Research and realization on three-dimensional visualization system of coal seam structure in minefield

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ABSTRACT

The three-dimensional visualization of coal seam structure in coal mines is the foundation for coal enterprises to implement transparent mining. Existing three-dimensional modeling systems generally have problems such as poor portability and single interpolation methods. Therefore, this paper adopts the development mode of front and rear separation, and designs and realizes a three-dimensional visualization system of no plug-in and strong portable field coal seam structure based on Springboot+Vue+Mysql. The system interpolates the seam elevation in unknown areas using the optimized Crekin interpolation method, uses the Delaunay rule to generate an irregular triangle network on the coal seam surface, and extends the triangle network along the coal seam elevation to generate a three-dimensional seam model based on generalized triprism prism; Finally, with the help of Three.js three-dimensional engine, the browser side displays the three-dimensional effect of the coal seam structure of the minefield. The application of this system has certain guiding significance and reference value for coal enterprises to make reasonable preparations.

Keywords: Three-dimensional visualization, kriging interpolation, Delaunay, generalized triangular prism

1. INTRODUCTION

The information construction of coal industry has advanced from digital mine to intelligent mine. In the construction of smart mines, 3D visualization technology, as an important part of its spatial information system, is widely used in coal mining design and production processes[1-2]. There have been a lot of studies on 3D visualization technology of coal seam structure by Chinese and foreign scholars. Wu[3] used MicroStation software to build a perfect 3D geological model, showing the geological structure, characteristics and occurrence of coal seam; Yang et al.[4] used VTK software to introduce a generalized triangular prism model based on borehole data to construct a three-dimensional stratum visualization system, which has the advantages of good visualization and fast modeling; Zhang[5] and others used C++, OpenSceneGraph graphics engine technology, Fusion of known data, comprehensive analysis of geological data and borehole data after kriging interpolation, using a triangular prism as a model unit to construct a three-dimensional stratigraphic model. Chinese and foreign scholars have achieved staged results in the processing of coal seam spatial data and the three-dimensional visualization of coal seam structure[6-8], but there are still the following shortcomings:

(1) The construction of the existing 3D visualization graphics of coal seam structure mostly relies on third-party software or secondary development of third-party software, which has the problems of poor portability and inability to cross-platform, and the use of unique methods for storage of 3D spatial data is not conducive to Data sharing is easy to produce data "islands".

(2) For the data in the unknown area of the coal seam, a single spatial interpolation algorithm or a curved surface fitting method is used, which leads to the built-up 3D visualization graphs not being accurate enough.

Therefore, this paper uses computer graphics, artificial intelligence algorithms, computer vision and other related technologies to design a three-dimensional visualization system for coal seam structure in mine fields. Design suitable data structure for unified storage of data required by 3D visualization; The ant colony algorithm optimized Kriging interpolation method was used to interpolate the elevation attribute values of unknown coal seam regions, which made the coal seam structure presented by the system more accurate. The three-dimensional model is constructed by combining triangulation and generalized triangular prism method. With the help of Three.js 3D engine, the 3D

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visualization system of coal seam structure in mine field with high portability and strong interaction is realized, which provides basis for reasonable mining preparation and better realization of transparent mining.

2. PROCESS OF THREE-DIMENSIONAL VISUALIZATION SYSTEM OF COAL SEAM STRUCTURE IN MINEFIELD

The drilling data generated during the design of coal mining is relatively sparse, so the establishment of the three-dimensional visualization of the coal seam structure in the minefield is first interpolated.

This paper uses the optimized Kriging interpolation method to estimate the elevation value of the virtual borehole. According to the Delaunay law, the irregular triangulated surface of the coal seam is generated, and then the roof/floor surface of the coal seam is generated. The Three.js three-dimensional engine is used to visually display the distribution of the coal seam. Realize human-computer interaction. The specific process is as follows:

(1) Classification and statistics of drilling data, coal seam data, and coal seam quality data generated during coal mining design;

(2) Supplement the virtual borehole data, and use the optimized Kriging interpolation method to estimate the elevation value of the virtual borehole;

(3) According to the stratum distribution characteristics, select a coal seam and obtain all drilling data of the coal seam;

