A three-dimensional simulation method of ground cracks based on images from drone

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Abstract: The ground cracks in the goaf will affect the safety of the local people and the ecological environment. Therefore, the three-dimensional model of the ground cracks can provide certain decision support for the coal mine safety production managers. In this paper, a three-dimensional model method for ground cracks based on images acquired by drones is proposed. Firstly, based on a small amount of original borehole data, Kriging interpolation method is used to generate enough stratum information, and the grid model is used to establish the original stratum three-dimensional model. Secondly, the image acquired by the drone is needs to be preprocessed, and the corner data is obtained as the key point of the crack by using the Harris algorithm. Thirdly, generate the three-dimensional model of the ground crack. It is inserted into the original three-dimensional model of the original stratum, and finally a three-dimensional model of the stratum containing the ground crack is obtained. The experimental verification shows that the method can effectively simulate the ground crack.

1. Introduction
The overburden will be deformed, fractured or broken after mining, thus extended to the ground to form ground fissures, it can cause unpredictable ecological and economic impacts on the local natural environment and people’s property[1-4]. Since the visualization of the three-dimensional model of the mining area can provide assistance for the safe production decision of the mining area, it has become one of the research hotspots in recent years. In China, it is common to use drilling information as the mainstay, combined with multi-source information such as profiles, remote sensing images, etc. for 3D modeling. For example, Xie Yijun[5], Li Qiaoqiao[6], and Tu Wensen[7] used borehole modeling. Guo Zhengyi[8] and Xu Mingxia[9] used multi-source data modeling.

In recent years, in the study of simulated ground fissures, some scholars have proposed three-dimensional modeling methods for geologic fractures[10]. For example, Dai Huayang[11] used multi-layer Tin model to simulate ground fissures. Xie Yijun used existing data to construct three-dimensional ground fissures in stratigraphic model, while Wu[12] uses fault control points and fault characterization data to derive its subsurface morphology, model the fault, and combine it with multi-layer DEM geological body model. This method can be applied to the modeling of ground fissures. WANG[13] proposed a three-dimensional virtual modeling architecture design method. However, in the above method, the acquisition method of the ground fissure data needs to be manually deployed to monitor the
device or further processed by the remote sensing image, and the above method is costly and time consuming.
Because the UAV acquires images with low cost and high real-time performance, it is widely used in many fields. Therefore, this paper proposes a three-dimensional simulation method of ground crack based on UAV images, which is based on the ground crack image of the mine obtained by the drone. After image pre-processing, the corner information of a single crack is obtained, which is used as the key control point of the boundary of the ground crack to generate the original three-dimensional data of crack, and then the Kriging interpolation is performed based on the drilling information, and the initial ground is obtained by using the grid dem model. Finally, combine with crack three-dimensional data to construct a three-dimensional model of ground cracks.

2. Algorithm structure framework
The simulation steps for the entire ground fissure in this paper are as follows:
Step 1: Records the drilling data through field survey, and inputs the drilling data into the computer file.
Step 2: Uses the drilling data to perform Kriging interpolation and to calculate the height of each stratum in order to simulate.
Step 3: The drone takes high-definition images of ground cracks, cropping the area of the ground crack, and eliminating the effect of the image outside the crack, so that the corner are identified.
Step 4: Analyzes the identified corner to obtain the ground crack line points, and then completes the ground crack modeling through the ground line information of the ground cracks.
Step 5: Intersects the ground fissure with the geological body and inserts the crack into the geological body model.

![Figure 1 Schematic diagram of the algorithm framework](image)

3. Stratum model establishment
3.1. Stratigraphic data
Stratigraphic data are mainly used for geological body modeling, which can be obtained from borehole sampling data or seismic exploration data. Each bottom data point (X, Y, Z) corresponds to the digital elevation information at the top of the formation. During exploration, the formation can be formed by drilling holes along the location (X, Y), and then by Kriging interpolation.

