A Practical Method for the Automatic Recognition of Rock Structures in Panoramic Borehole Image during Deep-Hole Drilling Engineering

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Abstract: Digital panoramic borehole imaging technology has been widely used in the practice of drilling engineering. Based on many high-definition panoramic borehole images obtained by the borehole imaging system, this paper puts forward an automatic recognition method based on clustering and characteristic functions to perform intelligent analysis and automatic interpretation researches, and successfully applied to the analysis of the borehole images obtained at the Wudongde Hydropower Station in the south-west of China. The results show that the automatic recognition method can fully and quickly automatically identify most of the important structural planes and their position, dip, dip angle and gap width and other characteristic parameter information in the entire borehole image. The recognition rate of the main structural plane is about 90%. The accuracy rate is about 85%, the total time cost is about 3 h, and the accuracy deviation is less than 4% among the 12 boreholes with a depth of about 50 m. The application of automatic recognition technology to the panoramic borehole image can greatly improve work efficiency, reduce the time cost, and avoid the interference caused by humans, making it possible to automatically recognize the structural plane parameters of the full-hole image.

Keywords: borehole image; automatic recognition; structural plane; clustering; image process; drilling engineering; application

1. Introduction

It is necessary to investigate the stability characteristics of rock mass structures in various engineering applications, such as geotechnical engineering, geological engineering, hydropower engineering, petroleum development and geological disaster prevention and control engineering [1–3]. The condition of structural planes such as joints, faults, weak surfaces, and layers in rock masses is very important for determining the stability of rock masses in practical engineering [4–6]. The digital panoramic borehole imaging system can obtain high-precision panoramic images of the internal structural planes of the borehole by using the borehole camera technique [2,7,8]. These high-precision borehole images can accurately record the characteristics of the structural planes of the rock masses [9–11]. In engineering practice, the accurate identification of the structural planes in the panoramic borehole images and the rapid extraction of characteristic parameters are of critical significance for engineering exploration, engineering design and construction [12–15].

The development of Artificial Intelligence (AI) and the Internet of Things (IoT), machine-learning approaches [16] and big-data techniques [17] provides novel ways to
process borehole video images with the help of multimedia tools [18]. However, there is a long road to realizing the actual application of such techniques in drilling engineering and borehole detection. At present, recognition of the structural planes of a panoramic borehole image is mainly done via manual interpretation. Generally, technicians subjectively define the sine curve control points or other necessary characteristic parameters of a structural plane. A computer performs preprocessing or characteristic curve fitting and then calculates the fitting parameters to identify and extract the structural plane parameters in a borehole image [19–23]. This process often requires human intervention and is cumbersome and slow to operate. In addition, different interpretation technicians may produce different recognition results, which leads to non-unique conclusions on the interpretation of rock-mass structural characteristics [24,25]. In practical engineering, especially in the field of panoramic borehole image recognition of deep hole or multi-hole detection, this manual identification process is a huge workload, involving repetitive operations. It is very time-consuming and laborious [26,27]. Therefore, the automatic recognition technology of panoramic borehole images with no or little human intervention is particularly vital, and can improve the value of drilling engineering.

Therefore, many scholars have improved the automatic process of borehole images, such as image color space transformation and Hough transformation for automatic interpretation of structural planes [28]. Chai Hua et al. attempted to use borehole image automatic recognition technology to realize the division of lithology and sedimentary facies in reef-shoal reservoirs [29]. Assous et al. realized the automatic detection of the plane features of borehole images through gradient boundary detection and sinusoidal retrieval methods [30]. Waleed Al-Sit et al. used methods, such as multi-resolution texture segmentation and pattern recognition methods based on a Gabor filter, to achieve accurate interpretation of fracture planes in borehole TV images [31]. Terry Malone et al. developed a relatively independent Borehole and Ice Feature Annotation Tool (BIFAT) software platform based on borehole images [32]. These researchers and contributions have effectively promoted automatic recognition technology for borehole images and laid the foundation for the automatic recognition of full-hole panoramic borehole images.

Based on the automatic recognition technology of borehole images of the predecessors, an automatic recognition method of panoramic borehole images based on clustering and feature function is proposed, which is specifically for use with high-definition borehole images obtained using a digital panoramic borehole camera system (DPBCS). This method was successfully applied in the geological drilling exploration of Wudongde Hydropower Station. Furthermore, the application of the method can solve the problem of continuous identification of the structural plane features during the full-hole panoramic borehole images.