(4) With borehole coordinates as the basic data source, the irregular triangulation of the coal seam surface is generated according to the Delaunay law;

(5) According to the order of spatial distribution of coal seam, the generated irregular triangulation network is set as the floor surface of coal seam, and the coordinates of the triangulation network vertex which constitutes the floor surface of coal seam are extended according to the elevation value to generate the top plate surface of coal seam, and the corresponding connecting top and floor surface generates a 3D coal seam model based on the generalized tri-prism volume element;

(6) Repeat steps (4) and (5) until all drilling data is traversed;

(7) Repeat steps (3) to (5) until all coal seams have been traversed;

(8) Using Three.js 3D engine, the distribution of coal seam is visually displayed and man-machine interactive operation is realized.

3. KEY TECHNOLOGIES FOR THE ESTABLISHMENT OF THREE-DIMENSIONAL VISUALIZATION OF COAL SEAM STRUCTURE

3.1. ACO-kriging interpolation method

Kriging interpolation has the advantages of high interpolation accuracy and strong uniqueness. It is widely used in reservoirs, reserves prediction and mineral product location estimation[9]. The basic equation is shown in equation (1):

$$z'(\mathrm{x}) = \sum_{i=1}^{n} \lambda_i z(x_i) \qquad (i = 1, 2, \cdots n) \tag{1}$$

where is the point to be inserted, n is the number of known points, $Z(xi)$ is the i known point, λi is the weight coefficient of the i location the known point and the point to be inserted, the weight λi depends on the known point, the distance and spatial relationship of the point to be interpolated, needs to meet unbiased optimality, namely:

$$\sum_{i=1}^{n} \lambda_i = 1 \tag{2}$$

$$\min Var(z'(x) - z(x)) \tag{3}$$

The main steps of ordinary kriging difference are:

Step 1: For the known point data, calculate the distance and semivariance in pairs;

Step 2: Group the distances according to the step length, and calculate the average semivariance of each group;

Step 3: Draw the variogram after grouping;

Step 4: Solve the variogram model parameters and fit the theoretical variogram model;

Step 5: Solve the semivariance from the unknown point to all known points;

Step 6: Use the optimal weight coefficient to weight and sum the attribute values of the known points to obtain the estimated value of the unknown point.

The fitting of the variogram directly affects the accuracy of the interpolation. The ant colony algorithm is used to solve the parameters of the variogram model, and a better fitting model is constructed. The fitting of the variogram model essentially represents the degree of approximation between the experimental variogram and the theoretical variogram[7], where equation (4) is used as the objective function:

$$f_{\min} = \sum_{i=1}^{n} [\gamma'(h) - \gamma(h)]^2 \tag{4}$$

This is the theoretical variance function value, the experimental variance function value, the number of n.

The process of using the ant colony algorithm to solve the objective function is shown in Figure 1:
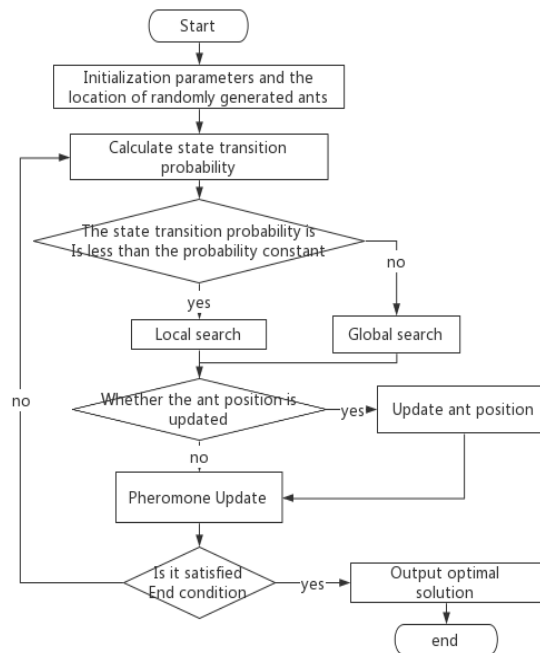

Figure 1. Flow chart of ant colony algorithm.

The formula for calculating the probability of state transition is:

$$p(iter, i) = \frac{\max(Tau) - Tau(i)}{\max(Tau)} \tag{5}$$

Among them, it represents the maximum value of pheromone, represents the pheromone of the i-th ant, and represents the pheromone of ant i in $iter$ times.

