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A STUDY OF JOINT SET MODELING BASED ON EDGE-BASE STEREO MATCHING

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Abstract

In order to estimate rock joint parameters, such as strikes and dips which geologists often inspect on site and/or calculate through 3-D joint surface recognition by use of stereo-photo system, an image processing algorithm of joint set modeling which simply simulates their interpretation is designed. Comparing resultant parameters in Schmidt-net diagrams, it is confirmed that the algorithm based on an edge-base stereo matching can treat 3-D joint parameters, while further enhancement of noiseless edge-detection algorithm has been needed.

Introduction

Joint system affects rock characteristics, such as permeability and strength. In general, parameters of rock characteristics are measured quantitatively by means of in-situ inspection as penetration tests and/or breaking strength tests in laboratory. They are also estimated qualitatively by means of rock classification according to its strength. Recently, a lot of researches have been made on the relationship between rock characteristics and joint system. And some of them are discussing a method of estimating quantitative rock parameters statistically from 3-D joint parameters of strikes and dips which are often inspected on site and/or calculated through joint surface interpretation with predicating continuities of rock edges and cracks by use of stereo-photo[1)2)] (see Fig.1). In those methods, however, a large number of joints should be investigated in a site.

Some systems based on image processing technique, which can treat 2-D crack modeling, have been already devised for rock-joint measuring. On the other hand, borehole camera system[3)] can treat 3-D crack modeling. In case of large area site, however, a lot of boreholes cause the data acquisition cost to increase.

In order to measure automatically 3-D joint parameters of strikes and dips, an image processing algorithm of joint set modeling has been designed. The algorithm simply simulates the interpretation of stereo-photo that is characterized by measuring undulations on a rock surface originated from joints.

Modeling of 3-D Joint Set Interpretation

Procedure of 3-D joint set interpretation can be broken down into three sequential stages: adoptive edge recognition, recognition of undulations on a rock surface, and estimation of joint surfaces. Since joints are revealed as edges in photo-images, these three stages can be realized to correspond to three procedures of edge-based digital image processing: edge extraction, edge-base stereo matching, and edge-grouping, respectively.

1) Edge recognition and edge extraction

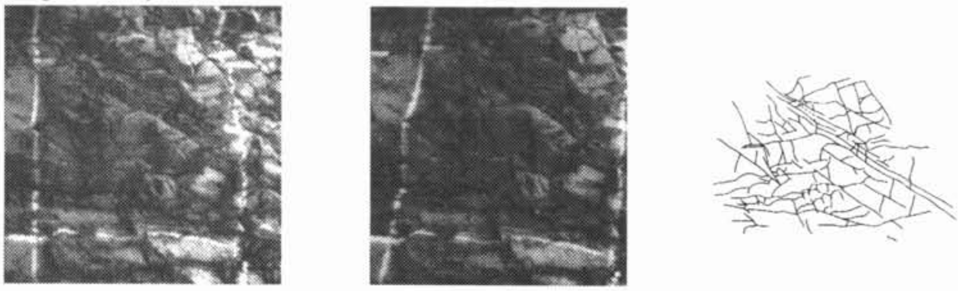
In the first stage of interpretation of joints, an interpreter have to extract adoptive edges which are regarded as parts of joint surfaces. For example, a corner of rock surface which shows a step-edge in a photo-image is often an intersection of two joint surfaces. And a crack of rock which appears like a line-edge is often an edge of joint surface itself (see Fig.2). In the image processing two kinds of edges should be extracted as line-segments.

2) Recognition of undulations and edge-base stereo matching

In the second stage, undulations on a rock surface is recognized by stereoscopy. Measurement of 3-D coordinates by stereo matching can take the place of stereoscopy. In this measurement edge-base stereo matching method is most effective, because the edges of joint surfaces have been already extracted as line-segments in former processing.

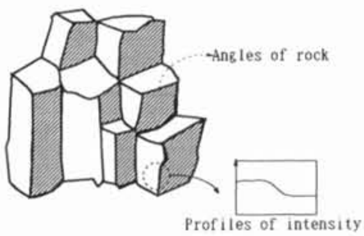
3) Estimation of joint surface and edge grouping

In the third stage, rock surfaces are connected to each joint by recognition of a group of surfaces which lie on a common plain. In the image processing, a joint is estimated by grouping the line-segments of edges which can be predicated to lie on the same surface.