3.2. Stratigraphic data structure
The data structure of the stratum adopts the grid DEM stratum model, each layer represents the boundary of each stratum. In each layer, each triangle is closely arranged and regularly distributed. When the formation is initialized, the X and Y positions of each triangle have been determined, so the corresponding points on the triangle can be represented by coordinate system, and only interpolation is needed in the formation simulation. But after optimizing the grid model, we find that the position of the
points on the triangle can be fine-tuned. This greatly increases the flexibility of the formation model, and the insertion of formation control points will no longer be limited to fixed positions. Below are the grid DEM stratigraphic model sketches and data structure maps.

![Network DEM grid structure diagram and data structure diagram](image)

**Figure 2 Grid structure diagram and data structure diagram**

In Figure 2, X, Y and High represent the three-dimensional coordinates of points in Point, and Layer represents strata: it is composed of a set of altitude data. Each triangle in the sub-grid model consists of three control points. The point information includes X, Y, Z three-dimensional coordinate information to describe the spatial position, and texture coordinates u and v to describe the mapping position and reflect the height of a position in the stratum. The following figure shows the structure information of points and triangles:

![Point and triangle structure diagram](image)

**Figure 3 point and triangle structure diagram**

| Triangle | Point 1 | Point 2 | Point 3 |
|----------|---------|---------|---------|
| A        | Data1   | Data2   | Data3   |
| B        | Data4   | Data5   | Data6   |
| C        | Data7   | Data8   | Data9   |
| D        | Data10  | Data11  | Data12  |
|          | ...     | ...     | ...     |

| ![Point Data](image) |
|----------------------|
| X, Y, Z              |
| Three-dimensional coordinates of the point |
| u, v                 |
| Texture coordinates |

It can simulate the regional shape by changing the height information of a certain point. It has high plasticity and good simulation effect for terrain with extreme features such as fault line, geophysical line and tectonic line. Its data structure is very concise, and it can accurately, efficiently and reasonably express the surface morphology.

![Raster DEM model simulation diagram](image)

**Figure 4 Raster dem model simulation diagram**

### 3.3 Kriging interpolation

In this paper, Kriging interpolation method is used to obtain continuous stratum interface in stratum modeling. The basic idea is: after acquiring geological exploration sampling data (borehole data), it is converted into spatial discrete point data, and Kriging spatial interpolation method is used to generate regular structured data, thus forming three-dimensional spatial volume data. Among the current data
interpolation modeling methods, Kriging method is the most commonly used and the most accurate one. Kriging method is usually used as an interpolation method in spatial modeling of ore bodies and geological bodies. In this paper, Kriging method is used to interpolate the geological body model in the region, and consequently the continuous stratum data are obtained. Finally, the geological body model is modeled by stratigraphic superposition.

4. Ground model building

4.1. Identify ground single crack corner

The corner point of the ground fissure is actually a kind of control point that plays a key role in fitting the ground fissure process (Figure 5). The points marked by the circle in the figure are the control points of the ground fissure. The simulation of surface cracks mostly uses such a series of control points. The distribution of most points is similar to the shape of cracks. Most of the points are similar in shape and shape to the cracks. They are distributed in a narrow and discrete shape are roughly symmetrically distributed. A narrow polygon with a crack can be simulated by connecting the edge points. In general, the more the number of corner of the ground fissure, the more realistic the three-dimensional model is fitted, and the closer the shape is to the real crack.

![Figure 5 Introduction to the corner point](image)

For the acquisition method of the ground crack corner point, the field survey method is mostly used before. This method is not only time-consuming but also the data measurement is not accurate. Therefore, this paper adopts a convenient and fast way to obtain the corner point, that is, the use of no The man-machine performs high-altitude overhead shooting to obtain a vertical high-definition view of the ground crack, and after image pre-processing, the image can be identified by the Tomasi algorithm.

