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Study on UAV Image Extraction of Surface Crack Information Technology in Goaf

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Abstract

The problem of extracting surface crack information in mining area is studied. The unmanned aerial vehicle (UAV) image is used as the data source for multi-scale segmentation. The rule set is constructed based on the spectral and shape features of surface cracks. The object-oriented extraction of crack information is carried out by using the principle of fuzzy classification, and the surface crack information in mining area is successfully extracted. The extraction accuracy of surface cracks is evaluated by five indexes: automatic extraction number, extraction rate, automatic extraction total length, length extraction rate and position overlap rate. Through statistical analysis, the overall extraction rate of surface cracks by object-oriented technology reaches more than 80%, which proves that this method has high accuracy. This paper aims to explore an effective fracture extraction method suitable for the surface conditions of Jinchuan copper nickel mine. The feasibility of applying UAV technology to visual monitoring of surface cracks in goaf is confirmed.

Subject Areas

Environmental Sciences, Mineral Engineering

Keywords

UAV Image, Object Oriented Information Extraction, Goaf, Surface Crack

1. Introduction

1.1. Research Background

The deformation and failure process of rock stratum and surface caused by underground mining is an extremely complex time and space phenomenon. When underground resources are mined out, a goaf is formed in the rock stratum, the stress balance of the surrounding rock mass is destroyed, and the rock mass is stretched, deformed and damaged. With the continuation of mining, the above complex physical and mechanical processes are repeated, and the mining impact finally reaches the surface, resulting in various forms of damage [1] [2]. Surface crack is one of the typical geological disasters caused by mining. On the one hand, the occurrence of surface cracks will bring major potential safety hazards to underground production; especially when the surface cracks are connected with the goaf, there may be safety accidents, such as air leakage, water and sand collapse. On the other hand, it will cause irreversible damage to the ecological environment of the mining area, such as vegetation degradation, river interruption, water and soil loss and so on [3]. Therefore, in order to timely and comprehensively understand and master the large-scale fracture geological disasters in the mining area, predict the potential hazards, reduce or avoid the economic losses caused by surface cracks, and provide a scientific basis for the comprehensive treatment of the mining area, we must first obtain the real-time, objective and high-precision distribution information of surface cracks in the mining area [4].

1.2. Research Status

Due to the influence of data spatial resolution, acquisition conditions and other factors, the use of satellite data cannot identify small width fractures, and the data acquisition is limited by the revisit period of satellite, so it cannot be applied to the dynamic monitoring of fractures; traditional field exploration and measurement methods have the highest data accuracy, but they are constrained by various environmental factors such as topography and regional scope, and they are time-consuming and labor-consuming [5]. In recent years, UAV remote sensing has developed rapidly. It has significant advantages, such as low cost, short revisit cycle, fast and efficient, light and flexible, simple operation, high temporal and spatial resolution of images [6], and less affected by topography [7]. It can realize the rapid acquisition of remote sensing images of coal mining surface subsidence area, and provide an ideal data source for the information extraction of ground fissures in mining area [8].

1.3. Overview of the Study Area

Jinchuan copper nickel mine is one of the three major metal symbiotic mines in China, located in Jinchang City, Gansu Province, China (101˚4'35" - 102˚43'40"E, 37˚47'10” - 39˚00'30"N). It is one of the important nickel sulfide copper mining areas in China [9]. The deposit consists of four mining areas [10]. The deposit is located in the Longshoushan uplift on the southwest edge of the Alxa uplift area of the Sino Korean quasi platform, with the inner area of the platform in the north and the Qilian Mountain fold system in the south [11]. The study area in this paper is the collapse area of the West Second Mining Area of Longshou Mine of Jinchuan copper nickel mine. The vegetation type of the West Second mining area is mainly low and sparse xeric and semi xeric vegetation, and the vegetation coverage is low, as shown in **Figure 1**. There is no surface water system passing through the relative position of the ground in the mining area, which is covered by thick aeolian sand. With the deepening of underground resource exploitation, the overlying surrounding rock of the mining area is unstable, and a large number of annular and intricate fracture groups and large collapse pits appear on the surface.