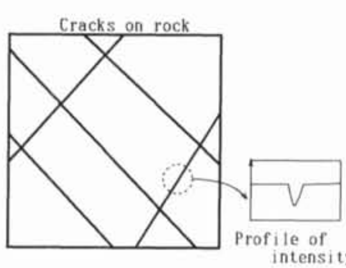


a left image of a stereo photo | a right image of a stereo photo | rock joints interpreted from rock surface image

Fig.1 Rock surface images and rock joints

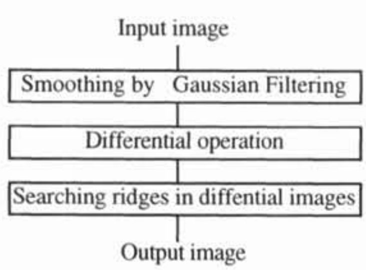


(1) Step edges

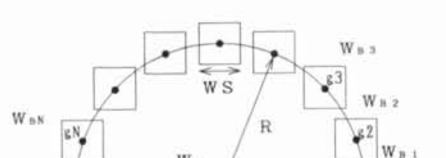


(2) Line edges

Fig.2 Angles and crack lines on rock



(1) Step edge extraction by the zero-crossing method



$$S = \frac{(N-1)\times WT}{\Sigma WBi - j\times Max(WBi)}$$

WS :Size of a target window

WT :Mean value of image in a target window

WBi:Mean value of image in a the i-th back ground window

R :Radius of target area

gn :Porlar coordinats of n-th back ground window

$$gn = (R, \frac{(2n-1)\pi}{N}), n=1\sim 2N$$

O :The center of target area

S :Output grade

j :A natural number less than N

(2) The circle filter for line-edge extraction

Fig.3. A schema of edge extraction

Details of Crack Measuring Algorithm

1) Edge extraction

Step-edges and line-edges in stereo-photo images are respectively extracted as corners and cracks on a rock surface. Roof-edges are negligible because they are not often appeared on joints but faults.

Step-edges can be extracted as border lines by the zero-crossing method[4] (see Fig.3(1)), and line-edges can be enhanced by the circle filter processing [5] (see Fig.3(2)). These lines derived from the edge extraction are thinned and divided into line-segments without junction. After segmentation, line-segments whose length have shorter than an appropriate threshold are removed automatically as noises (see Fig.4).

2) Edge-base stereo matching

3-D coordinates of each line-segment are calculated by edge-base stereo matching, called Edge Projection Method (EPM)[6][7]. Consistency of matching pair of line-segments whose shadows (projected to the base line direction) have about the same length is examined in EPM (see Fig.5).

Suppose that the axis of X is along the base line between stereo-photo images and the axis of Y is perpendicular to the X. A pair of line-segments, one is in a left image of stereo pair and the other is in a right, are nominated as a possible matching pair when the following condition is satisfied,

$$| Ymax\_l - Ymax\_r | < E$$
$$| Ymin\_l - Ymin\_r | < E$$

where Ymax_l is the largest Y-coordinate of the line-segment interested in the left image, Ymax_r the largest Y-coordinate in the right image, Ymin_l the smallest Y-coordinate in the left image, Ymin_r the smallest Y-coordinate in the right image, and E the allowable error, respectively (see Fig.5(1)).

A possible matching pair of line-segments is fixed when no nominative line-segment is existing but themselves. When several possible matching line-segments lie around an expectant line-segment, the pair which keeps consistency in localizing arrangement of each segment is adopted (see Fig.5(2)). On the contrary, a line-segment without any corresponding nominee is connected to a neighboring line-segment within an arbitrary threshold of distance between their ends (see Fig.5(3)), because it is possible that an line-segment is divided into some pieces by existent noises. After the combination of line-segments, the iteration for search of matching pair begins with connected line-segments. 3-D coordinates of matching pair are calculated by triangulation.

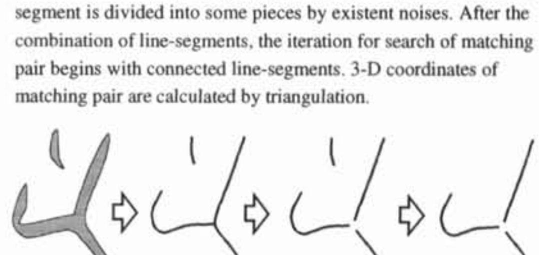
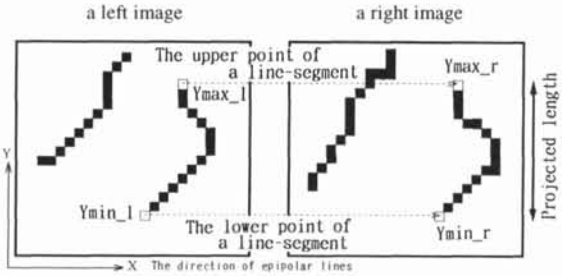
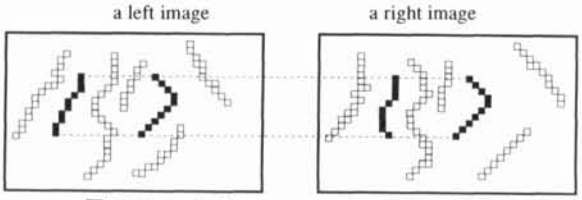


Fig.4. Thinning, segmentation, and noise reduction of extracted edges



A pair of line segments are matched in case that projected length of a segment is equal to another.

