A Dynamic Prediction Method of Deep Mining Subsidence Combines D-InSAR Technique

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Abstract. Traditional monitor measure methods can’t satisfy the demand for the large area of deep mining subsidence prediction and monitor. Put forward a dynamic prediction combine the probability-integral method with the D-InSAR (Differential Interferometric Synthetic Aperture Radar) measure technique base on the conclusion of mining subsidence prediction and monitoring technology’s exist problems. Combine the probability-integral method calculate the surface subsidence threshold value with the surface subsidence and deformation rates measured by D-InSAR technique, composition the dynamic prediction method which can calculate the subsidence rate and time threshold. The subsidence rate and time threshold calculated by mining dynamic prediction method can more accurately predict the level of deep mining subsidence and quantitative estimates the regularity of damage evolution of environmental resources.

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Keywords: D-InSAR technique; deep mining; mining subsidence predict; dynamic prediction

1. Introduction.

The increase of demand for resources and mining intensity cause the decrease of the shallow coal resource while the deep mining becomes the main source. The increase of deep mining range set demand for the rapid and large areas dynamic prediction and real-time monitoring to control the damage caused by deep mining subsidence. Traditional subsidence prediction method commonly can get the static subsidence prediction or restrict by the scope of application and the existing surface monitor method can’t satisfy the demand for the use of rapid and large area. D-InSAR (Differential Interferometric Synthetic Aperture Radar) is a method which uses the synthetic aperture radar to measure. The accuracy of measurement can achieve mm-level precision in theory. Monitor the mining subsidence and the

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environmental changes it caused by D-InSAR technique possesses superior reliability, which consistent with other precise measurement on the research both internal and external [1~5]. This paper presents a large areas deep mining subsidence dynamic prediction method combine D-InSAR technique and probability-integral method, which introduce how to combine the D-InSAR and the prediction of probability-integral method to be a dynamic prediction system to predict the level of deep mining subsidence and quantitative estimates the regularity of damage evolution of environmental resources.

2. Deep Mining Subsidence Prediction and Monitor

The geological conditions of Deep resource mining are complex, which lead to the increase of abrupt engineering disasters and significant pernicious accidents probability and the safety and efficiency of deep resource mining face a huge threat. So the deep mining subsidence prediction and monitor play a very important role in safe production in mining area.

2.1. Mining Subsidence Prediction Method

There are many prediction methods on the surface movement deformation can be roughly divided into section function model, continuum mechanics theory, numerical simulation method, physical simulation method and influence function method etc [6]. Probability-integral method is developed from the influence function method, which with the assumption that the strata and the laws of surface movement caused by mining as the granular medium model of stochastic medium. The laws of movement can be described in probability and the mining working face movement and deformation can be calculated by the integral from unit of mining subsidence [7].

2.2. Mining Subsidence Monitor Technique

The mainly monitor techniques include: precise leveling, electronic total station measurement, GPS and D-InSAR etc in domestic and overseas. The comparison of mainly monitor technique sees Table 1.

<table>
<thead>
<tr>
<th>Method</th>
<th>Accuracy(mm)</th>
<th>Data</th>
<th>Working limit</th>
<th>Period/Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precise Leveling</td>
<td>1—10</td>
<td>Points Lines</td>
<td>Weather, Personnel</td>
<td>Long/High</td>
</tr>
<tr>
<td>Electronic Total</td>
<td>2—5</td>
<td>Points Lines</td>
<td>Weather, Personnel</td>
<td>Long/High</td>
</tr>
<tr>
<td>Station</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPS</td>
<td>5—20</td>
<td>Points Lines and Grids</td>
<td>All day, Receiver</td>
<td>shorter/High</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>position</td>
<td></td>
</tr>
<tr>
<td>D-InSAR</td>
<td>10</td>
<td>Points Lines and</td>
<td>All day, Unstinted</td>
<td>short/low</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1 show that D-InSAR can get high precision multiple subsidence changes information points lines and surfaces scarcely affected by climate

