

## Research Article

# Construction of Underground 3D Visualization Model of Mining Engineering Based on Shear-Warp Volume Computer Rendering Technology

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In view of the complexity of mine geology, complex mountain structure, and strong concealment characteristics, the construction of 3D visual model of mining engineering is of great significance for mine mining design, production, and residual ore remining. Based on the comprehensive analysis of the development results of the existing 3D visualization software of ore body at home and abroad and the actual needs of domestic mines, this paper determines the key technologies and solutions to be studied. Focusing on the overall goal of real ore body visualization, relying on geology, mining, computer graphics CAD technology, and computer software engineering develops a set of 3D visual modeling general components for 3D simulation software developers to realize the 3D visual operation platform of ore body with independent intellectual property rights. By introducing the Shear-Warp volume computer rendering technology into the underground 3D visualization analysis process of mining engineering, a three-layer visualization platform structure based on hierarchical model is designed from the perspective of software engineering, which effectively strengthens the low coupling of data and high cohesion of function of the system. The example analysis results show that this method can accurately simulate the 3D structure and distribution of the actual ore body and make basic preparations for reserve estimation, mining design, mining development, and prospecting prediction. At the same time, the general component of 3D visual modeling provided by the system is ready for the interface of 3D simulation involved in mining software development.

## 1. Introduction

According to the large amount of data information of mining engineering and related data unified in the 3D coordinate system, the modeling of mine plan design, production management, and major event decision-making is completed. Taking into account the actual needs of the advanced Internet technology used in current mining, resources can be developed reasonably and meet the needs of safe production in mines [1]. The underground mining model of 3D underground mining engineering can truly simulate the actual operation situation and provide maximum service for the mining engineering. The 3D visualization technology is used, to construct the underground mining roadways, mining areas, ore bodies, and 3D mine models technology. The developed underground 3D

visualization technology of mining engineering is used to construct the underground mining roadway, mining area, ore body, and 3D mine models, which can truly show the relationship between the mine roadways, the relationship between the mine mountain body and the roadway, attributes and characteristics of the mine body and the mine from other angles, arbitrary positions, and proportions, which have gradually attracted the attention of many mining engineering scholars [2]. At present, the Chinese visual analysis system for mine tunnels is usually based on third-party software. The constructed analysis system can complete the effective design of the mining plan, but the simulation results of the 3D visualization model between the mine tunnel and the ore body are not very good; it is impossible to truly give feedback about the close relationship between the real-world situation of the mine and the

roadway. Meanwhile, because the user cannot obtain the source code, the system cannot analyze the complicated and diversified rock distribution of the mine roadway. It is also affected by software tools in the actual application environment; it is of great significance for the study of 3D visualization technology in mining engineering.

For a long time, mining and geological personnel hope to intuitively and accurately delineate the ore body boundary, understand the 3D shape of geological structure, accurately interpret the underground geological body, and realize the 3D visualization of the deposit, so as to carry out accurate reserve estimation and reasonable deposit mining design and guide mining development and deep prospecting prediction. An excellent 3D CAD mining modeling software has become the focus and difficult problem of people's attention. Fortunately, as computer graphics, artificial intelligence (AI), network communication, and other essential technologies continue to progress, it is possible to make 3D intelligent design, physical property analysis, and dynamic simulation of ore deposit. In recent years, the concept of "digital mine" has been deeply rooted in the hearts of the people. How to use information technology to transform conventional mine production has become a key problem for mine researchers. Because the mine itself is a true 3D geographical environment, all mine production activities are carried out in this true 3D environment. Hence, excellent mine information construction (such as mine monitoring and scheduling, production process control, and production planning) is inseparable from the simulation of 3D environment. Since the 1970s, computer graphics, AI, communication technology, and simulation technology have been further developed, and some new simulation theories have emerged one after another, such as UG simulation theory, image simulation theory, and virtual reality (VR) theory. On the basis of these theories, many excellent 3D modeling software programs have been produced, such as 3DMAX, AutoCAD, and photo3d. These software programs provide relatively convenient 3D modeling function and have been applied in mine geological modeling.

However, due to the randomness and imbalance of geological phenomena, as well as the 3D problems in geological modeling (such as 3D simulation of 3D strata, ore and rock mass, faults and roadways, automatic generation of profiles, analysis of spatial topological relations, volume computing of ore body, estimation of grade and reserves, etc.), the above software cannot conveniently carry out geological 3D visual modeling. In view of the above geological modeling problems, a large number of research studies on 3D visual modeling technology of ore deposits have been carried out at home and abroad. Foreign countries started earlier and launched a series of 3D mining modeling software. After years of improvement, these platforms have good system stability and have been widely used in China's mineral generation design, but there is a certain gap with China's actual demand. Its mine management concept, resource exploration, mining technology, and technical standards are different from those in China. Coupled with many factors such as localization, price, and service, its popularization and application in China has great

limitations. In addition, it is not a long-term plan to completely rely on foreign software.

A 3D visualization analysis method of mining process is proposed based on Shear-Warp computer rendering technology in this paper. This method mainly combines the accurate location of the mining project space with the physical properties of the mine rock, to provide the mining project with detailed 3D real data information, which can vividly display the spatial relationship between the mining projects and make the mining project design more reasonable.

## 2. Technology and Related Theories

*2.1. Shear-Warp Volume Computer Rendering Technology.* A combination of interactive graphics and image processing is used mainly by 3D visualization. It mainly obtains the data information required by users from the database, completes the representation, operation, and drawing of 3D visualization, and can mainly provide the data display for underground 3D visualization, reflecting the complex internal structure and constantly changing characteristics [3, 4]. The current underground 3D visualization method of mining engineering mainly adopts two methods. One is the screen space ray projection method, which projects the underground image of the mining engineering to any pixel on the screen. It starts from the visual point of view and calculates the method of interaction between the light and the 3D visualization database according to the emitted light, to obtain the color of the pixels corresponding to the accumulated sample samples. The second is a database-based unit projection method, by which each unit in the database is projected onto the screen in a certain order and meanwhile correspond to the range of pixels on the screen according to each unit.