2. UAV Image Acquisition and Processing

The basic data of this paper is the UAV image on June 27, 2021. The flight platform used is Dajiang spirit 4 RTK 4 rotor UAV, which is equipped with Dajiang fc6310r camera. The main technical parameters of the UAV are shown in **Table 1**. The UAV is equipped with Dajiang fc6310r camera. According to the camera calibration report, the camera parameters are shown in **Table 2**. In this paper, the image point displacement is 1.205 um and the flight speed is controlled at 10 m/s. Due to the visual monitoring and analysis of the surface cracks in the study area, most of the surface cracks are more than 2 cm wide. Combined with the camera parameters, the ground resolution of the UAV image is set to 2 cm, and the relative altitude is about 73 m calculated by the UAV relative altitude formula (1).

$$H = \frac{f \times GSD}{a}$$

In formula (1), GSD is the ground resolution, m; f is the focal length of camera lens, mm; a is the pixel size of the camera, mm.

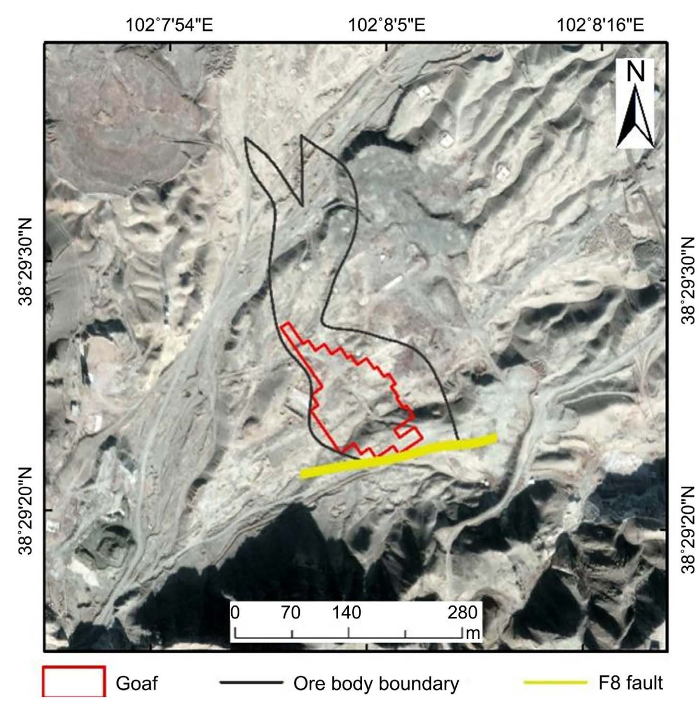


Figure 1. Overview of the study area.

Table 1. Main technical parameters of UAV.

Index	Parameter
Maximum horizontal flight speed	13.89 m/s
Maximum rising speed	6 m/s
Working ambient temperature	0˚ - 40˚
Maximum withstand wind speed	10 m/s
Satellite positioning	Single frequency high sensitivity GNSS/Multi frequency multi system high precision RTK GNSS
Obstacle perception range	0.2 - 7 m
Shutter speed	8 - 1/2000 s

Table 2. Camera parameters.

Index	Parameter
Sensor size	13.2 mm × 8.8 mm
Resolving power	5472 × 3648 pixel
Pixel size	2.41 μm
Focal length	8.8 mm

The data processing system selects ContextCapture image processing professional software. The software can quickly make multiple images into accurate two-dimensional images and three-dimensional real scene models. Import aerial survey images, coordinate POS and other data into ContextCapture software, successively complete image matching, aerial triangulation, dense matching, triangulation and texture mapping, and finally generate DOM (Digital Orthophoto Image), DEM (digital elevation model) and 3D real scene model. According to the common points obtained from ground control survey, the elevation fitting correction model of four parameter surface fitting is used to fit and correct the three-dimensional coordinate data obtained from UAV aerial survey.

3. Face to Face Feature Extraction of Surface Fracture Image

3.1. Multiscale Segmentation

In multi-scale image segmentation, scale is the threshold of the minimum heterogeneity of polygonal objects. The size of scale directly determines the size of the generated polygonal objects. For remote sensing images with a certain spatial resolution, the larger the segmentation scale, the larger the area and fewer the number of polygon objects generated. On the contrary, if the segmentation scale is smaller, the smaller the area and more the number of polygon objects generated. For a certain type of ground object in the image, the ideal situation is that after segmentation with a certain segmentation scale, the obtained polygonal object can clearly show the boundary of the ground object, and can express this kind of ground object with one or several objects, that is, it cannot be too broken or the boundary cannot be blurred. In multi-scale image segmentation, the smaller the segmentation scale, the higher the accuracy of information extraction. Although many small edges can be retained by using a small segmentation scale, there will be a lot of noise in the image at the same time, and there will be obvious over segmentation in the corresponding segmentation results; The use of a large segmentation scale will reduce the impact of noise, but it will thicken the edge at the same time, which may merge two adjacent edges, and the corresponding segmentation results will be insufficient. The error caused by insufficient segmentation is difficult to recover in the classification process, which affects the classification accuracy of the image. For different feature types in the image, the optimal segmentation scale is not absolute, but relative. If a certain scale is optimal for one feature, but not necessarily optimal for other features, each feature type in the image has its own optimal segmentation scale. The effect of multi-scale segmentation is controlled by three parameters: segmentation scale, band weight and mean factor.