3. Deep Mining Subsidence Dynamic Prediction Theory

3.1. D-InSAR Key Technology Principle

D-InSAR (Differential Interferometric Synthetic Aperture Radar) is based on SAR (Synthetic Aperture Radar), which have three methods to calculate. Two-pass: Difference and interference two images of study region before and after the deformation receive the interference fringe image, which difference with
the terrain phase simulated by the known study region DEM. Wipe off the terrain phase and receive the phase difference caused by surface deformation [8]. Three-pass: Difference and interference three radar images of the study region in different time remove the terrain phase and receive the interference fringe image only contain the surface deformation data, however, this measuring method do not demand for the study region DEM [9]. Four-pass is similar with three-pass.

3.2. The Advantages of D-InSAR Combine with Probability-integral Method

The surface deformation caused by deep mining is continuous. According to the existing researches the deeper mining depth, the surface deformation last for longer time [6]. D-InSAR can obtain the micro deformation, which achieve the centimeter or millimeter level precision and the mining subsidence data through the long-term surface deformation.

D-InSAR receive the displacement of arbitrary point on surface in the study region though difference and interference the SAR images, which can judge the surface deformation during the observation time and calculate the descending rate by measure the value of surface subsidence.

Probability-integral method can calculate the statically value of surface subsidence and deformation, the maximum deformation level on the surface. The predicted value of the mining areas subsidence is the index of security scope for the moved of the constructions and structures, also for the optimization design of the water conservancy and roads etc public infrastructures.

4. Deep Mining Subsidence Dynamic Prediction Method

4.1. Deep Mining Subsidence Dynamic Predict Surface Deformation Process and Result

D-InSAR is an effective way to large extensiveness and high resolution observed from space to ground. It need to extract the SLC from the original SAR signal after acquire the SAR data, registration of the main and auxiliary images, interference calculate generating interferogram, phase unwrapping and receive the DEM from the phase data etc multi-step [10]. The data processing flow chart of deep mining subsidence dynamic predict theory combine D-InSAR taking the three-pass as an example sees Figure 1.

Fig. 1 The data processing flow chart of deep mining subsidence dynamic predict theory combine D-InSAR
D-InSAR were used to obtain the gradient distribution map of the surface deformation in study region at the observation time and vertical displacement of any point in the deep mining sinking area, which also can draw the profile of the subsidence and simulate the subsidence value curve. Take the surface deformation variation of a certain point as the calculate threshold value can predict the time reach the deformation threshold value of this point. Use the subsidence rate during the observation time can get the time of reach the deformation threshold value at the maximum velocity.

4.2. Dynamic Mining Subsidence Prediction Method Analyses

It can get the maximum subsidence prediction value through the probability-integral method, however, the subsidence rate and the time it last in study area were not given. Take the shorter repeat period SAR as the data source of surface deformation analyses in study region and get more precise surface deformation gradient distribution map in short time, the maximum subsidence value predicted by probability-integral method as the threshold value of surface deformation, the dynamic prediction combine them can finish and the subsidence rate and the time it last at any point can be predicted in short time after the mining start. According to research of mining subsidence prediction in the shallow mining, the movement law of surface point in subsidence area is basically following: an arbitrary point Z in subsidence area, the subsidence rate increase along with the working surface close to point Z, the subsidence rate reach the maximum in the process of subsidence when the working surface pass directly below point Z, the subsidence rate drop off and gradually ceases with the working surface away from point Z and deep mining subsidence is completely in conformity with this law[11].

For example: Point Z is a point which is apart from the coal face within 30 meters. Probability-integral method predict the maximum surface subsidence value is 680mm and use the very short repeat period SAR can get the image of study region every six days. Monitoring data during one month sees Table 2.