In this paper, the Tomasi algorithm is used for corner detection. The basic idea of Tomasi corner detection method is to select a sizing window to scan the gray value of the image. In the process of window movement, calculate the gray value change in each direction. The greater the change, the greater the probability that the corner point of this area is located, so it is necessary to find the value of $E(u,v)$ is as large as possible. Carrying out the formula (1) Taylor expansion in order to improve the anti-interference ability and simplify the operation, the only first derivative part is taken, and the following infinitesimal quantity $O(u^2+v^2)$ can be ignored, and the expression is as follows: Available formula (2):

$$E(u,v) = \sum_{x,y} w(x,y)[f_x + f_y v + O(u^2 + v^2)]^2 \approx \sum_{x,y} w(x,y)[f_x u + f_y v]^2$$

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The expansion of \([I_xu + I_yv]\) is simplified again and expressed as a formula (3) using a matrix:
\[
[I_xu + I_yv]^2 = [u, v] \begin{bmatrix}
I_x^2 & I_xI_y \\
I_xI_y & I_y^2
\end{bmatrix} [u, v]
\] (3)

Finally, the expression of the gray value change \(E(x, y)\) is approximated, and it is converted into a quadratic form to obtain the formula (4):
\[
M = \sum_{x,y} w(x, y) \begin{bmatrix}
I_x^2 & I_xI_y \\
I_xI_y & I_y^2
\end{bmatrix}
\] (4)

Step3: Analyze the quadratic form of the gray value change formula. M is a 2×2 matrix. The expression of M is strongly correlated with the position \((x, y)\) of the pixel. The eigenvalues of M are \(\lambda_1, \lambda_2\). The values of \(\lambda_1, \lambda_2\) are the gray-scale change rates in the x-direction and the y-direction, respectively, and the regions on the picture are classified by the magnitude relationship of \(\lambda_1\) and \(\lambda_2\) (see Figure 6):

![Figure 6 Classification diagram](image)

Where flat is a flat area, edge is an edge area, and corner is a corner point.

1. When the two eigenvalues \(\lambda_1\) and \(\lambda_2\) are both small, indicating that the window moves in any direction will make the gradation change very fine, and the point is in the flat area of the image.

2. When \(\lambda_1 \gg \lambda_2\) or \(\lambda_1 \ll \lambda_2\), it means that the change will be obvious when moving to the horizontal (vertical) direction, and to the vertical (horizontal) direction. The change is not obvious, and the point is in the edge region of the image.

3. When both eigenvalues \(\lambda_1\) and \(\lambda_2\) are large, indicating that the window moves in any direction will make the gradation change obvious. The position of the point is the position of the corner point in the image.

Step4: Finally, after classifying the image region using the eigenvalues \(\lambda_1\) and \(\lambda_2\), we use the corner response function R to perform an accurate calculation to obtain the corner (as in equation (5)).
\[
R = detM - k(traceM)^2
\]
\[
detM = \lambda_1\lambda_2
\]
\[
traceM = \lambda_1 + \lambda_2
\] (5)

Where k is a constant, the range of values is generally 0.04-0.06, R is only related to the eigenvalue of M. When R is a large numerical positive value, the point is a corner point, and when R is a large numerical negative number, the point is in edge area, when R is in small value, the point is in a flat area.

4.2. Obtaining the ground fracture line and the ground fissure area
The ground fissure fold line that can abstractly represent the morphological features of the ground fissure (Figure 7), the solid line part is the ground fissure fold line, and the dotted line part is the ground line of the ground fissure. Because the information below the ground is difficult to obtain, this paper derives the ground fracture line through the ground crack control point and ground crack characteristics. After the image algorithm of the ground fissure is identified, the information of a set of corner of the ground crack is obtained, and then the coordinate information of the corner is distinguished. The following describes the distinguishing algorithm:
Figure 7 shows the ground crack line chart.

The general idea of distinguishing the algorithm is as follows: The center line is used to distinguish whether the crack corner point belongs to the left edge of the crack or the right edge of the crack, and the left corner of the middle line is the left corner point, and the right side is the right corner point. Specific steps are as follows:

Step 1: According to the trend of the ground fissure, the X class indicates a large change in the X direction, and the Y class indicates a large change in the Y direction (Figure 8).