The memory computing-based Shear-Warp volume computer rendering technology is basically characterized by minimizing the I/O operations on the hard disk and analyzing the relevant data on operations in the memory. The median values obtained are stored in memory by Hadoop's MapReduce computing engine, and the previous I/O request is stored externally in the subsequent computing. As median values are directly stored and replicated by Shear-Warp volume computer rendering technology in the memory, it can shorten the data transmission time compared with the previous MapReduce as a whole, thereby ensuring the work efficiency of the task. Figure 1 is a structural diagram of the Shear-Warp volume computer rendering technology.

The core module of the Shear-Warp volume computer rendering technology is to formulate the mission plan through the directed acyclic graph. In turn, the Shear-Warp volume computer rendering technology can have better flexibility in processing tasks. Stream processing mode, graph computing frame can be implemented; machine learning library (Mllib) can be implemented in order to provide Shark of distributed SQL query.

Berlious equation is used to assess the performance of classification by each classifier, described as follows:

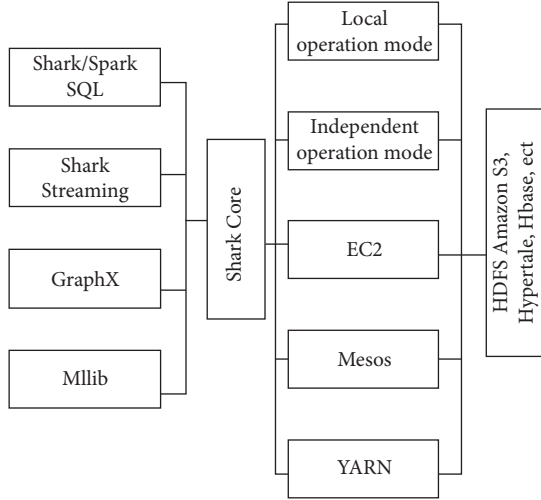


FIGURE 1: Shear-warp volume computer rendering structure.

$$\text{weight}(i) = 1 - \frac{1/\text{con}(i)}{\sum_{j=1}^T 1/\text{con}(j)} - \frac{N-2}{N}, \quad (1)$$

where  $N$  is classifier count,  $\text{con}(k)$  is the posterior probability of classification results by classifier  $k$  using the Shear-Warp volume computer rendering technique, and  $\text{weight}(i)$  is the weight of classifier  $k$ .

The equation has two features:

- (1) Higher accuracy of classification indicates a higher weight of decision tree
- (2) Equation  $\sum_{j=1}^T \text{weight}(i) = 1$  holds; i.e., all decision trees comply with the normalization condition

The out-of-bag data can be used to analyze Shear-Warp volume computer rendering. The results indicate that  $F1$  is smaller than that obtained by Bayes equation based on verification probability calculated. Hence, the posterior probability of classification results is discarded, and out-of-bag  $F1$  is used to determine the accuracy of classification. Equation (1) is modified to obtain

$$\text{weight}(i) = \frac{2}{N} - \frac{1/\text{oob}F_1}{\sum_{j=1}^T 1/\text{oob}F_1(j)}, \quad (2)$$

where  $N$  is classifier count,  $\text{oob}F_1(k)$  is out-of-bag  $F1$  of classifier  $k$ , and  $\text{weight}(i)$  is the weight of classifier  $i$ .

In general, industrial connections among firms are in a vertical chain, in which upstream and downstream firms are effectively connected by manufacturing links; their cooperative/competitive relationship is deemed as their center. It is assumed that the SDA method is used to process set  $X$  with  $n$  samples.

$$X = \{x_1, x_2, \dots, x_n\}. \quad (3)$$

With  $p$  index, fuzzy clustering is conducted by category:

$$x_k = \{x_{k1}, x_{k2}, \dots, x_{kp}\}, x_{kj} = [a_{kj}, b_{kj}], 1 \leq k \leq n, 1 \leq j \leq p. \quad (4)$$

$U$  is used to indicate the relative matrix membership in the model:

$$U = \{u_{ik}\}, (i = 1, 2, \dots, c; k = 1, 2, \dots, n). \quad (5)$$

$u_{ik}$  is the membership of  $k$  sample in  $i$  category, which complies with

$$\begin{cases} \sum_{i=1}^c u_{ik} = 1, \forall k, 0 \leq u_{ik} \leq 1, \forall k, i. \end{cases} \quad (6)$$

$g_i$  indicates the center of category  $i$  in the analysis:

$$g_i = (g_{i1}, g_{i2}, \dots, g_{ip}), g_{ij} = [\alpha_{ij}, \beta_{ij}], 1 \leq i \leq c, 1 \leq j \leq p, \quad (7)$$

where adaptive parameter  $\lambda$  is introduced to indicate the cluster weight:

$$\lambda_k^m = (\lambda_{k1}^m, \lambda_{k2}^m, \dots, \lambda_{kp}^m). \quad (8)$$

The expression of the comprehensive weight is

$$\begin{aligned} W &= \sum_{i=1}^c \sum_{k=1}^n (u_{ik})^2 \Phi(x_k, g_i) \\ &= \sum_{i=1}^c \sum_{k=1}^n (u_{ik})^2 \sum_{j=1}^p \left[ \lambda_k^m \left( \frac{a_{kj} + b_{kj}}{2} - \frac{\alpha_{kj} + \beta_{kj}}{2} \right)^2 \right]. \end{aligned} \quad (9)$$

This satisfies

$$\begin{cases} \lambda_{ij}^m \geq 0, \\ \prod_{j=1}^p \lambda_{ij}^m = 1. \end{cases} \quad (10)$$

Using the Lagrangian method to derive the aggregate function, we can get

$$\begin{aligned} \alpha_{ij} &= \frac{\sum_{k=1}^n (u_{ik})^2 a_{kj}}{\sum_{k=1}^n (u_{ik})^2}, \beta_{ij} = \frac{\sum_{k=1}^n (u_{ik})^2 b_{kj}}{\sum_{k=1}^n (u_{ik})^2}, \\ \lambda_{ij}^m &= \frac{\prod_{h=1}^p \left[ \sum_{k=1}^n (u_{ik})^2 \left( (a_{kh} + b_{kh}/2) - (\alpha_{ih} + \beta_{ih}/2) \right)^2 \right]^{1/p}}{\sum_{k=1}^n (u_{ik})^2 \left( (a_{kj} + b_{kj}/2) - (\alpha_{ij} + \beta_{ij}/2) \right)^2}, \\ u_{ik} &= \left[ \frac{\sum_{j=1}^p \left[ \lambda_{ij}^m \left( (a_{kh} + b_{kh}/2) - (\alpha_{ih} + \beta_{ih}/2) \right)^2 \right]}{\sum_{h=1}^p \left[ \lambda_{hj}^m \left( (a_{kh} + b_{kh}/2) + (\alpha_{ih} + \beta_{ih}/2) \right)^2 \right]} \right]. \end{aligned} \quad (11)$$

The firm set effect is generally subject to natural resources, geographical environment, process technology, and other factors. The preliminary combination mainly shows the partnership among various firms in manufacturing and operation. In essence, the geographical combination of firms allow matching of their internal resources with the clustered firms based on the competitive relationship and cooperative relationship, so as to reduce trade costs and maximize profits as much as possible.