<table>
<thead>
<tr>
<th>Date</th>
<th>Interval time (d)</th>
<th>Subsidence value(mm)</th>
<th>Interval of subsidence value(mm)</th>
<th>Subsidence rate(mm/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.83</td>
</tr>
<tr>
<td>X-7</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>2.00</td>
</tr>
<tr>
<td>X-13</td>
<td>6</td>
<td>12</td>
<td>7</td>
<td>4.00</td>
</tr>
<tr>
<td>X-19</td>
<td>6</td>
<td>24</td>
<td>12</td>
<td>5.83</td>
</tr>
<tr>
<td>X-25</td>
<td>6</td>
<td>35</td>
<td>13</td>
<td>8.00</td>
</tr>
<tr>
<td>X-31</td>
<td>6</td>
<td>48</td>
<td>13</td>
<td></td>
</tr>
</tbody>
</table>
It can get a surface subsidence curve by the way of the Monitoring data sees Figure 2

![Surface Subsidence Curve of Point Z](image1.png)

**Fig. 2** The Surface Subsidence Curve of Point Z: **Fig. 3** Surface Subsidence Time Curve of Point Z

The simple linear regression equation of surface subsidence curve of point Z

\[ y = 1.7917x - 7.1845 \]  \hspace{1cm} (1)

Take the maximum subsidence value as the threshold value for \( y \) can get that point Z will subsidence to 680mm 383.5 days later. Take the subsidence rate to calculate, the average rate of subsidence is 5.2mm/d, the maximum subsidence value is 680mm, and then point Z will reach to 680mm after 130.2 days. The subsidence rate of point Z will reach its maximum in 130 days after the mining start and the subsidence value will close to the maximum predicted subsidence value.

Point Z will subsidence to 680mm 383.5 days later, the subsidence value and the surface deformation velocity will become the maximum in first 130 days. The subsidence value will be close to the maximum predicted subsidence value and low down lately, finally reach to the maximum value, based on the comprehensive analysis the probability-integral method predict data, the simple linear regression equation of surface subsidence prediction and the subsidence rate. Surface subsidence time curve sees the Figure 3

### 4.3. Application Analysis of Deep Mining Subsidence Dynamic Prediction Method

The prediction of deep mining subsidence dynamic prediction method can get the subsidence rate and the time it last at any point in one or two months after the mining start.

The problem worthy of note in practical application of dynamic prediction method:

1. The selection of the SAR data: The chosen data source needs to have high-resolution, multi-line of sight angle and the shorter repeat period SAR data to get the images, which can get the high-resolution and higher temporal, spatial coherence. The cost of image is relatively increased because of the strict demand for quality of SAR images.

2. The selection of the prediction point: The prediction point need to be apart from the working surface within 30m. This point may obviously influence by the working surface and the trend analysis will be more accurate. Less influence on the prediction point beyond 30m, the deformation rate will lower
and the subsidence time will be longer than the point within 30m. The distance between the surface deformation point and the mining gob is proportional to the subsidence time and the distance between this point and the mining gob has the inverse ratio with the subsidence rate. The subsidence rate and the time it last along with the mining gob distribute in form of isoline.

(3) The range of dynamic prediction: The range of prediction point divide in the form of isoline based on mining gob effected in the selection of the range of dynamic prediction point. The range of mining gob influence is different according to the geological conditions, mining depth, mining methods in different region. The ranges of mining gob influence isoline partition have to base on the actual conditions during practical application.

5. Summary

The damage of environmental resource in mining area is become an important security issue for the sustainable development of mining area with the increase of the deep mining area. The deep mining subsidence prediction and monitor method should satisfy the demand for wide range and high precision. The theory proposed in this paper provides a reference dynamic prediction for deep mining subsidence as the new method of safety assessment of deep mining based on the analysis of the existing prediction and monitor methods. The deep mining subsidence dynamic prediction method combines the D-InSAR and probability-integral method can provide the subsidence area a rapid and dependable reference to judge for the damage of environmental resource. The theory can predict the maximum subsidence value, the subsidence time and the surface deformation rate before all the subsidence happened. The subsidence rate and time threshold calculated by deep mining dynamic prediction method can more accurately predict the level of deep mining subsidence and quantitative estimates the regularity of damage evolution of environmental resources, it also provide a dynamic evaluation factors for establishing the evaluation of environmental resource bearing capacity.

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