Step 2: Since the coordinates of the points above the formation have been roughly determined, the center line can be inserted in the corresponding place of the ground fissure area of the stratum. If the trend is X, the center line coordinates \((x_1, y_1, z_1), (x_2, y_2, z_2), (x_3, y_3, z_3), \ldots (x_n, y_n, z_n)\), input in the order of the size of \(x\), and vice versa, input in the order of the size of \(y\).

Step 3: The line between two consecutive points in the midline of the ground fissure forms an interval line, such as \((x_1, y_1, z_1)\) and \((x_2, y_2, z_2)\). Form an interval line between \(x\) and \(y\), and form \(x\) and \(y\) between \((x_2, y_2, z_2)\) and \((x_3, y_3, z_3)\). The relevant interval line, the \(x\) (X class) or \(y\) (Y class) interval segments thus formed are all connected and arranged in order of size.

Step 4: Distinguish the corner, first coordinate the coordinates of the corner to the coordinates of the ground. Since the corner is read from the image, the acquired position is the relative position of the image. In this paper, the coordinate stakes are transformed by panning the coordinates of the corners and multiplying the zoom factor, so that the ground crack corner points are translated to the corresponding position of the formation. After the coordinate transformation, find the interval that matches the corner coordinate, that is, find the straight line of the interval (the straight line formed in Step 3), then substitute the corner coordinate into the straight line, judge whether it is greater than 0 or less than 0, and then separate the left edge of the crack. And the right edge point (Figure 9).

After the distinction, all the distinguished corner are divided into two categories: the crack left control point and the crack right control point, and the left and right control points are respectively stored by the two sets of the left control point set and the right control point set, and the center line starting point is
first Put the left and right control point sets, and then put the left crack control points into the left control point set according to the size of x (X class) or y (Y class). Similarly, the right crack control point is x (X class) or y. The size of the (Y class) is sequentially placed in the right control point set, and finally the center line end point is pressed into the left and right control point sets, and the points of the left and right control point sets are connected in the order in which they are placed, so that a closed fold line can be formed. The left and right ground cracks are broken.

In this paper, the ground fissure region is obtained by the left and right ground fissure fold lines, using a set \([x_1, y_1), (x_2, y_2), (x_3, y_3) \ldots (x_n, y_n)]\). The point at which the ground fissure area is stored. This set will be used for the construction of the ground fissure body and the intersection with the formation. Since the ground fissure fold line is also in the stratum coordinates, the ground fissure area can be obtained by traversing all points on the stratum. For the point on the stratum, as long as it is located between the two ground fissure fold lines, it is the area where the ground fissure is located, and the left ground is set. The left ground crack line is P1, and the right ground crack line is P2. For any point on the formation, the position altogether to P1, P2 is determined by the distinguishing algorithm, and the point between the two fold lines can be added to the set of ground fissure regions. After all the points in the formation have been traversed, the acquisition of the ground fissure area is completed.

4.3. Ground fracture body structure

The main idea is to assume that the midline of the ground fissure is roughly in the middle position, and the height is closer to the similarity (value) of the distance from the midline. When the ground fissure edge control line is reached, the height of the edge of the ground fissure remains similar, similar to the inverse distance interpolation method, the algorithm steps are as follows

Step 1: Obtain the width of each position of the crack one by one.

1) Traverse all points in the ground fissure region, and mark these points as \((x_1, y_1), (x_2, y_2), (x_3, y_3) \ldots (x_n, y_n)\), The point at which the ground fissure area is stored. This set will be used for the construction of the ground fissure body and the intersection with the formation. Since the ground fissure fold line is also in the stratum coordinates, the ground fissure area can be obtained by traversing all points on the stratum. For the point on the stratum, as long as it is located between the two ground fissure fold lines, it is the area where the ground fissure is located, and the left ground is set. The left ground crack line is P1, and the right ground crack line is P2. For any point on the formation, the position altogether to P1, P2 is determined by the distinguishing algorithm, and the point between the two fold lines can be added to the set of ground fissure regions. After all the points in the formation have been traversed, the acquisition of the ground fissure area is completed.