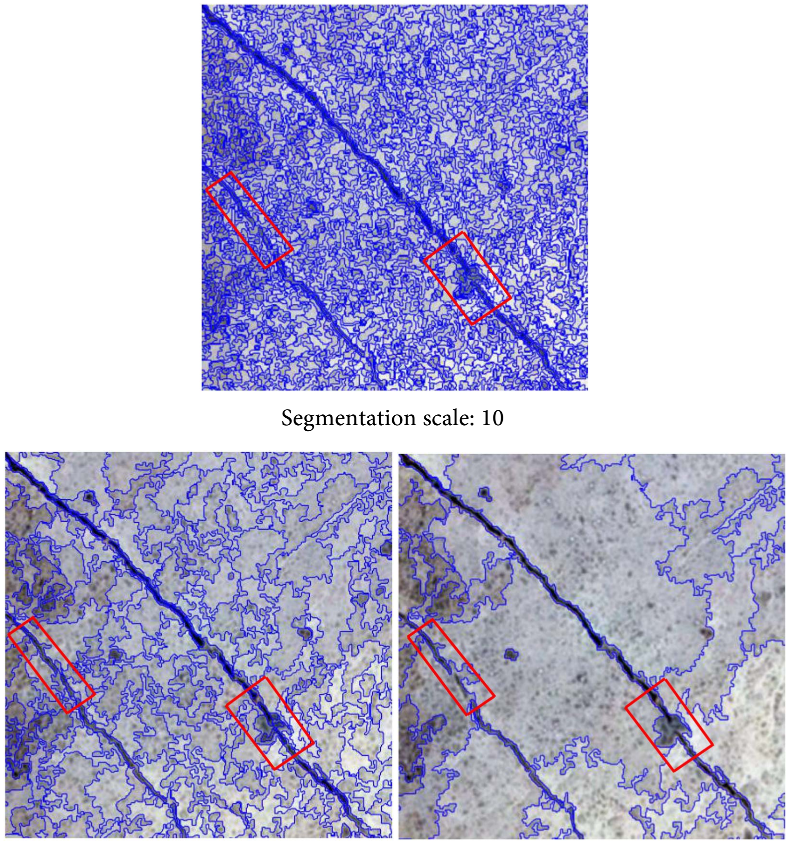
1) Segmentation scale

The segmentation scale is the heterogeneity threshold of image objects. Each segmentation and merging of image objects will calculate the object heterogeneity value and judge the size of the heterogeneity value and the predetermined threshold (*i.e.* segmentation scale). When the heterogeneity value is less than the predetermined threshold, the lower objects are merged; When the heterogeneity value is greater than the predetermined threshold, the merging is stopped. The segmentation scale determines the size, number and classification accuracy of the minimum polygon, and is an important parameter for the quality of image segmentation results.

Figure 2 is the experimental takes the color factor and compactness as the default values, and compares the object segmentation under different scales. Compare the object segmentation under different scales. If small-scale segmentation is adopted, the segmented object is too fragmented, and the overall information of features is lost, which affects the classification accuracy in the later stage. Similarly, large-scale segmentation is adopted. An object contains a variety of ground objects, which increases the homogeneity of different types of objects and affects the extraction accuracy; Several analysis and comparison experiments are carried out to find the parameters corresponding to the optimal segmentation results. In this paper, in the experimental process, under the condition of ensuring the same other factors, taking scale 10 as the starting data and interval 10 as the unit, many experiments determine that the best segmentation scale is 50.

2) Band weight

The band weight indicates the influence of the band on the segmentation results in the process of image segmentation. The band weight should be set according to the extracted figure type. If the extracted feature information has obvious characteristics in this band, a large weight can be given to this band; If the band has little contribution to feature information extraction, the weight of the



Segmentation scale: 10

Segmentation scale: 40 Segmentation scale: 100

Figure 2. Segmentation scale experiment.

band can be assigned to 0. Under the general extraction task, in order to remove redundant information, emphasize useful bands and improve the segmentation speed, users will reasonably set the segmentation weight of each band according to the variance (the greater the variance, the greater the amount of band information).