The pheromone update formula is:

$$Tau = (1 - \rho) * Tau + f \tag{6}$$

where is the pheromone volatilization factor, Tau is the pheromone, and f is the objective function value. According to the flowchart of Figure 2, ant colony algorithm, the parameter values of the variogram are solved.

Selecting 50 known sampling data of the C2-2 coal seam of a coal mine as the sample data set, and useing Kriging and ACO-Kriging to perform cross-validation to calculate the theoretical elevation value of the sample, a line chart is obtained comparing the theoretical elevation value and the actual elevation value as shown in Figure 2 shows:
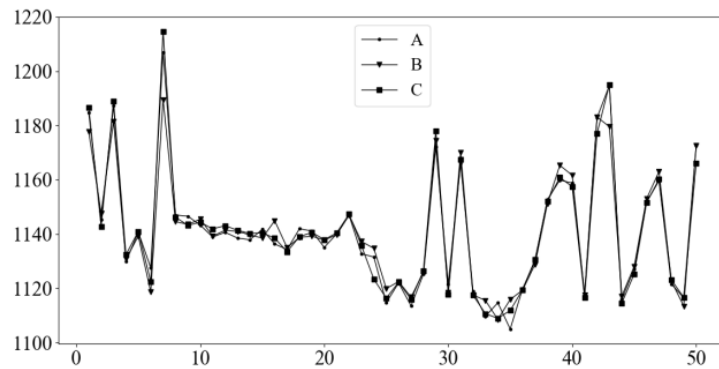

Figure 2. Line chart of sampling point elevation comparison.

Among them, line A represents the actual elevation value distribution line chart of 50 sample points, and lines B and C represent the theoretical elevation distribution line chart of the corresponding position of the sample calculated according to Kriging and ACO-Kriging, respectively. At the inflection point, the theoretical elevation value obtained by the ACO-Kriging algorithm is closer to the actual elevation value than the Kriging algorithm, so it is feasible to choose the ACO-Kriging method to complete the interpolation of the coal seam elevation attributes.

3.2. Delaunay triangulated graph

Triangulation is to form a set of discrete points, connect the set of points into triangles, and form a plane plan by these triangles. Delaunay is one of the most widely used triangulation methods in computational geometry, and the triangular network composed of Delaunay methods must satisfy the empty circle properties and maximize the minimal angle properties[10].

3.3. Generalized triangular prism model

The generalized triprismatic model consists of two not necessarily parallel triangles[11], which can represent the minimal three-dimensional spatial unit of the stratigraphic model and can also handle complex geological formations through boundary constraints. The three prisms can be divided into three and four cones under boundary constraints[5]. Three-and four-prism cones can be used to express complex geological structures such as faults, folds, voids, and pinch off.

4. DESIGN OF THREE-DIMENSIONAL VISUALIZATION SYSTEM FOR COAL SEAM STRUCTURE

The system adopts Springboot+Vue+Mysql technology to build a development mode with separation of front and back ends. This mode realizes the on-demand loading of pages through the configuration of front-end routing; the back-end server no longer needs to parse front-end pages, less load pressure, higher availability and better performance.

4.1. System architecture design

The overall system architecture is mainly divided into user interaction layer, data interface layer, business logic layer, and data persistence layer. The user interaction layer visually displays the functions of the system to users, and at the same time receives user requests and returns system responses. The data interface layer realizes the transmission of messages and completes the interaction between user request messages and the processing results of the business logic layer. The business logic layer processes specific business content by calling the data persistence layer, including two parts: interface and implementation. The data persistence layer is directly connected to the database and manipulates the data according to actual business needs[12].

4.2. Data table structure design

The system data table includes a drill hole information table for storing information such as drill hole number,

coordinates, and coal seam number; a coal seam information table for storing information such as coal seam number and coal seam thickness; a coal seam quality information table for storing coal quality data such as coal ash, water, and calorific value, the coal-bed coal quality range table is used to store the maximum and minimum values of coal thickness and coal quality data; the prediction information table is used to store interpolated borehole coordinates, coal seam information, and coal quality information data; unit information Table user storage unit name, code and other information; user information table user name, password and other information; role information table user storage role name, and its corresponding unit, user ID information.