Shear-Warp volume computer rendering technology can build the most serialized time series model and use it in

large-scale underground 3D visualization analysis process of mining engineering. The  $N$  states that exist in the model can be set as  $S = \{S_1, S_2, \dots, S_n\}$ ; then  $q_t$  is the state at  $t$  time;  $A = \{a_{ij}\}$  is the transition matrix between various states; the following expressions can be obtained:

$$\alpha_{ij}(k) = P[q_{t+1} = S_j | q_t = S_i], 1 \leq i, j \leq N. \quad (12)$$

In certain RFAMs, any state can access others in one transition, while in other RFAMs, only transitions between some states are allowed; i.e.,  $a_{ij} > 0$  for  $j$  in some  $i$  only.

The difference between RFAM and Shear-Warp volume computer rendering technology chain lies in the fact that only one external value is observed per state, with the observation vector correlated with the system state in a discrete or continuous distribution.

$$b_j(v_t) = \sum_{m=1}^M \omega_{j,m} N(o_t, \mu_{j,m}, \Sigma_{j,m}), \quad (13)$$

where  $M$  is mixture Gaussian distribution count,  $\omega_m$  is the weight of positive mixture, and  $N(o_t, \mu_{j,m}, \Sigma_{j,m})$  indicates Gaussian distribution with  $n$  dimensions.

### 3. 3D Visualization Analysis of Underground Mining Engineering

*3.1. Parallel Optimization Strategy for 3D Visualization Analysis of Mining Engineering.* As the data acquired and the node feature division are random, no connection will be established between numbers determined. At the same time, the 3D visualization analysis of mining engineering can be used to make it characterized by initial parallelism. The 3D visualization analysis method can be used to effectively give feedback about the mining engineering visualization, node visualization, and feature selection.

The 3D visualization analysis method of mining engineering is used to visualize the mining engineering data, which allows data computing of samples accordingly. I/O operations can be stored through dispersing many computer nodes to reduce the bandwidth occupation of the network as compared to conventional identification methods with single machine. 3D visualization analysis of mining engineering is performed on data from parallel computing, combined with the frame characteristics of the Shear-Warp volume computer rendering technology, to design an analysis model of mining engineering 3D visualization in this paper.

*3.1.1. Identifying Characteristic Sampling Cut-Off Point for Statistics.* The optimal mining project feature is identified as required, and cut-off points are selected accordingly. Based on the features of data distribution, sampling and analysis are conducted on various features of the data and summarized at the master node in the end. It is operated mainly to perform computing at various nodes. However, at the final integration phase, just a relatively low bandwidth is required. Thus, relatively high bandwidth and I/O operation

for the value of overall data feature should be avoided if possible during data consolidation as the data acquisition method can directly influence its accuracy [5, 6].

*3.1.2. Training Samples by Layer.* According to the single sample mode, the deep optimization based on mining engineering converted to priority strategy is the training focus. For the purpose of training each layer in a distributed environment, various cycles of the same number should be established at the maximum tree level. Moreover, parameter statistics is performed in the cycle phase on the segmentation points of nonleaf nodes, to judge the segmentation points according to the characteristics.

In the past, the 3D visualization analysis algorithm of mining engineering was mainly learned by using multiple base classifiers mining engineering, based on the integrated model of prediction samples [7]. The corresponding working steps are as follows:

- (1) Through the existence of samples returned to the original data set,  $n$  samples are selected to form a new training subset.
- (2) In the sub-data set generated in step 1, all features are sampled, and  $m$  features of the decision tree are selected as separation nodes; the decision tree does not undergo a paper-cutting process.
- (3) Repeat steps 1 and 2 until a set with  $s$  decision trees is obtained.
- (4) Transfer the obtained data samples to step 3 to extract the decision tree for predictive analysis, record in detail the prediction categories of different decision trees, and merge them simultaneously. The final total number is the best method by selecting the model.

During the sample training, the parameter that can realize the classification of the mining engineering 3D visualization analysis method is most affected is the number of features that are not generated in the feature parameters. Hence, the value of  $k$  is the most important in the visual analysis and training process of mining engineering, so the value of  $k$  needs to be less than the total number of feature values. In the application of the 3D visualization analysis method of mining engineering, the method of combining the verification set and the cross-validation method is usually used to calculate the value of  $k$  before the sample data training.

The 3D visualization analysis algorithm has more excellent results from data mining; on the other hand, it may reduce the accuracy in data training. For the purpose of addressing this issue, category 1 is determined by data mining as the final results. However, it still cannot fundamentally solve the tie situation that the average value cannot solve. This can effectively avoid the defects in the model. Aiming at the problems caused by the conventional 3D visualization analysis method of mining engineering, the following improvement measures are proposed in this paper [8]. The basic idea is as follows:



- (1) Before visualization processing, weight is given to the decision tree according to the classification performance of the decision tree
- (2) If the classification result of the mining project is obtained, the weight of the mining project will be multiplied by the classification result
- (3) Perform statistics on all weighted results, sort them in descending order, and finally determine the highest category as the classification result

**3.2. Shear-Warp Training.** According to the mining engineering 3D visualization analysis algorithm, there is great relationship between the results obtained and the preliminary parameters. After iteration, whether the transition matrix is 0 is determined by initialization, and the observation sequence is defined as  $O = o_1 o_2 \cdots o_T$ :

$$P(O|\lambda) \geq P(O|\lambda). \quad (14)$$

The forward-backward algorithm is used to calculate  $P(O|\lambda)$ . For parameters  $\lambda$  in  $i$  state of Shear-Warp technology, forward probability  $\alpha_t(i)$  is defined as

$$\alpha_t(i) = P(o_1 o_2 \cdots o_T, q_t = i | \lambda), \quad (15)$$

where  $\alpha_t(i)$  is the probability of A parameter generating  $(o_1 o_2 \cdots o_t)$  sequence in  $o_t$  state at  $t$  time.