3) Mean factor

The mean factor includes spectral factor and shape factor, and the sum of their weights is 1. The shape factor includes two attribute factors: smoothness and compactness, and the sum of their weights is also 1. Compactness refers to the compactness of the image object, which is conducive to maintaining the consistency of features; Smoothness indicates the smoothness of the image object boundary.

Figure 3 shows the experimental diagram of shape factor. The experimental setting of segmentation scale 40, compactness 0.5, and comparison of shape factors 0, 0.2 and 0.9. It can be seen from the figure that the shape of the feature is too broken when the color factor is fully used; However, if the weight of the shape factor is set too high, a large amount of spectral information will be lost during segmentation, and the segmentation results will not be available. Therefore, when setting the mean factor, the weight of color factor and shape factor should be reasonably allocated. In most cases, in order to create valuable objects, the weight of color factor should be set relatively large, assisted by shape factor to maintain the integrity of image. After many experiments, the shape factor is set to 0.2 and the color factor is set to 0.8.

Figure 4 shows the experimental diagram of compactness factor: the experimental setting of segmentation scale 40, shape factor 0.2 and comparison of compactness 0, 0.6 and 0.9. It can be seen from the above figure that when the scale parameters and shape parameters are certain, the smaller the compactness is, the more broken the shape of the segmentation result is, and the boundary is more consistent with the characteristics of ground features; The greater the compactness, the higher the structural consistency of similar features, but the smaller the boundary stability. After many experiments, the compactness is set to 0.6 and the smoothness is set to 0.4.

Due to the complexity of multi-scale segmentation technology, it is difficult to predict the impact of different segmentation parameters on image segmentation results [12]. It takes a lot of time to conduct experiments to determine a relatively optimal segmentation parameter to obtain satisfactory segmentation results.

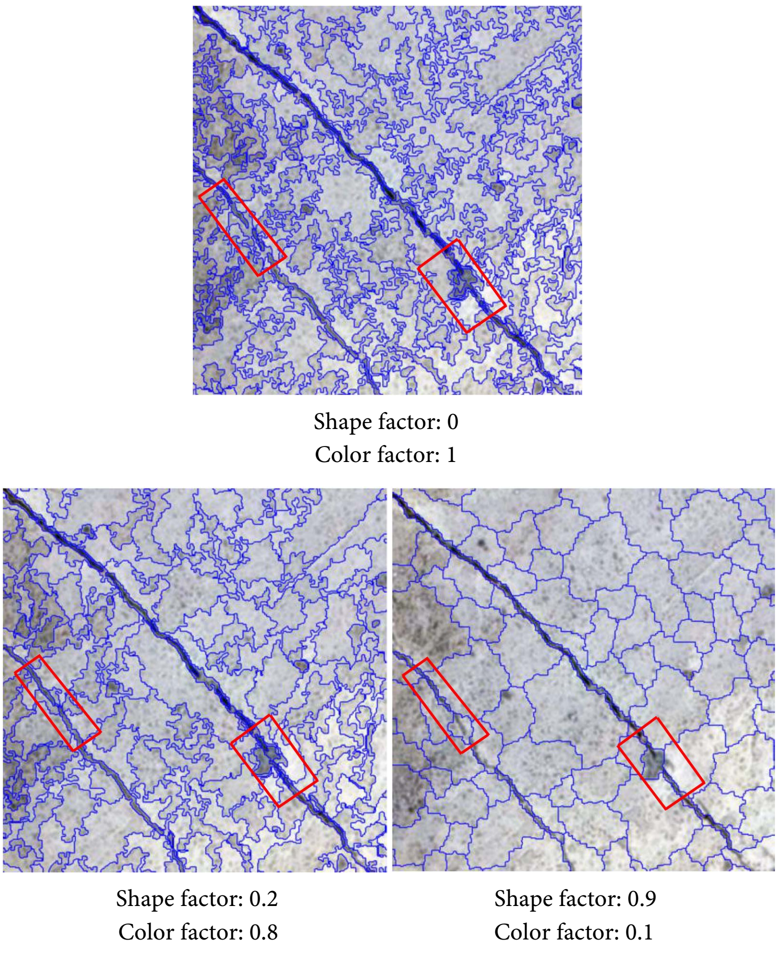


Figure 3. Shape factor experiment.