5. REALIZATION OF THREE-DIMENSIONAL VISUALIZATION SYSTEM OF COAL SEAM STRUCTURE

5.1. Data preparation

The system conducts unified storage and management of the data required for three-dimensional visualization of coal seam structure, which mainly includes drilling information, basic coal seam information, coal seam quality information and coal seam coal quality range. The ability to add, modify, delete, display these data is implemented, and the need for mass import of excel table data through Java POI technology is realized.

5.2. Coal seam elevation interpolation prediction

According to the coal seam number, the borehole number in the coal seam information table corresponds to the borehole number in the borehole information table, and the coal seam number, borehole coordinates X and Y, seam floor elevation and coal seam thickness are integrated, using ACO-Kriging interpolation. The method uses the maximum and minimum values of the drilling coordinates X and Y as intervals to supplement the drilling coordinates in the unknown area, and interpolate to obtain the coal seam floor elevation and coal seam thickness of the drilling coordinates, and then the coal seam roof elevation can be obtained. The interpolated data is stored in the database as the basic data for 3D visualization.

5.3. Three-dimensional visualization of coal seam structure

(1) Three-dimensional visualization of a single coal seam

Based on the interpolated data, Realize the rendering of 3D renderings based on Three.js 3D engine, the Delaunay method connects the discrete data points to obtain a single face model of the coal seam, and the single face model of the coal seam is obtained as shown in Figure 3, using a generalized triangular prism. The model connects the top and floor surfaces of the coal seam, and the three-dimensional model of the coal seam is shown in Figure 4.
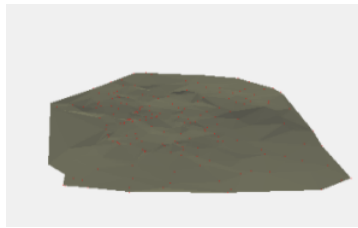

Figure 3. Coal layer model.   Figure 4. Coal seam model.
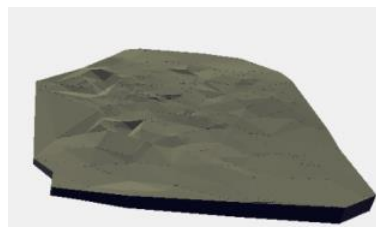
Through the method of picking Raycaster object in three.js, a triangular plane that forms the 3D model is obtained with the mouse, according to the coordinates of the triangle, the corresponding coal quality data is queried from the database, and the coal quality data is correlated with the coal seam structure. The results are returned to the front page, as shown in Figure 5. Compared with other 3D visualization software, this system has better interactivity.

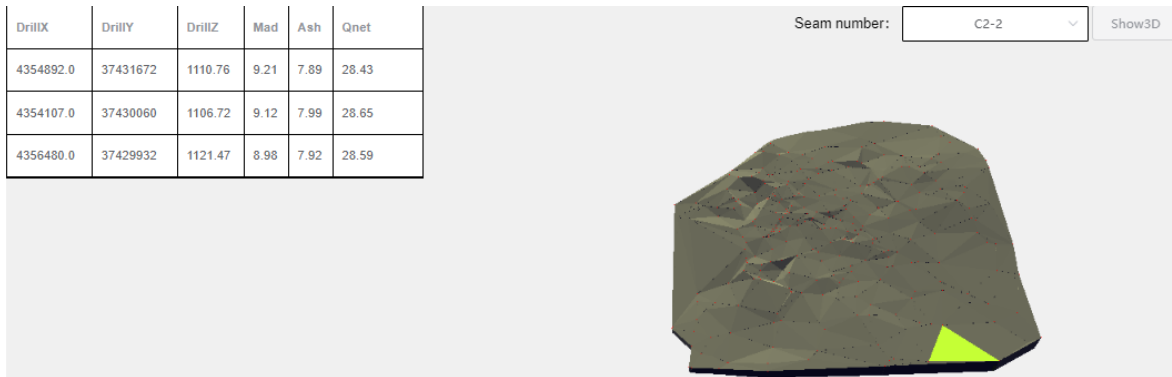| DrillX	DrillY	DrillZ	Mad	Ash	Qnet
4354892.0	37431672	1110.76	9.21	7.89	28.43
4354107.0	37430060	1106.72	9.12	7.99	28.65
4356480.0	37429932	1121.47	8.98	7.92	28.59

Seam number: C2-2   Show3D

Figure 5. Interaction diagram of coal seam.

