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ScienceDirect
Trans. Nonferrous Met. Soc. China 21(2011) s723−s726

Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Water distribution extracted from mining subsidence area using Kriging interpolation algorithm

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Received 19 June 2011; accepted 10 November 2011

Abstract: By comprehensively analyzing the data of geology and mining, Kriging algorithm was introduced to analyze the thematic information of geological data, to rapidly extract mining parameters for predicting mining subsidence, and to effectively integrate geomorphology and predict information. As a result, the change information of water body is successfully detected from the prediction of surface subsidence due to mining activity. Analysis shows that the elevation of farmland in the west side of water body will be lower than ever, and the west part farmland will be submerged. However, there is no evidence for impacting the villages. All the information provides a reference for efficiently assessing environmental impact due to mining activity, which can help to govern the subsidence of the area reasonably.

Key words: Kriging interpolation; water body; mining subsidence; prediction parameters; data fusion

1 Introduction

Underground coal mining may lead to surface subsidence and damage the environment of mine area. Therefore, it is important to accurately predict surface subsidence before mining, and moreover, to assess the impacts of mining on environment.

Previous researches of the coal mining under water body are mainly on the fractured zones in overburden structure, the maximal elevation of the fractured zone and the water resource running on profiles [1−4]. However, there are few studies on plane. Routine methods extracting geological and mining parameters for mining subsidence prediction are visual estimation extraction on CAD maps, refereed to as the coal thickness extracted from the discrete borehole data, floor depth extracted from the discrete contour with ground elevation data and dip extracted by artificial taken. These methods for parameter extraction are not rapid and automatic enough. In addition, the predicted results of surface subsidence only perform the mining conditions on the surface plane which cannot take into account the existing geomorphology features, and reflect the real changes in geomorphologic features after mining. Therefore, it is difficult to extract water body information after mining subsidence using traditional methods in complex terrain surface.

In this work, Kriging interpolation algorithm was introduced to solve the shortcomings of traditional methods. The geological and mining data were analyzed. The continuous geological body was generated from discrete geological data, so that the geological and mining parameters for mining subsidence prediction at any point can be rapidly and automatically extracted. On the same principle, the geomorphology and prediction information were effectively integrated using the above method. Thus, the water body distributions after subsidence in mine area were extracted.

2 Study area

The general situation of study area is shown in Fig. 1. All the mine areas are shown on the top right, and the rectangular represents the study area. The mine is sustained inclined piedmont plain with eroding packing type. The terrain is low in the west and south, and high in the east and north. The elevation is from 93.58 to 173.2 m. The range of the study area is 5 000 m×5 000 m. The planned mining area is described with a blue line (see Fig. 1) which covers mine field from west to east. The water level is about 108 m.

Foundation item: Project (200911036) supported by the Ministry of Land and Resources research special, China; Project (2010YD05) supported by the Fundamental Research Funds for the Central Universities, China
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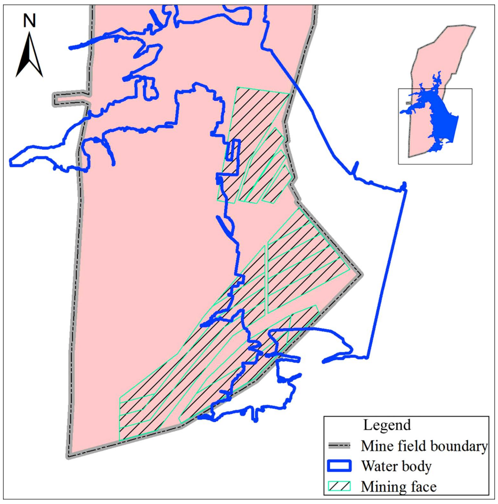

Fig. 1 General situation of study area

3 Kriging interpolation algorithm

Kriging interpolation algorithm is also known as the best interpolation of spatial autocovariance [5−7]. It is a method of interpolation which predicts unknown values from data at known locations. This method firstly considers the variability of spatial attribute in spatial location. Secondly, the influenced distance range of a point is determined and its value is to be estimated. At last, the attribute value of the point to be estimated is computed using the points within this range. It has the features of unbiasedness and optimality. Not only the relative positions between observed points and estimated points are considered, but also the relative positions of observed points are taken into account in the Kriging method. As a result, the optimal prediction of attribute of point to be estimated could be obtained [8].

This method uses variogram to express the spatial variation. The variogram $r(h)$ is defined as half of the variance (V_{ar}) of regional variables $Z(x)$ and $Z(x+h)$ difference which are the values at the points of x and $(x+h)$, and $r(h)$ is given as:

$$r(h)=\frac{1}{2}V_{\mathrm{ar}}[Z(x)-Z(x+h)] \tag{1}$$

Kriging method is a mathematical model obtained through fitting semivariogram, then the distance of any given semi-variance function is estimated. Thus, the spatial weight is calculated. The ordinary Kriging, which estimates the unknown value using a weighed linear combination of the available samples, is given as

$$Z_s=\sum_{i=1}^{n_s}W_{is}Z_i \tag{2}$$

where s is the point needed to be estimated; i is the observed point; Z_s and Z_i are the attributes of points s and i, respectively; W_{is} is the weight calculated.