The following forward algorithm can be used to calculate  $P(O|\lambda)$ :

- (1) Initialization:

$$\alpha_1(j) = b_j(o_1), \quad 1 \leq j \leq N. \quad (16)$$

- (2) Recursion:

$$\alpha_t(i) = b_i(o_t) \left[ \sum_{j=1}^N \alpha_{t-1}(j) \alpha_{ji} \right], \quad 2 \leq t \leq T, q \leq i \leq N. \quad (17)$$

- (3) Termination:

$$P(O|\lambda) = \sum_{j=1}^N \alpha_T(j). \quad (18)$$

Simultaneously, define  $\beta_t(i)$  and  $\xi_t(i, j)$  as

$$\begin{aligned} \beta_t(i) &= P(o_{t+1} o_{t+2} \cdots o_T, |q_t = i, \lambda), \\ \xi_t(i, j) &= P(q_t = i, q_{t+1} = j | O, \lambda), \end{aligned} \quad (19)$$

where  $\xi_t(i, j)$  in forward-backward computing is

$$\begin{aligned} \xi_t(i, j) &= \frac{P(q_t = i, q_{t+1} = j | O, \lambda)}{P(O|\lambda)} \\ &= \frac{\alpha_t(i) \alpha_{ij} b_j(o_{t+1}) \beta_{t+1}(j)}{P(O|\lambda)} \\ &= \frac{\alpha_t(i) \alpha_{ij} b_j(o_{t+1}) \beta_{t+1}(j)}{\sum_{i=1}^N \sum_{j=1}^N \alpha_t(i) \alpha_{ij} b_j(o_{t+1}) \beta_{t+1}(j)}. \end{aligned} \quad (20)$$

Probability  $\gamma_t(i, m)$  of mixed component  $m$  of the system in  $i$  state at  $t$  time can be obtained:

$$\gamma_t(i, m) = \frac{\left[ \frac{\alpha_t(i) \beta_t(i)}{\sum_{i=1}^N \alpha_t(i) \beta_t(i)} \right] \left[ \frac{\mu_{j,m} N(o_t, \mu_{j,m}, \Sigma_j, m)}{\sum_{m=1}^M \omega_{j,m} N(o_t, \mu_{j,m}, \Sigma_j, m)} \right]}{\quad} \quad (21)$$

**3.3. Shear-Warp Is Used for 3D Visualization Analysis.** First, different types of Shear-Warp are trained using the training set labeled. Set the type that needs 3D visualization analysis as  $k = \{1, 2, \dots, K\}$ , with  $\lambda_k$  as the model parameter for each type. Posterior probability is maximized based on maximum likelihood criteria with Bayes Warps considered as follows:

$$\bar{k} = \operatorname{argmax}_{1 \leq k \leq K} P(\lambda_k | O) = \operatorname{argmax}_{1 \leq k \leq K} \frac{P(O|\lambda_k) P(\lambda_k)}{P(O)}. \quad (22)$$

Let prior probability  $P(\lambda_k)$  per type be consistent. Since  $P(O)$  is irrelevant to  $k$ , the decision can be ignored:

$$\bar{k} = \operatorname{argmax}_{1 \leq k \leq K} P(O|\lambda_k). \quad (23)$$

Due to the minimal value of  $P(O|\lambda_k)$ , there may be underflow of floating points (often logarithmic) in computer operation. In case of several observation sequences, each formula is weighed.

**3.4. Visualization of Underground 3D Training in Mining Engineering.** Based on the characteristics of the Shear-Warp volume computer rendering technology computing engine and the conventional visualization process, the visualization training of the 3D visualization analysis algorithm is divided into four main steps combined with the improved point analysis of the 3D visualization analysis algorithm in this paper [9]:

- (1) Obtain the characteristics of the samples distributed on the nodes through random sampling, and carry out the characteristic subcontainer operation
- (2) Use the RDD of each mining project to construct a visual random forest based on feature subspace and bagging sampling
- (3) Obtain the F1 value of each decision tree by predicting the out-off-bagging data
- (4) Combine the deterministic trees generated in step 3 to synthesize an underground 3D model of complete parallel mining engineering

In the current mining engineering space identification industry, it is crucial to timely respond to and meet the various demands of each firm. The mining engineering includes two main aspects: development and design [10]. With comprehensive analysis on market demand variation, the emerging mining engineering development process and design cycle are analyzed to provide personalized services for

firms; meanwhile, customized design of mining projects is conducted based on the practical demand of firms. Although their goals differ from primary tasks, they are connected inherently. Modularization and standardized design are carried out during space identification of mining engineering to lay a foundation for the process, where non-segmented segments are converted to a VR model [11]. Additionally, the relevant expertise and corporate design should be included to develop new mining projects based on their demand.

The real-world scene developed based on VR is “enhanced” by Shear-Warp volume computer rendering technology through superimposing virtual objects, scenes, or system prompts generated by computer. Virtual objects can be introduced to the real-world environment by Shear-Warp volume computer rendering; moreover, the position and posture of the virtual objects are provided dynamically to ensure virtual consistency between them and cultivate the observation habit for more customized design and more natural interactions based on Shear-Warp computer rendering [12, 13]. Moreover, the real-world scene kept in Shear-Warp volume computer rendering makes the output more realistic. It allows the capture of real-world situation by camera via video streams, in which each frame is processed by tracking to calculate the real-world coordinates and states by geometric computing and register the coordinates and states of virtual objects in a real-world context to establish a virtual scene. The system allows zoom-in/out by proportion based on the design drawing of mining projects. When the exterior wall of the mining project was realized, the solution was to stick lines of consistent specifications. The overall line of the mining project can be used to solve the problem of scale according to the length/width of a line [14]. After the coordinate system and scale are established, geometric objects in the virtual mining project indicate each line of the mining project composed of a series of computing.