2. Application of Borehole Camera Technology in Engineering

2.1. Digital Panoramic Borehole Camera System (DPBCS)

The DPBCS is a new set of advanced and intelligent exploration equipment which integrates electronic technology, video technology, digital technology, and computer technology. The system records and analyzes the borehole wall without disturbance in situ from a panoramic angle. The disturbing influence of the drilling core is avoided by directly studying the hole wall. The structural plane condition inside the borehole can be accurately detected. The state of the rock formation inside the hole can be reflected in detail. The system can observe the 360°-hole wall at the same time. The system can display and analyze the entire drilling data on site in real-time monitoring.

The key component of the panoramic borehole camera system is the panoramic camera probe, as shown in Figure 1. It contains a truncated cone reflector that can obtain panoramic images, a light source for detecting illumination, a magnetic compass for positioning, and a miniature CCD camera. The entire probe adopts high-pressure sealing technology, which enables the probe to work in water. The depth encoder is one of the positioning devices of the system, which consists of a measuring wheel, a photoelectric corner encoder, a
depth signal acquisition board, and an interface board. The software part of the system includes data acquisition software and data analysis software. The software can digitize the recorded borehole video, analyze the panoramic borehole image, identify and interpret the structural plane, realize the storage and maintenance of borehole image data, and provide reliable borehole data and rock mass structure parameters for various kinds of drilling engineering.

![Panoramic borehole camera probes.](image)

Figure 1. Panoramic borehole camera probes.

2.2. Boreholes and Image Characteristics of Wudongde Hydropower Station

Wudongde Hydropower Station is the uppermost one of the four hydroelectric escalators (Wudongde, Baihetan, Xiluodu, and Xiangjiaba) planned and constructed in the lower reaches of the Jinsha River. The right bank of the river section where the dam site is located is in Luquan County, Kunming City, Yunnan Province, China, and the left bank belongs to Huidong County, Sichuan Province. The designed water storage level is 975 m, and the total storage capacity is 5.863 billion m³. The dam is a concrete double-curved arch dam with a maximum height of 265 m. The power station is an underground powerhouse, with six 725 MW units on each side. The total installed capacity is 8700 MW, and the average power generation over many years has been 39.46 billion kw/h. The Wudongde Hydropower Station is a Class I project in China. The pivot project consists of dams, flood discharge and energy dissipation buildings, and water diversion and power generation systems. The borehole camera system is mainly used to divide the lithology of the important boreholes in the dam site, determine the geological structure, determine the presence of any weak layers, and divide the rock mass unloading zone after conducting the borehole hydrogeological survey [33–35]. It is also used to establish the bedrock occurrence, slip zone and overburden properties of the key parts of the Jinpingzi landslide, providing a reliable basis for the geological department to demonstrate the stability status and deformation development trend of the landslide. The schematic diagram of dam body structure is shown in Figure 2.

The panoramic borehole images of eight important parts of the dam site area and the Jinpingzi landslide area of the hydropower station demonstrate that the DPBES can obtain real-time video images of the rock structure in the borehole wall. Furthermore, the obtained panoramic borehole images can accurately record the structural characteristics of the rock mass in the borehole and provide a construction basis for engineers. Therefore, the analysis and extraction of the rock mass structure parameters obtained from the borehole
image are valuable final data outcomes. Therefore, the next step is to analyze and study the borehole image record data of the Wudongde Hydropower Station.

Figure 2. Schematic diagram of dam body structure.

A panoramic borehole image is an indirect reflection of the rock mass structure of the borehole wall. It is the image resulting from the illuminated rock mass structure being reflected in the conical mirror of the panoramic camera probe. Therefore, the rock mass structure of the hole wall determines the color depth composition of the drilling image. Due to the poor reflectivity of cracks, fracture planes, holes, broken zones and other areas, such features appear dark in the borehole image, as shown in Figure 3.

Figure 3a is of hole number DJ1, from a panoramic borehole image taken at a depth of about 0.3~2.3 m as an example; Figure 3b is of hole number DJ4, from a panoramic borehole image taken at a depth of about 30~32 m as an example.

