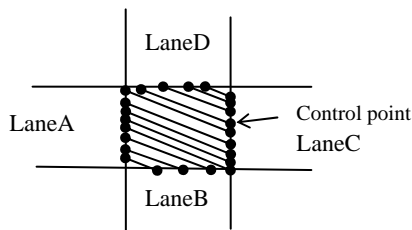


Figure 4. Sketch map of 4 crossing laneway

During the actual work, we take the manual modeling and automatic modeling with careful consideration. As for main laneway, rock laneway and other fixed equipment, 3DMax models can be taken into account to describe a lifelike virtual scene. As for working face models use automatic modeling method. Only in this way can we get a better VR effect and a real dynamic underground environment.

#### 4.2 Collision detection and response algorithm

Underground mining environment is labyrinthic and intertwining. Collision detection must be used to keep the true feeling during walking and interacting in the virtual laneway. Otherwise, the observer will penetrate through the objects and scene and destroy the third dimension to the whole VR program. Granted observer can be simplified as a sphere and the object in the virtual environment as triangular surface, collision detection is a detecting algorithm between a sphere and many triangles. This algorithm is universal and suitable for many cases. The main step to detect whether collision happens is given as follows:

- 1) Calculate the spatial relationship between the sphere and the triangular plane. The relation can be divided into 3 kinds: sphere is in front of triangle plane, sphere is crossing the triangle plane and sphere is in back of triangle plane. If sphere and plane intersect, then continue following step. Otherwise, the collision does not happen.
- 2) Calculate the intersection point between the sphere and the plane.
- 3) Check whether the intersection point is inside of triangle. If the point is inside the triangle, the collision happens. Otherwise continue following step.
- 4) Check whether the intersection point is on the 3 edges of triangle. If it is on the edge, the collision happens. Otherwise, collision does not happen.

If collision between the observer and objects is detected, we must take measure to response collision. Here we ignore the complicated mechanical problems and take a simple method to simulate the collision. The simplest method is to stop the observer's moving when collision happens. Obviously, this method is unsuitable because the observer will stop suddenly during the roaming. We take another method that we change the observer's moving direction from opposite the triangular surface into along the triangular surface. The algorithm is shown as follow.

- 1) According to the normal vector, sphere radius and distance between sphere and plane, we can get the offset along the object surface plane.
- 2) Offset vector add observer's place and moving direction. The observer changes the direction and moves along the surface.
- 3) Continue to detect collision. And if collision happens, repeat the upper 2 steps.

#### 4.3 Industrial system integration

VRLane not only provides an immersive and interactive environment, but also closely integrates with industrial automation system. As far as supervisors, visitors or trainees are concerned, they do not need to go the dangerous underground mining sites. On the contrary, they can investigate underground safety information on a PC or a remote console. It is one of the most attractive features of VRLane.

Industrial automation means integration of mechanics and electrics and facility automation related mining production process, such as coal mining, ventilation, drainage, belts, coal

preparation, exaltation and related self-running equipments, as well as the automation of monitoring and controlling of the ventilation, gas, water disaster, and staff (Tan Dejian, 2006). Put in a simple way, the industrial automation can be categorized into two parts. One part is automation of mining equipments, and another part is automation of monitoring and controlling equipments. Based on the industrial ethernet, all the automatic equipments and monitoring facilities are shown in the scheduling center on a huge screen, and all underground information are transmitted to the database by the net for decision-making.

VRLane can embody the real-time situation underground and implement the monitoring data query. Fig. 5 shows the principle of monitoring data integration.

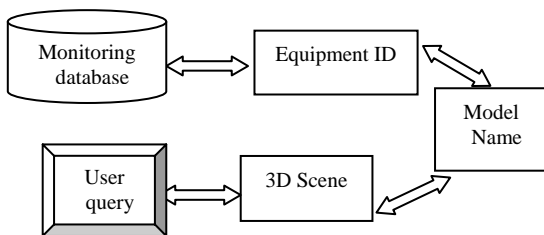
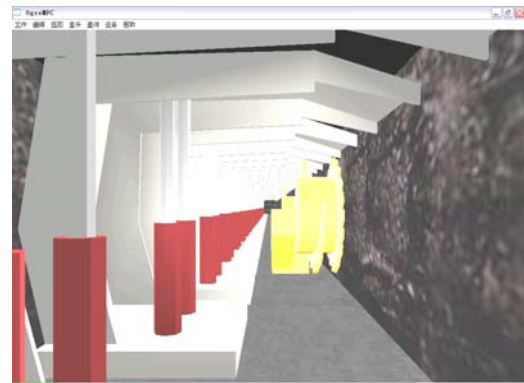


Figure 5. Monitoring data integration

Monitoring data are stored in SQLServer database. The base information of all kinds of ventilation, gas and electromechanical equipments are store in many database tables. Table's structures with the detailed illustration are established according to database analysis and design. Taken gas monitoring data as an example, real-time data from gas sensors are written into database in a specified time interval, which include gas sensor's parameter and related functionary. When user selects the virtual gas sensor in the laneway, the system marches the 3D model name with the right equipment ID and finds the corresponding parameters by its keyword in the database. The search results will return to system interface and give a voice warning.

## 5. SYSTEM APPLICATION

VRLane program has been applied into Dongtan Mine, Yankuang Mining Group, Shandong Province. The main object is to demonstrate the underground mine environment vividly and provide a useful and simple system of safety information management. Fig. 6 shows virtual scene built from a 2D mining engineering map automatically. A high performance computer was used for navigating around the simulation environment, and complicated situation will be displayed on the large projection screen in the mine control center room. The system, with advantages of cheap, dynamic, easy to maintenance, provides a useful tool for safety production management in coal mine.



(a) Simulation of coal shearer and hydraulic support



(b) A virtual scene of the mine and mine cars

Figure 6. A virtual scene of underground laneway.

## 6. CONCLUSIONS

VRLane, a virtual VR program for mine safety management, explored a new solution to apply the visualization technologies into practice mining. To sum it up, VRLane has five unique features as follows:

- 1) VRLane provides the mixed modeling method. It can automatically build and update various underground 3D models such as strata, laneways and equipments. Also, it can import the 3DMax and other format's model.
- 2) VRLane blends the functions of 2D GIS and 3D visualization closely. Due to restriction of mine design and mine engineering, most of mining drawings are finished by AutoCAD or 2D GIS. We present a 2D & 3D integrated GIS platform to extend the application field of VR technologies.
- 3) VRLane can describe the ground and underground environment realistically and thoroughly. It can get the real-time monitoring information from virtual environment. It is a good tool for supervisor to control the various underground monitoring data.

**REFERENCES**

Tan Dejian, Xu Xikang, Zhang Shen, 2006. Comments on automation, information and digitalized mine. *Coal Science and Technology*, 34(1), pp.23-27(in Chinese).

Wu Lixin, Zhu Xiwang, Zhang Ruixin, 2004. Digital mine and the future development of mines in China. *Science & Technology Review*, (7), pp. 29-31(in Chinese).

Wang Bing-jian, Zhou Xin-quan, Wang Hai-yan, Zhang Ya-wei, 2007. Development and Application of Accident Simulation Virtual Reality System for Coal Mine. *Mining and metallurgical engineering*, 27(2), pp. 14-17 (in Chinese).