*3.5. Realization of the 3D Visualization Model of Mining Engineering.* Through mining production, the metal ore is transported from the working face to the ground and transported to the channels for ventilation, drainage, and safe transportation of workers. For the entire mine, visualization is its core part. During the modeling process, first import the mid-section engineering plane grid diagram into the MapsGis software for coordinate correction, and after conforming to the actual geographic coordinates, the visualized floor line is vectorized and saved in the form of DXI. Figure 2 shows the modeling method and flow of the mining process.

The following points should be paid attention to when vectorizing the plan view of the middle section of the project:

- (1) Connect and close the coil area in a multistage manner, which cannot be connected with an arc wire.
- (2) Each line segment is inseparable in the vectorization process, in this case; connect the line segments; repair function.

- (3) No duplicate points appear on the closed line. After the vectorization is completed, the line error topology check is performed to delete the duplicate points.
- (4) You must unify the special set of vectorized lines in the same layer. Otherwise, an error will occur after importing the DATMNE software.

In DAIAMNE software, there are several ways to model roadways:

- (1) A method of drawing a single section on the center line of the alley floor is adopted. Using this method, first determine the shape (such as circle, square, arch, etc.) and size of the cross section, and then generate a visualization solid model along the center line of the visualization base (Figure 3).
- (2) The method of drawing multiple sections on the center line of the alley floor: Specify the set section as the desired centerline position, specify different sections in the same centerline, and finally generate a visual solid model between the sections (Figure 4).
- (3) By vectorizing the top or bottom plate of the single-contour road, a single contour of the ceiling or bottom plate is obtained, and a value is assigned to the contour line according to the visualization height to generate a visual entity model [15].
- (4) Obtain the contour lines of the desktop and the bottom plate from the ground measurement data of the 2-contour road, and generate the engineering visualization solid model between the top line file and the bottom line file. Although this method requires a large amount of work in the early stage of data acquisition and data processing, the modeling accuracy is very high (as shown in Figure 5).

According to the existing ore production materials, the single-contour method and the method of adding a single section online on the visualization floor are adopted in order to construct the visualization model of the mine. The engineering drawing in the copper mine was vectorized using MapsGis software. After format conversion, it was imported into the mine digital software DATAMINE for 3D coordinate conversion and correction, and then the above-mentioned two line-frame modeling methods were used to construct a visual entity model. Figure 6 is the puzzle of the ore surface model and the three middle-section road physical models of  $-380$  meters,  $-260$  meters, and  $-140$  meters. Figure 7 is the five middle-section road physical models ( $-380$  meters,  $320$  meters,  $-260$  meters,  $-140$  meters, and  $-100$  meters).

The modeling of the goal is of great significance to the recovery project of the mining area. Hence, the modeling effect of the goaf directly affects the economic evaluation results of the residual mine. With the continuous development of Shear-Warp computer technique and advancement of technical levels, many Shear-Warp-based mining projects start to emerge. As one of the commonly used visualization analysis methods, underground 3D

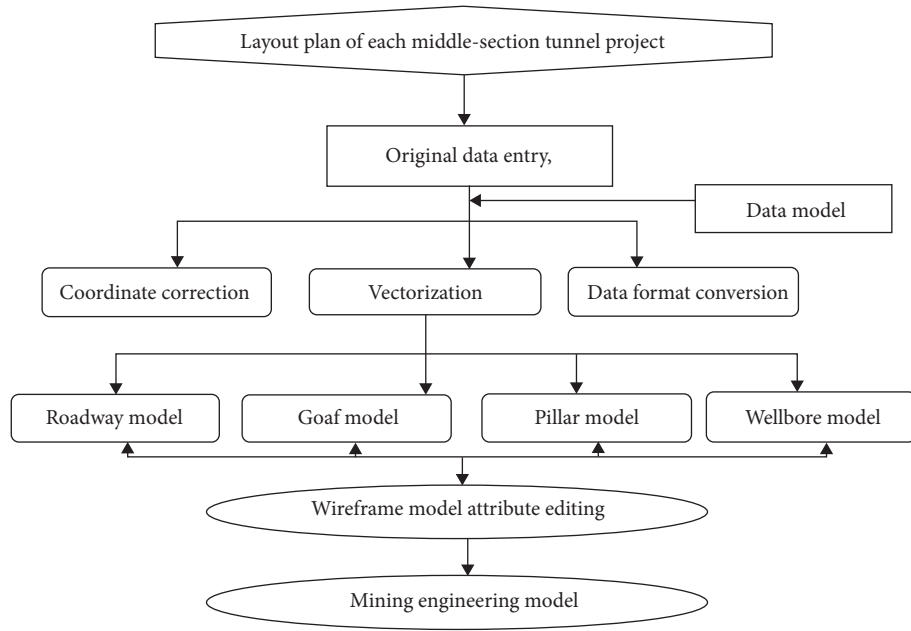


FIGURE 2: Mining engineering modeling method and process.

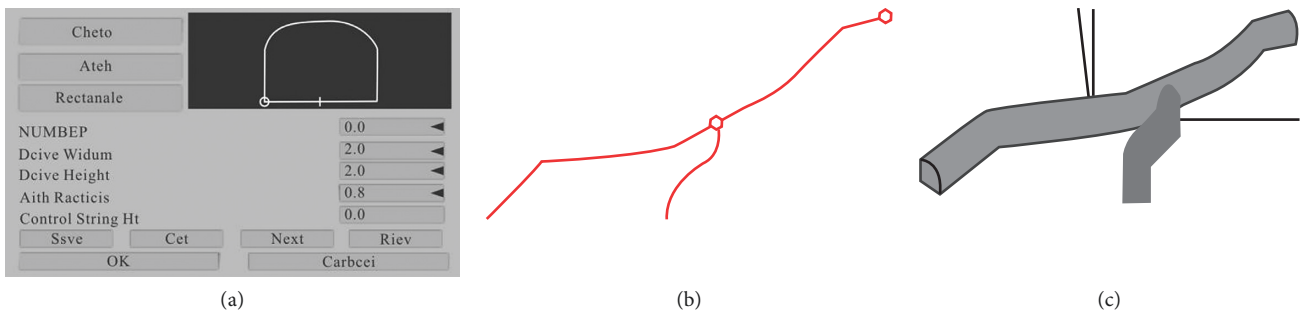


FIGURE 3: Roadway model construction by adding a single section to the center line of the floor. (a) Section specification setting. (b) Center line of roadway floor. (c) Entity model of roadway.