Step 2: Calculate the distance between a point in the ground fissure area and the center line:

\[
\text{distance}(x_{\text{fissure}}) = x_{\text{fissure}} \cdot y - x_{\text{center}} \cdot y
\]

Step 3: Calculate the height of the point based on the assumed height and the distance:

\[
f(x) = h_z + 2(h_b - h_z) \times \text{distance}(x) \times \text{wide}^{-1}
\]

Where f(x) is the height of the point x in the ground fissure region, h_z is the height of a point in the midline of the ground fissure, h_b is the height of the point at the edge of the ground crack, distance(x) is the distance from the point x of the ground crack in the vertical x-axis (Y-type) direction to a point on the midline of the corresponding ground crack, and the width is the distance of the ground crack in this direction. According to the above formula, the linear reconstruction height of each point can be obtained. The amount of data required for this reconstruction method is small, and it is suitable for simulating the shape of the trend comparison rule, and there is no crack with a sharp height change on the side slope. Similarly, because the amount of data required is small, the actual shape of the ground fissure may not be more vividly simulated. Only on the basis of increasing the amount of data, it is possible to simulate a more realistic crack.

5. Intersection of ground fissure and stratum

After the local layer model and the ground fissure model are completed. It is necessary to insert the ground fissure into the stratum model. The main idea is intended to cover the acquired ground fissure body data onto the stratum so that the ground fissure is embedded in the stratum. The algorithm steps are as follows:
Step 1: Obtain all the points of the ground fissure region \((x_1, y_1, z_1), (x_2, y_2, z_2), (x_3, y_3, z_3), \ldots (x_n, y_n, z_n)\).

Step 2: Find the point where the \((x, y)\) of the stratum surface is close to the \((x, y)\) of the ground fissure area. Since the edge point of the ground fissure area does not necessarily coincide with the initial point of the grid stratum model, it is necessary to carry out the similar point. Fine-tuning changes its position to make it coincide. The following is a schematic diagram:

![Ground fracture control grid point fine tuning](image)

Figure 10 Ground level fine-tuning diagram

Step 3: Set the elevation information \(z\) of the coincidence point to the elevation information of the ground crack, and the original regional stratum information is covered, so that the information of the ground fissure is transferred to the visualized stratum.

Step 4: Repeat Step 2 and Step 3 until all the points in the ground fissure area are set, thus completing the embedding of the ground fissure body. So the ground cracks can be observed.

6. Experiment
This experiment was simulated in the environment of Windows10 64-bit 8G memory computer, i7-7700HQ CPU and DirectX 9.0 environment.

The stratum information selected in this experiment from Red Willow Forest Coal Mine. (Shenmu County, Shaanxi Province, China).

1. Collect drilling data and write the data to a file for Kriging interpolation.
2. The drone takes pictures of the ground cracks, selects the corresponding areas, and manually performs image cropping and corresponding processing.
3. The corner image recognition algorithm performs corner recognition (see Figure 11):
4. The simulation is based on the midline information of the exploration and the corner point. The effect is as follows (see Figure 12):

![Corner recognition map](image) ![Ground crack simulation](image)

The simulated ground fissures were compared with the real ground fissures. It was found that the two were similar in shape and the simulation effect was very good, which confirmed the feasibility of the method adopted in this paper.

7. Conclusion
(1) This paper uses Harris algorithm to extract corner from the ground crack image taken by the drone, and makes three-dimensional simulation based on the grid model, which is simple and effective.
(2) The model of individual ground crack is very similar to real crack using the method in the paper.
(3) The future research direction is to simulate the 3D data model with higher precision for complex multi-crack selection, and consider the ground subsidence data after extraction to establish a more accurate surface primitive model.

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