(2) Three-dimensional visualization of multiple coal seams

A mine generally contains multiple coal seams. The interpolated drilling coordinates and coal quality data of each coal seam are obtained from the database. According to the coal seam distribution sequence, the Three.js 3D engine, Delaunay method, and generalized triangular prism model are used to obtain the three-dimensional renderings of multiple coal seams, as shown in Figure 6.
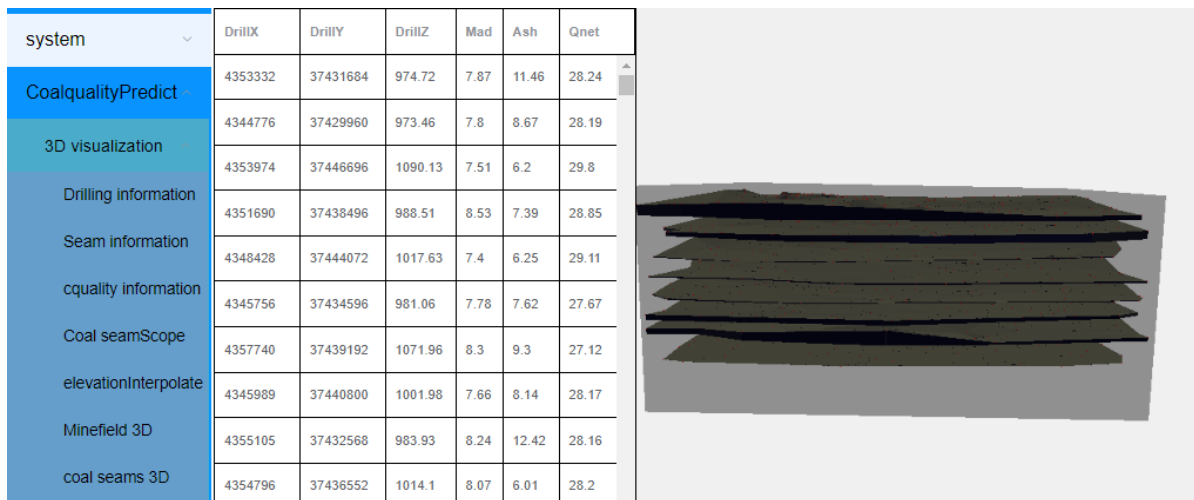
system						
CoalqualityPredict	DrillX	DrillY	DrillZ	Mad	Ash	Qnet
3D visualization	4353332	37431684	974.72	7.87	11.46	28.24
Drilling information	4344776	37429960	973.46	7.8	8.67	28.19
Seam information	4353974	37446696	1090.13	7.51	6.2	29.8
cquality information	4351690	37438496	988.51	8.53	7.39	28.85
Coal seamScope	4348428	37444072	1017.63	7.4	6.25	29.11
elevationInterpolate	4345756	37434596	981.06	7.78	7.62	27.67
Minefield 3D	4357740	37439192	1071.96	8.3	9.3	27.12
coal seams 3D	4345989	37440800	1001.98	7.66	8.14	28.17
	4355105	37432568	983.93	8.24	12.42	28.16
	4354796	37436552	1014.1	8.07	6.01	28.2

Figure 6. Three-dimensional visualization of coal seams.

6. CONCLUSION

The three-dimensional visualization system of the coal seam structure of the minefield realizes the unified storage and management of the relevant data of the coal seam in the minefield; the ACO-Kriging method is used to interpolate and supplement the drilling information in the unknown area of the coal seam in the minefield to avoid the sparse drilling points that affect the accuracy of the model; use The Three.js 3D engine combines triangulation and generalized triangular prism 3D modeling methods to realize the 3D display of the geological spatial characteristics of coal seam structure and coal quality indicators. The system can be integrated with the existing systems of coal companies to achieve the construction requirements of intelligent mine information integration.

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