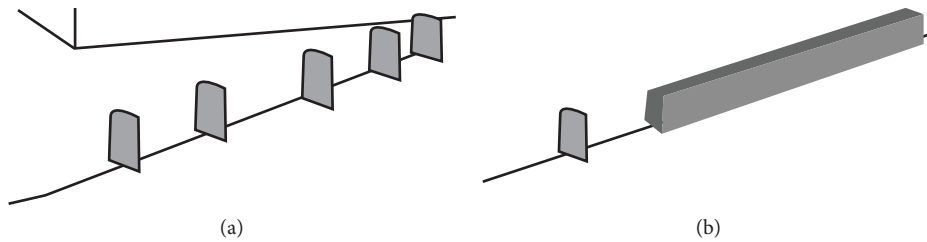


FIGURE 4: The method of adding multiple sections to the center line of the floor to build a roadway model. (a) Position of the section on the centerline. (b) Roadway entities are generated between sections.

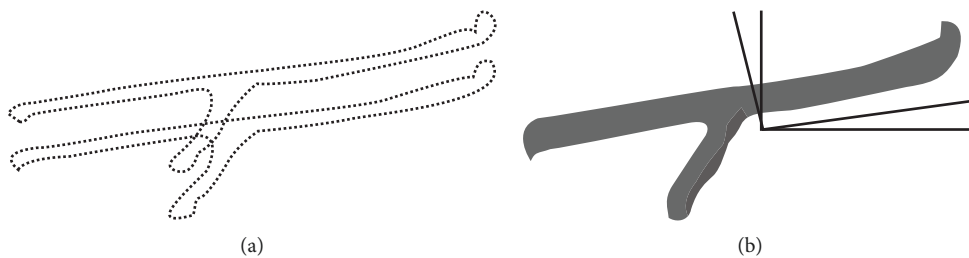


FIGURE 5: Roadway model built by double contour method. (a) Measured contour line of top and bottom plate. (b) The roadway entity generated by the connection between the roof and the floor.

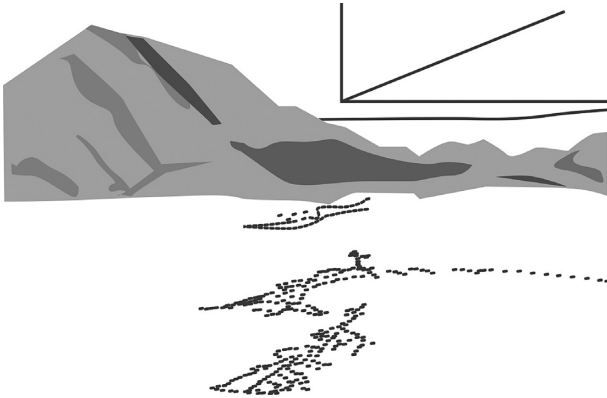


FIGURE 6: Partial roadway model and surface model.

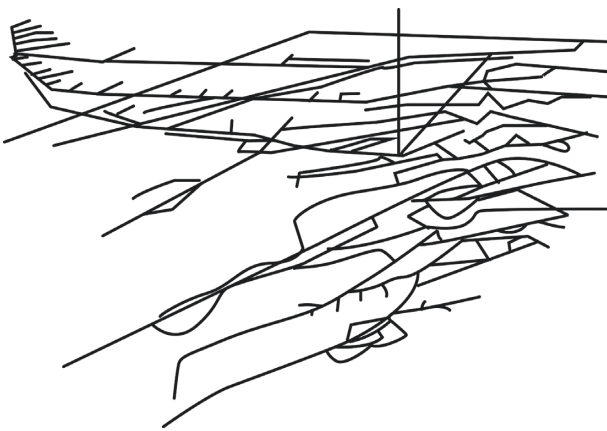


FIGURE 7: Five middle-section roadway models.

visualization analysis of mining engineering has become a focus of researchers in the country. However, it is a tremendous challenge to trace the source of raw data in mining engineering where the content is not clearly defined in underground 3D visualization analysis of the mining process, because the mining engineering is a time-sequencing method by which the Shear-Warp volume computer rendering with excellent visibility is applicable. The other classification methods are simple, with inaccurate characteristics of mining engineering. In this paper, the Shear-Warp volume computer rendering technology is applied to the underground 3D visualization analysis process of the mining process. This method can be applied to the underground 3D visualization analysis process of the mining engineering as the current prior knowledge of the mining engineering according to the spatial characteristics of the mining engineering. For the purpose of obtaining the mining engineering content, the weight of underground space is analyzed by Shear-Warp volume computer rendering. The information on the significance of mining engineering and space with high similarity are combined to establish a 3D visual analysis model of the mining engineering, respectively. By constructing a random forest spectral model system, model visualization greatly improves efficiency and timeliness. Figure 8 is an automatically generated cavitation area model. Figure 9 is a cavitation area

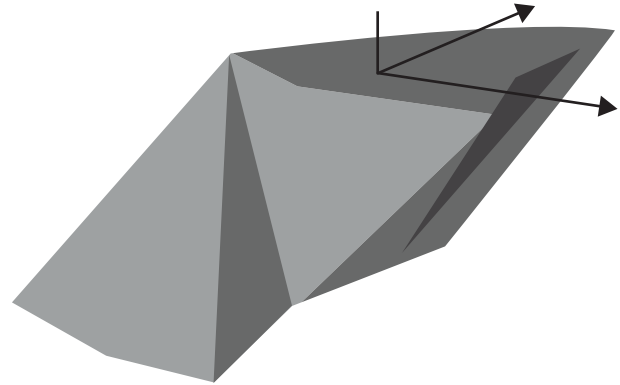


FIGURE 8: The goaf model automatically generated.