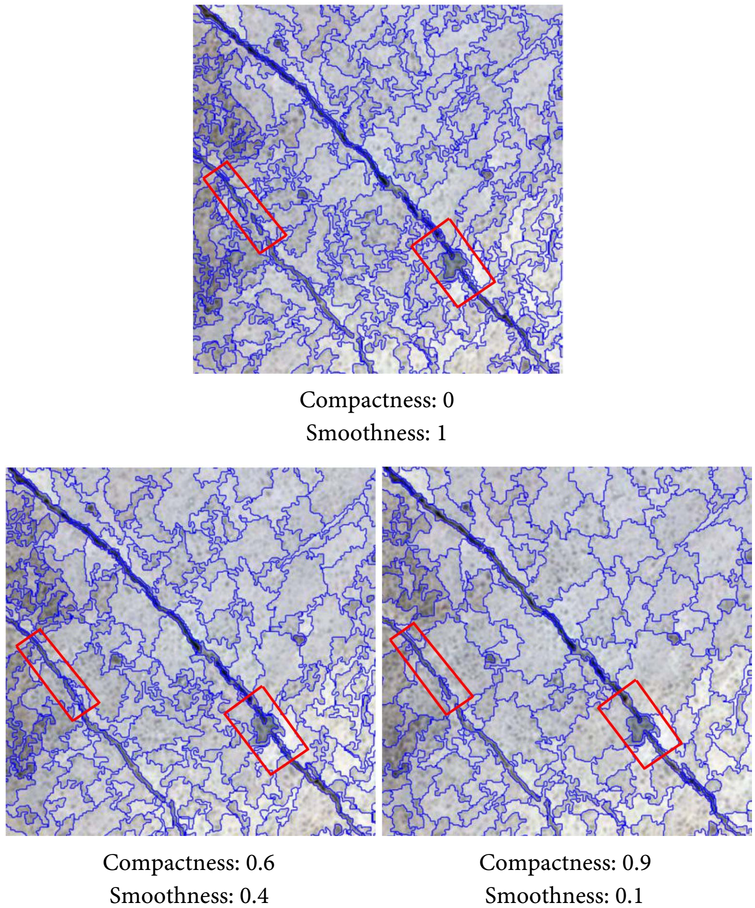


Figure 4. Compactness factor experiment.

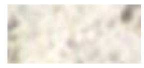
3.2. Eigenvalue Analysis of Surface Cracks

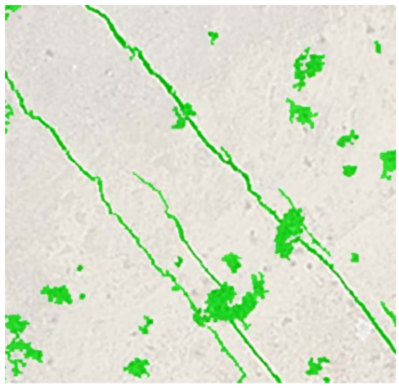
Feature extraction is a very important link in object-oriented analysis method. The feature information reflected by image objects is the main basis of remote sensing image information extraction. The spectrum, texture, shape and context features of image objects are important basis for information extraction [13]. The main features in the goaf include bare land, sandy soil, vegetation and surface cracks. The interpretation signs of typical feature types are shown in **Table 3**.

1) Analysis of spectral characteristics of surface cracks

Spectral feature is the essential feature that distinguishes one kind of ground object from another. It is the reflection of the composition, structure and other attributes of ground objects. It is the most important and direct information to extract texture and shape in remote sensing image classification. Although the brightness of the remote sensing object is low, it is usually a kind of material with low reflectivity on the surface, but it is not reflected in a certain depth. According to the statistics, the mean value of brightness characteristics in the spectral characteristics of surface cracks in the study area is basically stable between 110 - 135, the average brightness value of the image is between 158 - 175, and the brightness of surface cracks is obviously small. **Figure 5** shows the effect of threshold selection of spectral features.

Table 3. Interpretation marks of typical feature types in Goaf.