In Kriging interpolation method, the weight is calculated from variogram which considers the distance as an independent variable. The variogram can reflect the structural components of spatial data and random distribution of variables, and describe the error information. So, the method can be applied to construct a continuous surface of layered deposit model from discrete points of geological and mining data.

4 Method of water information extraction

4.1 Geological and mining parameters extraction for subsidence prediction

In the course of geological exploration, the borehole data is one of the important information describing geological features in the study area. Borehole data as the most direct means are often used to analyze the geological environment. There are 107 boreholes in the mine with the attributes of floor depth of coal seam, coal thickness and dip. The floor depth, thickness and dip prediction are interpolated and contrasted between the boreholes. Then the global properties of geological and mining parameters are obtained from the borehole data. In this study, geological and mining parameters for mining subsidence prediction mainly include the floor depth of coal seam, coal thickness and dip. The data processing and information extracting are as follows:

1) The properties of borehole data should be statistically analyzed before interpolation to judge whether there are abnormal data. These abnormal data are judged whether need to be removed or as a special eigenvalue participate in the calculation and the edge data which are not proper to participate in the calculation would be removed; then the data are statistically analyzed by the histogram of χ^2 test. If the histogram meets normal distribution, the ordinary Kriging interpolation method can be used to interpolate. If not, the original data are needed to be converted to meet normal distribution.

2) The trend analysis on properties data is made. The trend analysis on floor depth property of coal seam is shown in Fig. 2. The global distribution trends of the property are shown. According to the trend analysis, parabola trend with blue line in rough north−south axis and a rising linear trend with green line in rough east−west axis. It suggests that there is significant correlation in east−west axis direction, but weak correlation in vertical direction. Therefore, the distribution trend of property is different in each direction with anisotropic characteristics, which cannot be achieved in classical statistical analysis. Through the analysis above, it can be found that the observed data meet an approximate normal distribution and have a strong spatial correlation. The Kriging interpolation can be used as the global

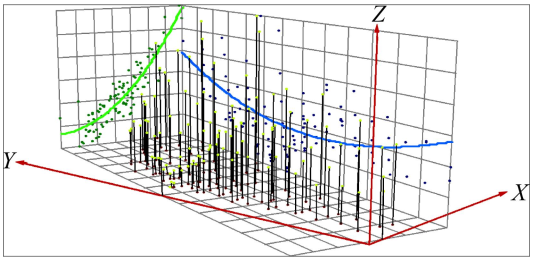

Fig. 2 Trend analysis on floor depth property of coal seam

prediction for property. In the process of interpolation, firstly the trend needs to be removed, secondly the residual error is used for local interpolation, and last the overall trend is re-integrated. The overall accuracy will be increased in this way.

3) The experimental variogram is calculated. Parameters for variogram such as range and nugget can be determined. By fitting the variogram theory model and cross-validation, the parameters are modified to determine the experimental variogram model. Then the property of point to be estimated can be obtained through Eq. (2).

4) The thematic property analysis and parameter extraction are made. There are 107 boreholes which detect the coal seam. The output result is a field of estimated value with continuous property. The raster resolution is 40 m×40 m. The thematic property analysis of floor depth is shown in Fig. 3. Due to the same resolution, the thickness and dip use, the different properties of the same point can be extracted. In this work, the mean standardized value is used as the error indicator to inspect the prediction quality in cross-validation. The mean standardized errors of floor depth, coal thickness and dip are −0.06747 m, −0.04145 m and −0.1154°, respectively. The accuracy prediction is high,

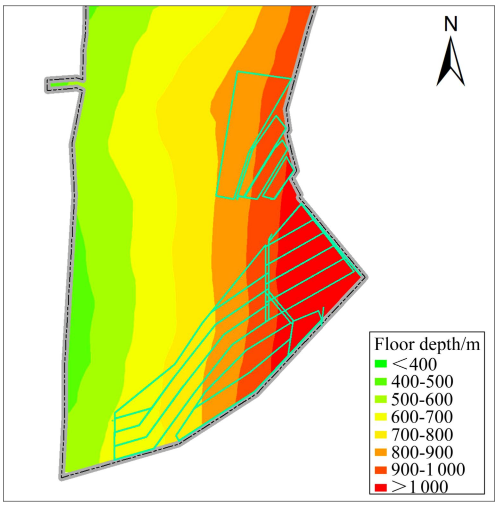

Fig. 3 Analysis on floor depth property of coal seam and geological parameters extraction

so the prediction can be used to extract parameters.