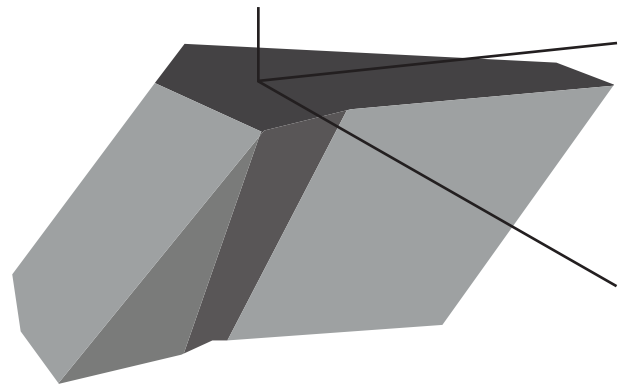


FIGURE 9: Blank area model generated using control lines.

model generated using control lines. But in comparison, the model in Figure 9 can reflect the real-world situation.

The Shear-Warp volume computer rendering technology is used to conduct 3D visualization analysis of mining engineering, and the optimal parameter for the proposed model is obtained to improve the efficiency of 3D visualization analysis. By introducing Shear-Warp volume computer rendering technology into the independent 3D visualization analysis of mining engineering, accurate and fast 3D visualization analysis can be realized. Meanwhile, combined with the rhythm characteristics of mining engineering, the accuracy rate of underground 3D visualization of the mining process of the Shear-Warp model can be enhanced. In order to solve this problem, parallel Boolean operations and subtraction are required. Here, the obtained pillar model is used as the actual model, and the Boolean cross computing of the pillar solid model and the goaf solid model is used. Figure 10 is a group diagram of ore pillars and goaf without Boolean crossover operation. One of the pillars is located in the goaf and the ore pillar in Figure 11 is obtained through Boolean crossover computing.

In underground mining projects, the shaft is an important channel connecting the surface and the work area, such as main wells, auxiliary wells, storage wells, air wells, etc. Compared with the above modeling, the modeling of the well is relatively simple and the coordinates are relatively single. If the 3D coordinates and cross-sectional shape of the bottom of the well are determined, a solid model can be



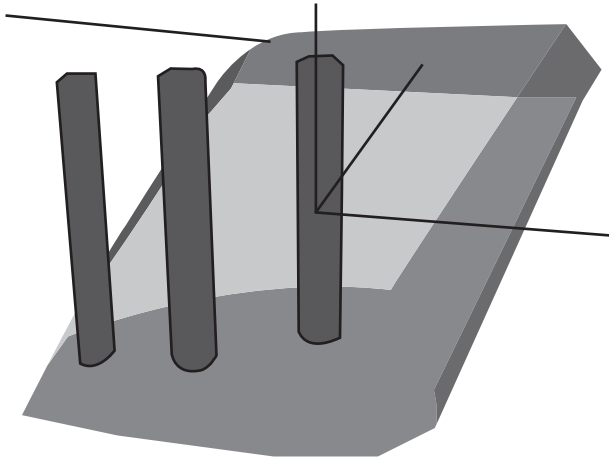


FIGURE 10: Pillars and goaf (transparent display).

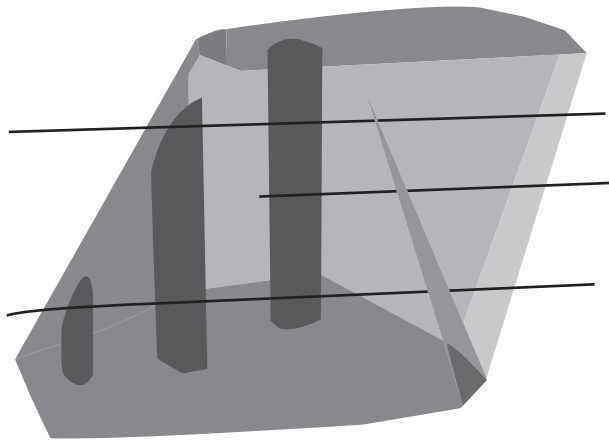


FIGURE 11: The pillars and empty area after Boolean cross operation (transparent display).

quickly constructed. For ore, the comparative rules of cross section size and shape are the method used for well type modeling. Draw the centerline and individual sections of the well to generate a solid model of the well. The well is not an ideal straight tube, but is somewhat curving. The center line of the well is determined according to the coordinate value of the intersection of the well and the plane of each middle section. Figure 12 shows the signals of the well model and part of the visualization model.

In this research, physical modeling and numerical simulation results of Shandong gold ore are combined on the VR platform of VRP. The external whole is shown in Figure 13. The surface, ore bodies, faults, shafts, inclined roads, and main visualization projects have been modeled by 3DMine software and introduced a VR system.

The construction of the VR system is helpful to formulate the overall recovery plan of the ore, and it can also guide the construction of the regional numerical computing model and finally integrate the numerical computing results into the VR system for comprehensive display.

The rock mass structural planes obtained from the on-site scanning planes are grouped and displayed in different colors according to the progress and trends, which promotes

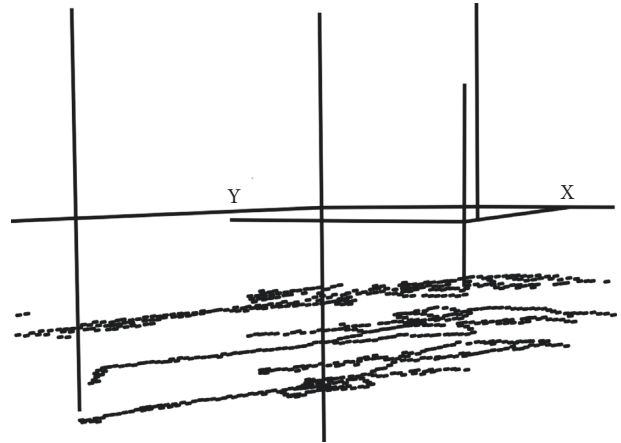


FIGURE 12: Shaft model and partial roadway model.

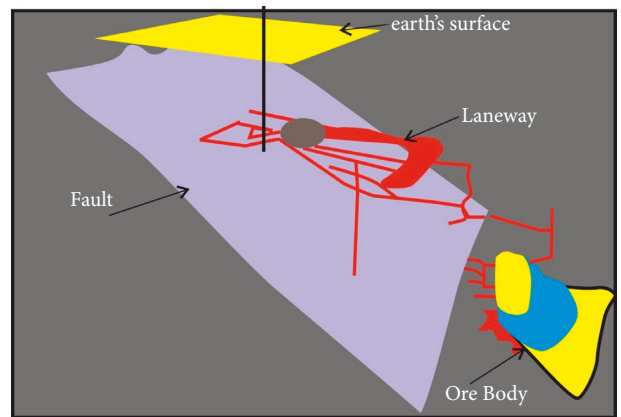


FIGURE 13: The overall effect of the ore VR system.

observation and statistics. The scanned joint surface is integrated into the VRP editor, as shown in Figure 14, to realize the 3D reconstruction of the rock structure surface. Meanwhile, the results of the plane scanning of the acquisition field and the visual structure are converted into digital information as a quantitative basis for the rock mass.