The structural planes in a panoramic borehole image are similar to sine curves after unfolding. The standard structure surface in an ideal state is a standard sine curve distributed in the horizontal plane after being expanded [12]. The structure plane in a non-ideal state is also an approximate sine curve in the expanded image of the panoramic borehole image, as is shown in Figure 3. The characteristics of the structural plane are mainly manifested in the difference in the position, dip direction, dip, and gap width of the structural plane, which, when represented as a sine curve, is the difference in position, amplitude, phase, and line width of the curve. Different structural plane curves also present different characteristics, mainly manifested in the shape, width, color, staggered relationship, and rock lithologies around the curve, such as metamorphic surface, structural joint, and micro-structure plane dyke intrusion joints. The differences in these structural features cause huge differences in borehole image structural planes. Moreover, to a certain extent, they have limited the
development of automatic identification and parameter extraction technology for borehole image structural planes.

Figure 3. Sections of the measured panoramic borehole images. (a) Section of the panoramic borehole image taken at a depth of about 0.3~2.3 m in hole number DJ1; (b) Section of the panoramic borehole image taken at a depth of about 30~32 m in hole number DJ4.

3. The Practical Method of Automatic Recognition for Rock Structures

With the development of computer technology and image processing technology, panoramic camera technology, borehole image analysis and processing application technologies have also been further developed [36], and panoramic borehole image automatic recognition technology has also been widely applied. This paper proposes an automatic recognition method for borehole images based on cluster projection and feature function. This method uses the idea of clustering projection to intelligently divide the structural plane area of the full-hole borehole image. First, it divides the full-hole image into small segments according to the characteristics of the area where the structural plane is located. Then, within each the small segment of the image, the characteristic sine function iterative matching method is used to screen the best-matched sine curve of the structural plane. From this, it is possible to carry out automatic identification and extract the parameters of
the structural plane. Thus, the method is mainly divided into structural plane area division and structural plane feature matching. The main steps of the methodological scheme for automatic recognition of rock structures are shown in Figure 4.

![Diagram](https://via.placeholder.com/150)

**Figure 4.** The main steps of the automatic recognition process to identify rock structures within a borehole.

### 3.1. Structural Plane Area Division Based on Cluster Projection

Cluster analysis [16] is a method that can be applied without prior knowledge of the category of each sample in a batch of samples or other information; the only classification basis is the characteristics of the sample (for example, the structural plane in the borehole image is similar to a sine curve). A similarity measurement method (such as the shortest distance method in the hierarchical clustering algorithm) is used to classify the same or similar features into one category. For instance, when the borehole image is longitudinally projected along the depth direction, the feature points of the same structural plane are relatively concentrated in the same area over a short distance. Furthermore, all the feature points in this area can be classified into one category to achieve clustering. According to this idea, the overall division of the structural plane area in the panoramic borehole image can be realized.

In the panoramic borehole image, the structural planes appear as a sinusoidal-like black curve belt which is relatively continuous with a prominent color, as shown in Figure 5. The pixels that make up the black sine curve of the structural plane are referred to as feature points. These feature points are relatively concentrated in the projection of the depth direction of the borehole image. Thus, in borehole images, the feature points of independent structural planes are relatively concentrated. In order to further highlight these features and avoid their being covered by other irrelevant points, this paper uses the minimum grey value and maximum gradient value of each row of pixels to characterize the grey information of each row of pixels.

In order to describe the grey value information of the crack curve zone of the structural plane, this method records the minimum grey value of each line in the image as $\text{MinV}(i)$ and records the maximum gradient value of each line as $\text{MaxG}(i)$. These datapoints are then merged into the feature value $\text{ComS}(i)$. $\text{ComS}(i)$ represents the feature value of all pixels in row $i$ and records the variation of the feature value of each row with the number of rows. The method for calculating $\text{ComS}(i)$ is shown in Equation (1), where 255 is the maximum grey value of the pixel in the image.

$$\text{ComS}(i) = 255 - \text{MinV}(i) + \text{MaxG}(i)$$  \hfill (1)
The feature value $ComS(i)$ of each row can be used to describe the extreme value of the structural plane in the panoramic borehole image. It can effectively express the structural surface features of the panoramic borehole image and can highlight the longitudinal distribution characteristics of the structural plane area in the image. Accordingly, the area division of structural planes can then be established. All the structural planes shown in the borehole image can be effectively divided according to the distribution of regional positions. The entire panoramic borehole image is divided into many relatively independent small segment images to facilitate the subsequent analysis and processing of the image. The above method was applied to the panoramic borehole image in Figure 3; the result of dividing the structure surface area in the borehole image is shown in Figure 5, which presents the division effect and demonstrates practical value of dividing the structure plane area.