Land type	Features of ground features	Corresponding image
Bare land	Brown or light yellow, uniform tone or yellow with gray, irregular shape	
Sand	Gray or dark gray, uniform tone or white in gray, irregular shape	
Vegetation	Dark green or black with green strips, gray with white, obvious boundary, and the shape is mostly dot or partial circle	
Collapse pit	The whole is black, the edge part is brownish yellow, and the shape is mostly circular, which is generally closed	
Crack	Black or light yellow, uniform internal tone, generally linear, streamline, curved strip, linear outline as a whole and obvious boundary	



Brightness (110 - 135)

Figure 5. Effect diagram of threshold selection of spectral features.

2) Analysis of shape characteristics of surface cracks

Shape is an advanced visual feature in image, which is mainly characterized by geometric parameters. It is used to measure and calculate the geometric parameters of image objects. The shape feature can be used to recognize the ground objects with certain geometric shape on the image. Shape features include the area, length, width, aspect ratio, area, shape factor, density, main direction, extension line, symmetry and position of the image object. In the high-resolution remote sensing image, the surface cracks show the geometric shape of linear, broken line, bifurcation or irregular shape extending along a certain direction, which has good extensibility, which is one of the main characteristics different from other ground objects or geological phenomena. Therefore, this paper calculates five parameters: asymmetry, density, roundness, ellipse fitting and shape index to analyze the shape characteristics of surface cracks.

Asymmetric features describe the relative length of image objects compared with ordinary polygons. Ellipse is similar to a given image object. It can be expressed by the length ratio of its minor axis to its major axis. The eigenvalue increases with this asymmetry. The density feature describes the distribution in the pixel space of the image object, and the most "dense" shape is square; The more an object looks like a filament, the lower the density. The density is calculated by dividing the number of pixels constituting the image object by its approximate radius based on the covariance matrix. The roundness characteristic describes the similarity between an image object and an ellipse, which is calculated by the difference between the closed ellipse and the closed ellipse. The ellipse fitting characteristic describes the fitting degree of the image object in an ellipse with similar size and proportion. This calculation is based on an ellipse with the same area as the selected image object. The area of the image object outside the ellipse is compared with the area not filled by the image object in the ellipse. The proportion of the ellipse is equal to the length and width of the image object, 0 indicates mismatch and 1 indicates complete match. The shape index describes the smoothness of the border of the image object. The smoother the border of the image object, the lower the shape index. It is calculated by dividing the boundary length feature of the image object by four times the square root of its area.

Through the statistics of the shape characteristics of surface cracks in the study area, the characteristic threshold of the shape characteristics of surface cracks is obtained. Figure 6 is the effect diagram of threshold selection of each shape feature.

As can be seen from Figure 6, due to the slender shape of surface cracks, the mean value of asymmetry characteristics is large and the range of characteristic values is small. Density is one of the main characteristics that distinguish surface cracks from other ground features. Because surface cracks are closer to linear in image, the density is small. The surface cracks are linear and not similar to ellipses, so the roundness is small and the ellipse fitting degree is also small. The shape index describes the smoothness of the boundary of the ground object. From the image, it can be seen that the edge of the surface crack is clear and more fine, so the shape index is large.

3.3. Rule Extraction Based on Multi Features

1) Construction of surface crack extraction rule set

Through multi-scale segmentation, the polygonal objects for further classification are obtained. Based on the spectral and shape feature values calculated above, the fuzzy membership function classifier is used to construct the fuzzy rule set for surface crack extraction, as shown in Table 4.

2) Extraction of surface cracks based on multi features

Because there are few features in the study area and the proportion of bare land is relatively large, the hierarchical structure of bare land and non bare land is established first. The brightness characteristic value of bare ground on the enhanced image is greater than that of surface cracks. The brightness characteristic value range can be set as 110 - 135 according to the spectral characteristics of surface cracks, and the bare ground part can be eliminated.