According to the actual harvest sequence, the ore body model is virtualized, data measurement is performed, and the scene demonstration effect is displayed (as shown in Figure 15). On the other hand, it can display the progress of mining production and the overall design plan. On the other hand, combined with different recovery stages, it can display the force of the excavation field and the visualization project in a specific state, so that it is convenient to adjust the arrangement of mining production at any time.

The stress nephogram calculated by the FLAC numerical simulation software and the key block information calculated by the Shape MetriX3D software are integrated and displayed on the visualization model, as shown in Figures 16 and 17. According to information such as important blocks and stress nephogram, there is a more scientific basis for mine visualization and stope protection. The stress field data obtained through numerical simulation is integrated in the virtual scene. With the dynamic development of the mining process, the formation of the goaf and visualization can be



FIGURE 14: 3D display of structural surface.

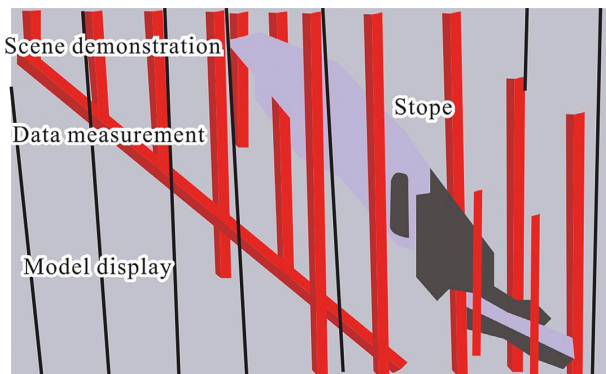


FIGURE 15: The progress of ore body mining.

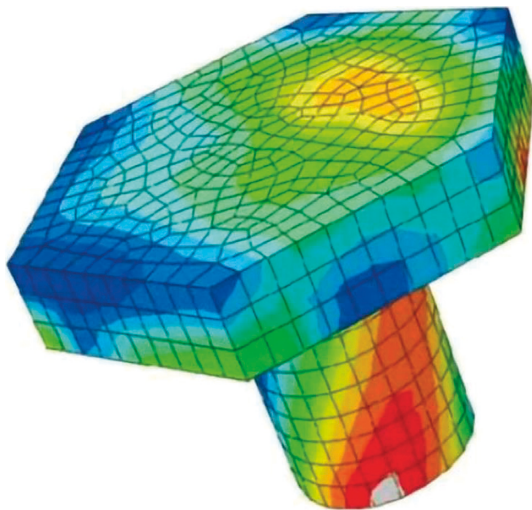


FIGURE 16: The external stress nephogram and key block information of the roadway.

used to visually display the perturbation status of the original in situ stress field in the surrounding rocks. The process of ground pressure changes caused by deep mining is reproduced. On this basis, ore mining engineers can intuitively obtain stress field information in the first time during the production design process, which helps to improve the safety of production decision-making.

As shown in Figure 18, the region of interest can be domestically monitored, and the monitoring information

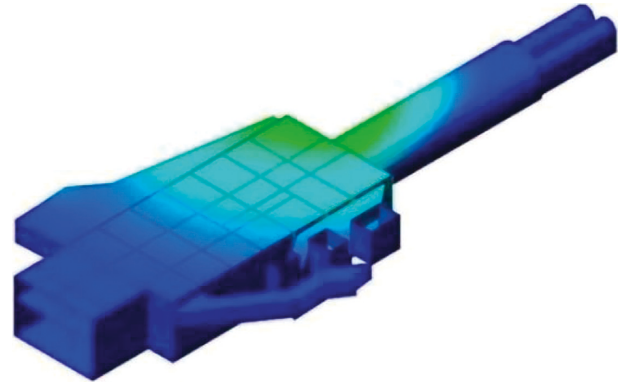


FIGURE 17: The internal stress nephogram and key block information of the roadway.



FIGURE 18: Display of roadway displacement monitoring information.

can be displayed in the VR system in the form of a list. This monitoring information can also be updated in real time with mining production.

The somewhat ore VR system can be constructed to provide real-time updates of stress nephogram, key blocks, displacement monitoring data, and other information. On the basis of promoting ore body recovery and visualization engineering construction, it is convenient to determine the entire mine and partial mining plans. The ore VR system is a digital mine system with virtual roaming, data query, and interactive control functions. According to the Shear-Warp volume computer drawing technology, the engineering geological conditions, ore body shape, visualization, and location of the mining area in the mine production process, a large number of 3D data sets such as mining progress are used as a dynamic visualization 3D model, combined with the numerical simulation of the surrounding rock stress field, visual displacement monitoring, and other means; a complete 3D visualization platform of the mine has been constructed.

#### 4. Conclusions

This paper studies the key technologies involved in 3D ore body modeling, including program construction, data storage and access, scene control, borehole data visualization, graphics rendering, triangulation, solid rendering, solid Boolean operation, solid automatic sectioning, storage and

access of graphic files, and the release and deployment of this kind of software, which can be used as a reference for developers. The use of Shear-Warp volume computer rendering technology in the underground 3D visual analysis process of mining engineering can effectively combine the display of underground spatial position of the mine with the attribute description corresponding to ore and rock mass and provide accurate image information for mining engineers in detail, realize the effective processing of different rock mass pictures of the mine, and better understand and master the hidden dangerous situations of the mine as a whole, which has guiding significance for the design of underground space and mining scheme of on-site mining engineering. Based on the computer rendering technology of Shear-Warp volume, a 3D visual analysis method of mining engineering is proposed in this paper. Based on advanced modeling software and operation skills, this method can effectively improve operation efficiency and mining accuracy.

### Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

### Conflicts of Interest

The authors declare no conflicts of interest.

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