### 3.2. Feature Matching of Structural Planes Based on the Sine Function

Since the structural plane fracture in the expanded panoramic borehole image is a characteristic curve similar to a sine curve, this paper takes a sine curve as the characteristic function and then changes the parameters of the characteristic function in turn. We change the position, phase, and amplitude of the sine function to iteratively match the structural plane in the borehole image. We take each line as the initial position of the sine function,
change the amplitude and phase of the sine function in turn at this position, and analyze the sum of the feature values of the pixels at the position where the sine curve passes each time. The sine curve with the smallest sum of grey values is selected as the characteristic curve of the structural plane. The characteristic function taken in this paper is shown in Equation (2):

\[ y(x) = y_0 - \frac{D}{2} \tan \beta \cdot \sin \left( \frac{2\pi x}{W} + \alpha \right) \]

In the equation, \( y_0 \) is the initial position of the sine function, increasing and decreasing by line moving unit; \( D \) is the diameter of the borehole aperture; \( \alpha \) is the dip direction of the structural plane; \( \beta \) is the dip of the structural plane; and \( W \) is the width of the expanded view of the panoramic borehole image. For specific engineering conditions, the borehole diameter, \( D \), and the image width, \( W \), are generally known constants. Among them, \( (D/2\tan \beta) \) constitutes the amplitude of the sine function, and the structural plane dip \( \beta \) increases and decreases sequentially from 0° to 90°. In addition, the structural plane dip direction \( \alpha \) also constitutes the phase angle of the sine function, and the dip direction \( \alpha \) increases and decreases sequentially from 0° to 360°.

In engineering, the method for calculating the feature value of the pixel point of the panoramic borehole image can be expressed by the extreme value (or the opposite value) of the point and the sum of the horizontal and vertical gradients. The calculation equation is:

\[ g(i, j) = 255 - f(i, j) + |f(i + 1, j) - f(i - 1, j)| + |f(i, j + 1) - f(i, j - 1)| \]

In the equation, \( f(i, j) \) represents the grey value of the pixel in the original image at \( (i, j) \), while \( g(i, j) \) represents the feature value of the grey value of the pixel \( (i, j) \) after calculation. The feature value of the pixel is used to determine whether the pixel is on the structure plane, and the sum of the feature values of the pixel is used to determine whether the sine curve is optimal under a certain condition. Thus, determining eigenvalue \( g(i, j) \) is the key to using the sine function to match structural plane parameters. It is also the basis for the feature point decision of Equation (2).

The implementation steps of using the sine function to match the feature function of the panoramic borehole image structural plane are as follows. First, according to the result of the division of the structural plane area in part 2.1, starting from the position of the first row of each structural plane area, increase the dip and dip direction corresponding to the phase-amplitude value in turn (0° to 360° and 0° to 90°). Next, statistically analyze the sum of the eigenvalues of the pixels passed by each sine curve. Then, select the sine curve with the largest sum of eigenvalues as the sine curve of the structural surface that may exist in the row, and perform the same operation in the next row. Finally, select one or more optimal sine curves from the possible sine curves of all lines as the characteristic curve of the structural plane of the area. Repeat until the entire structure area has been operated upon. Figure 6 shows the sine curve matching results obtained from the divided structural plane area presented in Figure 3.

As shown in Figure 6, in each separated area, each line has found a sine curve with the largest number of matches. For these sinusoids, the curve that best fits the cracks of the structural plane is among them. The place with the largest matching points is likely to be the center of the structural plane fracture. Near the maximum, the fastest change in the number of matching points is likely to be the boundary area of the structural plane fracture. Thus, the most suitable sine curve can be selected to represent the current structural plane fracture.
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Figure 6. Sine function matching results of regions. (a) Results for Figure 3a; (b) Results for Figure 3b.

When one or more sine curves with the largest number of specific weighted matching points are found in each divided area, a curve is selected as the optimal sine curve and used as the structural plane characteristic curve matched to the area. Finally, the depth position of the corresponding structural plane can be calculated according to the position of the optimal sinusoid. The dip direction of the structural plane can be calculated according to the phase angle of the optimal sinusoid. And the dip of the plane can be calculated according to the amplitude of the optimal sinusoid. By shifting the optimal sine curve until the number of specific weighted matching points is zero, the sum of the upper and lower translation distances of the optimal sine curve can be obtained. Thus, the average width of the planes in the area can be calculated according to the average value of the pixel distance.