The continuous floor depth property of coal seam obtained from interpolation is shown in Fig. 3. From the figure, the whole distribution trend and scope of floor depth are seen. The depth is from 400 to 1 000 m. A color map is used to display the depth change. The red and green color areas represent the maximum and minimum properties in the map. The depth changes smoothly. So, it is a gently inclined coal seam. Because this information is continuous, the depth at every desired point can be extracted from this estimated area. The extracted location represents the location of spatial point and the property of this point means the depth of the data. Similarly, coal thickness and dip can be extracted as geological and mining parameters for the prediction of mining subsidence.

4.2 Prediction of mining subsidence

According to the previous research results, the rules of reservation and mining of protective coal pillar for building, water, railway, shaft and road [9−10]. In this work, the probability integral method model of mining subsidence is used to calculate the ground movement and deformation caused by underground mining with the reference to the underground mining of this mine, rock characteristics of mining overburden layer to the surface and ground movement, and deformation observation data. The calculation parameters for prediction of mining such as subsidence coefficient q, horizontal movement coefficient b, main effecting angle tangent $\tan\beta$ and displacement dislance of inflection point s are estimated from observations. The geological and mining parameters such as floor depth, coal thickness and dip in the mining area are obtained by the method described in section 4.1. The size of grid is set to be 50 m×50 m. The subsidence at any point in the ground movement basin can be predicted as:

$$W(x,y)=W_{\max}\iint_D \frac{1}{r^2}\exp\left[-\pi\frac{(\eta-x)^2+(\xi-y)^2}{r^2}\right]\mathrm{d}\eta\mathrm{d}\xi \quad (3)$$

where (x, y) is any point on the surface; $W_{\max}$ is the maximum subsidence of the full mining of surface; r is the main effecting radius; η and ξ are the integral variables in X and Y directions, respectively.

4.3 Data fusion between ground elevation data and subsidence prediction data

The predicted results of mining subsidence above only perform the subsidence situation where the mine surface is horizontal plane without regard to the original geomorphology. In order to extract the distribution information of water body after mining subsidence, the original geomorphology information described with discrete elevation data and mining subsidence prediction described with grid data which are inconsistent in sampling rate are needed to do spatial data fusion. So, the change characteristics of geomorphology are displayed in detail after mining subsidence [11]. Therefore, ground discrete elevation points obtained from digitizing topographic map are interpolated into regular grid which is consistent with the predicted grid using Kriging method mentioned in Section 3. Thus, these two spatial data are effectively integrated. Then the water distribution can be well extracted from mining subsidence areas [12−14].

4.4 Water body information extracting

Based on the above algorithms, the water body distribution information after mining subsidence is shown in Fig. 4. The coordinates in lower-left and upper-right corners are the independent coordinates for the study area in the figure. The surface water body distribution before mining is displayed with blue solid line and that after mining is displayed with red dashed line. The landmarks between red and blue lines are farmlands. The villages near water body are enclosed with green line. Some typical effects of mining subsidence on water body are shown, including the elevation lowers and slope changes on farmland, the redistribution of ground water body borders, the scope of water body expanses to west side and the farmland in west are submerged. The terrain is low in the west and high in the east, therefore, mining does not affect the eastern part of water body. In addition, there is no impact on the eastern area of water body.

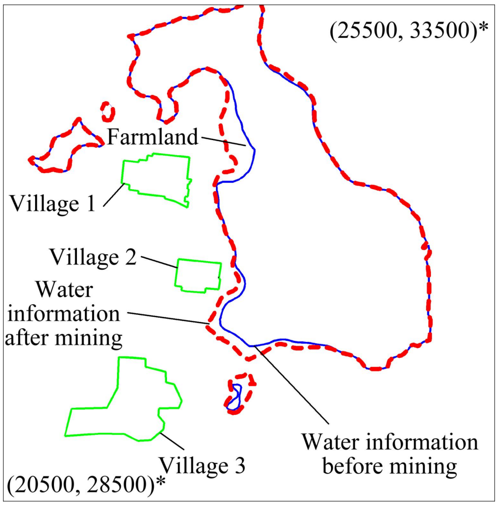

Fig. 4 Extraction of water body information after mining subsidence (* Boundary coordinates of study area)

5 Conclusions

1) Kriging algorithm was introduced to analyze the thematic information of geological data, rapidly extract mining parameters for prediction on mining subsidence and to effectively integrate geomorphology and predict information. As a result, the distribution information of water body after mining subsidence is extracted rapidly and accurately with respect to the original geomorphology.

2) The mining subsidence and extract water body distribution information after mining subsidence were predicted. Analysis indicates that partial farmland is submerged in the west of water body, and there is no impact on the villages. The application proves the method mentioned in this study can assess the environmental impact due to mining activity, and it provides a reference for reasonably govern subsidence area.

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(Edited by FANG Jing-hua)