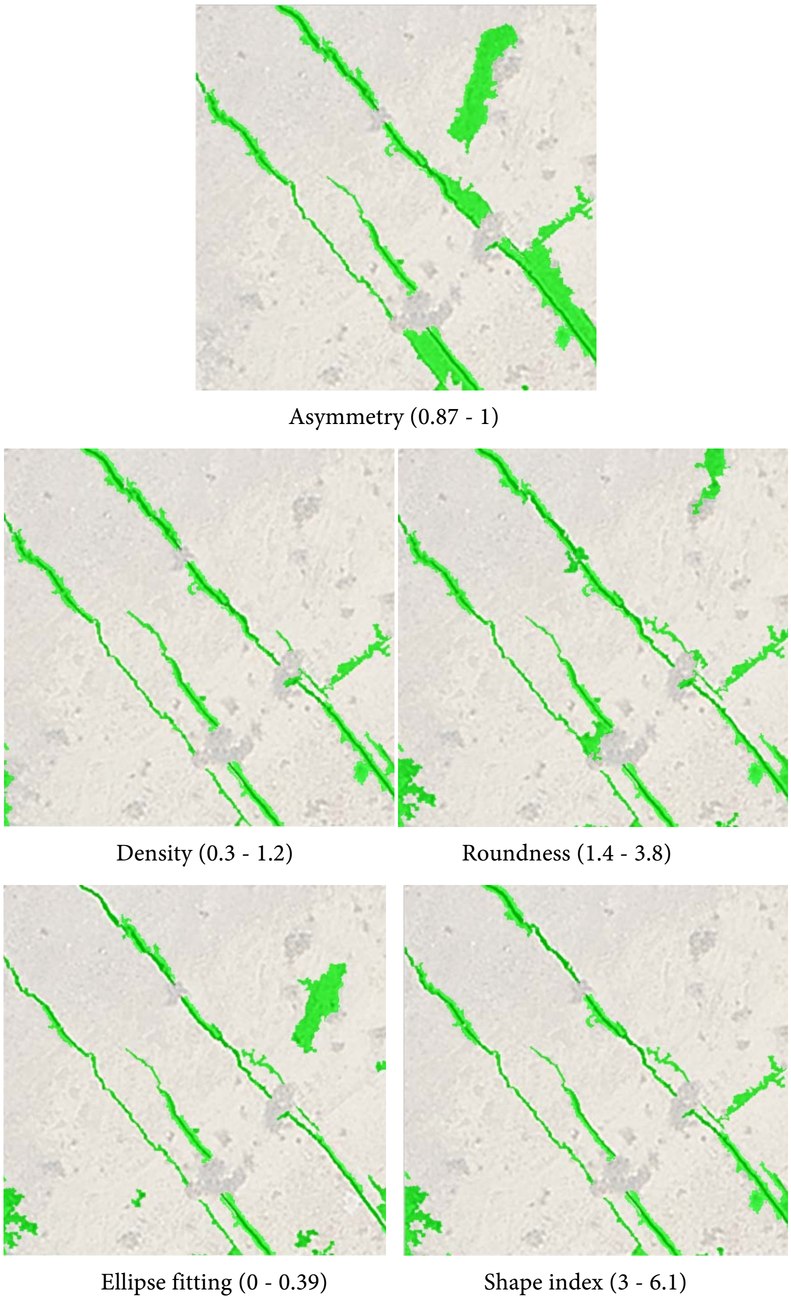


Figure 6. Effect drawing of threshold selection of shape features.

Table 4. Fuzzy rule set.

Features	Characteristic threshold range
Brightness	(110 - 135)
Asymmetry	(0.87 - 1)
Density	(0.3 - 1.2)
Roundness	(1.4 - 3.8)
Ellipse fitting	(0 - 0.39)
Shape index	(3 - 6.1)

Then classify the non bare land. Because the brightness characteristics of surface sand, roads and vegetation are similar to those of surface cracks, the non bare land is divided into cracks and non cracks. According to the shape characteristics of surface cracks, extract the information of surface cracks and eliminate the information of non cracks.

4. Analysis of Object-Oriented Automatic Extraction Results

4.1. Rule Extraction Based on Multi Features

Firstly, the UAV image is enhanced by using the above methods, the relative rule set is constructed, and the object-oriented extraction is carried out. Because the surface features are relatively simple and the interference is relatively less, the better extraction effect is achieved. The UAV image extracts the surface crack information, as shown in Figure 7. The extraction effect of some cracks is shown in Figure 8. Due to the dark color of surface vegetation and dirt roads, some ground objects are wrongly extracted, as shown in Figure 9.

4.2. Accuracy Analysis of Object-Oriented Automatic Extraction

In order to verify the accuracy of object-oriented automatic extraction results, combined with length statistics and position statistics, the overall accuracy of automatic extraction is evaluated, and the causes of errors are discussed. For the accuracy analysis of surface cracks, this paper evaluates the following five quantities: the number of automatic extraction, the number of extraction rate, the total length of automatic extraction, the length extraction rate and the position overlap rate.

It can be seen from Table 5 that the number and length of surface cracks automatically extracted are slightly less than the actual length of cracks. On the whole, the extraction rate has reached more than 80%, which has achieved a good recognition effect and can meet the monitoring requirements of surface cracks.