4. Application Results and Discussion

This paper uses the above-mentioned panoramic borehole image automatic recognition method to analyze the image data of eight boreholes in the Jinpingzi landslide area. For the panoramic borehole image data obtained by the DPBCS for each hole, the system automatically preprocesses the image to obtain some initial data. Next, the full-hole image is automatically divided and the structure plane areas are selected. After that, the structure planes in each area are automatically identified. Finally, the automatic recognition results and related structure surface parameters are saved to the relevant file for reference. This method enables the automatic identification of borehole images and statistical analysis.
of parameters. The results from applying this method for the automatic identification of structural plane parameters to the images presented in Figure 6 are shown in Table 1.

### Table 1. The automatic data generated for the structural planes of Figure 6.

| No. | Depth/m | Dip/° | Dip Angle/° | Gap Width/mm |
|-----|---------|--------|-------------|--------------|
| a1  | −0.618  | 155    | 44          | 9.1          |
| a2  | −1.083  | 315    | 42          | 10.5         |
| a3  | −1.782  | 100    | 46          | 8.3          |
| a4  | −1.994  | 282    | 46          | 6.6          |
| b1  | −30.072 | 275    | 49          | 6.2          |
| b2  | −30.396 | 287    | 53          | 7.4          |
| b3  | −30.675 | 279    | 58          | 8.1          |
| b4  | −31.015 | 301    | 44          | 9.7          |
| b5  | −31.256 | 276    | 42          | 6.5          |

Table 1 presents the results generated by the automatic recognition technology for panoramic borehole images when applied to the images from Figure 6. In order to determine the effects of the automatic recognition method, we used the structural surface area divisions shown in Figure 5. This produced the sine curve that is most suitable to describe the structural surface characteristics of the rock mass within the determination line (red lines) for each area, as shown in Figure 6. Furthermore, it can be seen from Figure 6 that the automatically identified sine curves are in good agreement with the rock structure planes, which is in line with engineering practice.

To improve the recognition rate and accuracy of the structural plane recognition method described in this article, we performed a deeper fine matching of structural surface sine functions based on the two steps mentioned in Section 2. The specific operation method is: based on the result of the last sinusoidal curve matching, in each divided area, taking the y₀ value obtained in the last matching as the baseline value, increase and decrease it by 20%, and then increase the y value by line moving unit sequentially. Similarly, β and α are also determined by taking the last matching value as a baseline, increasing, and decreasing by 3°, and then sequentially increasing them in steps of 0.1°. This enables finer recognition of panoramic borehole images, which in turn makes it possible to obtain more accurate structural plane parameters, reduces the error rate, and also makes up for the omission of some structural planes. Figure 7 and Table 2 present the results obtained after refined identification was applied to the image shown in Figure 6b. It can be seen from Figure 7 that the missing structural planes (those numbered 2 and 4 in Figure 7) can be re-identified. It can be seen from Table 2 that the structural surface parameters obtained after the sine curve matching are much accurate.

In the automatic identification of panoramic borehole images, the software system of the digital panoramic camera system can automatically identify all structural planes in the entire borehole image at the same time. Moreover, it can obtain the position, dip direction, dip, gap width and other vital parameters of each structural plane. In order to compare and analyze the practical effectiveness of the automatic recognition of full-hole images, the authors conducted a statistical analysis of the automatic recognition results and compared them with the manual interpretation results. The outcomes of the statistical analysis are shown in Table 3.
Figure 7. Fine recognition results for Figure 3a.

Table 2. Fine recognition data for the structural planes in the borehole images shown in Figure 5.

| No. | Depth/m | Dip/° | Dip Angle/° | Gap Width/mm |
|-----|---------|-------|-------------|--------------|
| 1   | −0.616  | 154.6 | 44.37       | 8.57         |
| 2   | −1.083  | 162.3 | 71.96       | 9.48         |
| 3   | −1.083  | 315.1 | 41.59       | 10.66        |
| 4   | −1.083  | 315.8 | 50.73       | 6.74         |

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Table 3. Comparison between automatic recognition and manual reading for structural planes in the borehole images.

| Type                 | Total Number | Right | Wrong | Missed | RMS (%) | Time  |
|----------------------|--------------|-------|-------|--------|---------|-------|
| Manual interpretation| 217          | 217   | 0     | 0      | 0       | 7 days|
| Automatic recognition| 196          | 192   | 26    | 21     | 3.2     | 4 h   |

Since the manual interpretation results were repeatedly proofread, they can be taken as the correct standard data. As such, they were used as a reference point from which to statistically measure the effectiveness of automatic recognition. The standard of accurate recognition was defined as a deviation of less than 15% between the automatically identified structural plane parameters and the actual ones. Accordingly, the standard for
inaccurate recognition was defined as a deviation of not less than 15%. Four structural plane parameters were analyzed: structural plane position, dip direction, dip, and gap width. The recognition result is regarded as inaccurate if the deviation in any one of the four parameters is not less than 15%.

Table 3 shows that, taking the manual interpretation result as the standard data, the recognition rate of the automatic recognition method was about 90.3%, the accuracy rate was about 88.5%, and the average deviation of the parameters of the accurate recognition results was about 3.2%. The time cost was reduced from seven days at normal manual working efficiency to about four hours of continuous computer operation. A closer look at the panoramic borehole image area to assess misjudgment and missing structural planes shows that these errors all occurred in damaged areas of rock mass structure. The structural plane fractures are very irregular and not obvious or without ambiguity. The imaging quality of the hole wall in the area where these misjudgments are located is also very poor. The manual interpretation of the fracture characteristics of rock mass structures is also controversial, and images need to be compared with drill cores to make a judgment. In addition, in image areas where the image quality of the hole wall is high and the structure surface is relatively clear, the automatic recognition technology was able to accurately identify all the structure planes and their characteristic parameters. The deviation between manual interpretation and automatic recognition was small. The technology described in this article is feasible and reliable for fully automatic identification of structural planes of panoramic borehole images and the intelligent extraction of related parameters. From the perspective of working hours and working methods, the automatic identification method can greatly improve work efficiency, from several days of manual work to a few hours of computer work, speeding up engineering progress, and saving workforce and material resources.

5. Conclusions

The authors used the DPBCS to perform borehole imaging of eight borehole walls in the dam site area of Wudongde Hydropower Station and the Jinpingzi landslide area of the hydropower station, and to obtain data from the panoramic borehole image of each hole. In the obtained borehole video image data, an automatic recognition method based on cluster projection and feature function matching was used to identify features from each panoramic borehole image and practical engineering application automatically. The engineering application results show that the automatic recognition technology can comprehensively and quickly identify most of the structural planes and their position, dip, dip direction, and gap width from full-hole panoramic borehole images. Furthermore, preliminary classification of the parameters of the structural planes was performed and the results were statistically analyzed. As a result, the following conclusions can be made:

(1) In practical engineering, the automatic recognition method based on cluster projection and feature function matching can automatically identify the structural planes in a full-hole panoramic borehole image. Furthermore, it can extract the position, dip, dip direction, and gap of structural planes, and perform annotation and statistical analysis.

(2) When used on the panoramic borehole images from Wudongde Hydropower Station, the recognition rate of this automatic recognition method was approximately 90.3%, the accuracy rate was approximately 88.5%, and the average deviation of the parameters of the accurate recognition results was approximately 3.2%. Thus, the efficiency was much greater compared to manual interpretation.

(3) The application of automatic recognition technology to panoramic borehole images in engineering practice greatly improved efficiency. The working time was reduced from the original seven days to about four h, which shortened the engineering time cost and provided a timely and effective data analysis result. The technology also contributes to the further intellectualization of borehole imaging.

(4) In complex or poorly imaged structural surface areas, especially in the crushing zone of a rock mass, the automatic recognition method inevitably returns some erroneous
or inaccurate recognition results. In order to ensure the quality of the practical project and the authenticity and reliability of the structural plane data, it is recommended to use the automatic identification method to reach a preliminary result, and then use the fine identification method and manual interpretation to identify the structural plane data compared to the original panoramic borehole images. If necessary, the data can be manually modified to ensure the authenticity of the final structural plane data.

Author Contributions: Conceptualization, X.Z. and C.W.; methodology, X.Z.; software, X.Z.; validation, X.Z. and H.Z.; formal analysis, X.Z.; investigation, S.C.; resources, X.Z.; data curation, X.Z.; writing—original draft preparation, S.C.; writing—review and editing, X.Z.; visualization, X.Z.; supervision, C.W.; project administration, X.Z.; funding acquisition, X.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (42007266) and the Natural Science Foundation of Hubei Province (2019CFB345).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data, models, and code generated or used during the study appear in the submitted article.

Acknowledgments: All the images and data are from our actual tests and permitted by the owners. We are compliant with ethical standards, and all authors declare that this paper has no conflict of interest. Finally, we are grateful for the many helpful and constructive comments from many anonymous reviewers.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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