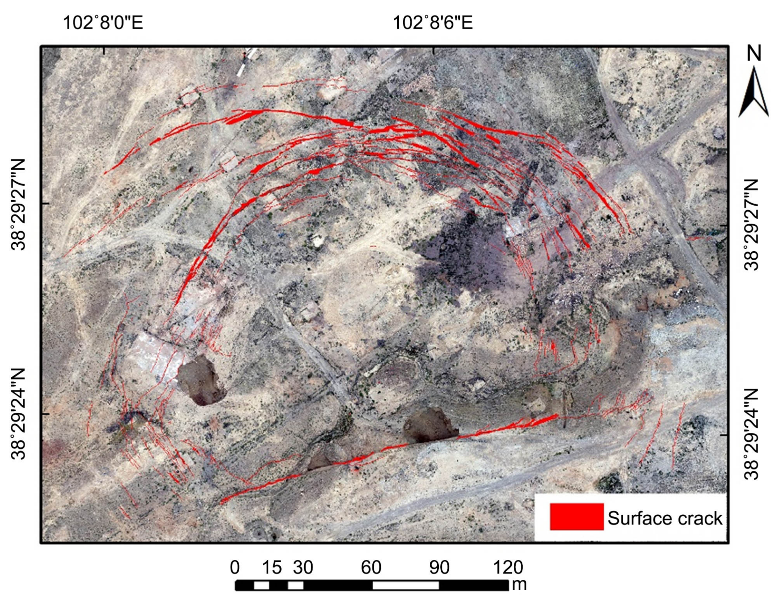


Figure 7. Surface crack extraction results of UAV image.

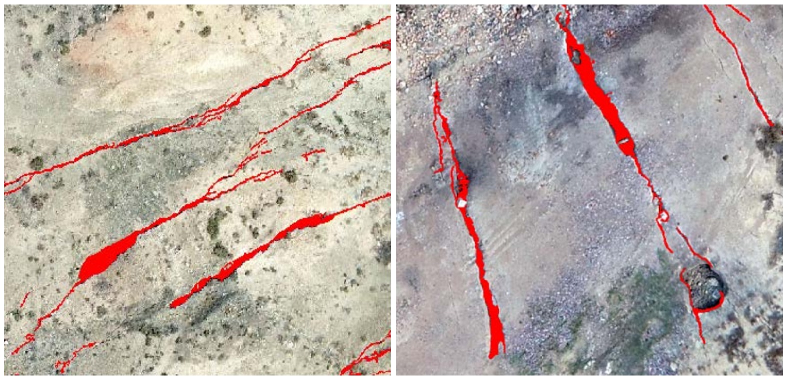


Figure 8. Partial crack display.

Figure 9. False mention part display.

Table 5. Statistical table of surface crack extraction results.

Comparison parameters	Extraction results
Automatic extraction number/Actual number	178/220
Number of entries extraction rate	80.9%
Automatic extraction of total length/Actual total length	3430 m/4236m
Length extraction rate	80.9%
Position overlap	81.3%

5. Conclusions

UAV aerial survey technology provides an effective technical method for safe and efficient monitoring of surface cracks in goaf in western mining area. In this paper, the Digital Orthophoto Image and three-dimensional model of goaf surface with ground resolution better than 2 cm are obtained by setting reasonable aerial photography parameters, which meets the basic requirements of fine extraction of surface fractures. The feature of UAV image is extracted, the rule set is constructed based on the spectral and shape features of surface cracks, and the object-oriented crack information is extracted by using the principle of fuzzy classification.

This paper draws the following conclusions: 1) the optimal scale segmentation of surface cracks in this study area is studied. Through comparison, it is found that the optimal segmentation effect is obtained when the segmentation scale is set to 40, the shape factor is set to 0.2 and the compactness factor is set to 0.6; Then, according to the spectral and shape characteristics of surface cracks, six features such as brightness, asymmetry, density, roundness, ellipse fitting and shape index are selected to establish a fuzzy rule set, and the surface crack information of goaf is successfully extracted. 2) Combined with field exploration and UAV three-dimensional model, the actual situation of surface fractures is counted, and the object-oriented results are compared and analyzed. The extraction rate of surface fractures in UAV image is 80.9%, the extraction rate of length is 80.1%, and the position overlap is 81.3%. The overall extraction rate of surface fractures in goaf is more than 80%, and good results are obtained.

Conflicts of Interest

The authors declare no conflicts of interest.

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