(1) Line segment matching by EPM

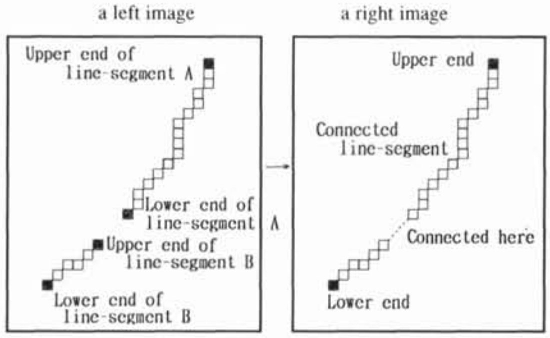


■:Multi-matched segments

□:Segments whose matching pair are fixed

The pair which keeps consistency in localizing arrangement of each segment is adopted.

(2) Matching of multi-matched segments in EPM



(3) Connection of unmatched line-segments

Fig.5. Edge-base stereo matching by Edge Projection Method

3) Edge grouping

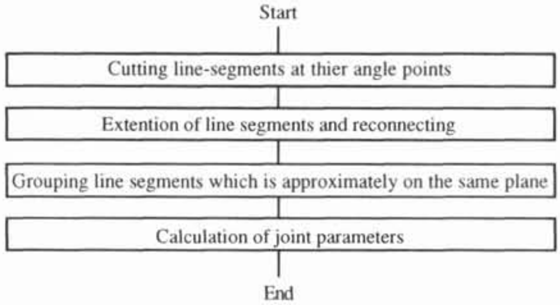
Edge grouping is executed through four parts of processing: cutting line-segments, extension of line-segments, grouping of line-segments, and calculation of joint parameters, respectively. Fig.6 shows the flow chart of recognition of joints from line-segments as follows.

In the first, each line-segment is cut into small pieces of approximate straight at a corner whose angle is larger than an appropriate threshold, because there is a possibility that line-segment can have some participants belonging to different joints (see Fig.6 (2)).

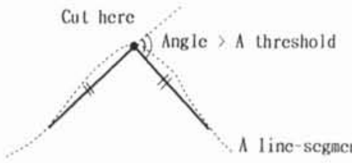
In the second, line-segments which lie roughly on a common straight line are reconnected each other when distance between neighboring line-segments is nearer than an appropriate threshold (see Fig.6(3)).

In the third, line-segments lain in parallel are made into a group, because they are considered to share a common plane. And line-segments whose ends are close to one another are also grouped to form a common plane. Grouping of line-segments is performed repeatedly as long as further combination can be found (see Fig.6(4)).

In the last, directions of each grouping plane which is regarded as a joint surface are approximated by the eigen vectors led from a covariance matrix of every line-segment consisting of one plane. In actual computation, every 3-D coordinates of points which consist of each line-segment lain on a common plane are gathered and the eigen vectors are calculated.

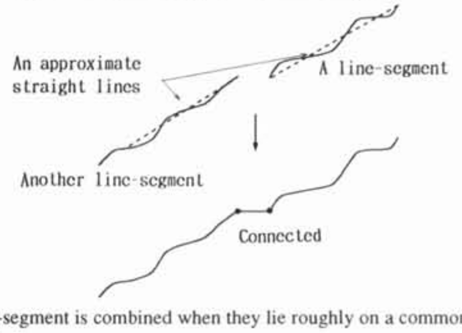


(1)The flow chart of recognition



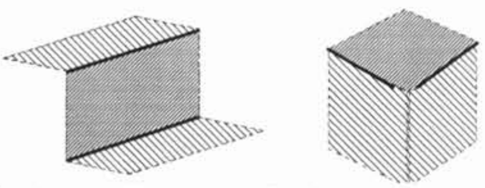
Each line-segment is cut into small pieces of approximate straight at a corner whose angle is larger than an appropriate threshold.

(2) Cutting line segments at their angle point



A line-segment is combined when they lie roughly on a common straight line.

(3) Extention of line-segments and reconnection



Grouping pararell line-segmets   Grouping close line-segments

(4) Grouping line-segments

Fig.6. Recognition of joints from line segments

Discussion of the Algorithm

The algorithm has been examined by following three tests.

1) Simulation using an analytical plotter

With a view to proving the efficiency of the basic idea of the algorithm, a simulation using an analytical plotter has been executed on stereo-photo of a rock surface shown in Fig.1. After stereoscopic interpretation of joints, 3-D coordinates of every edge which is expected to be extracted as step-edges and/or line-edges is measured by using an analytical plotter. Gathering adoptive edges lain on the same plane, directions of the plane which are regarded as strikes and dips are calculated.

Comparing resultant parameters with in-situ measurement in Schmidt-net diagrams, Fig.7 shows that distribution of joint set is well estimated. The basic idea is concluded to be efficient to treat 3-D parameters of joint set.

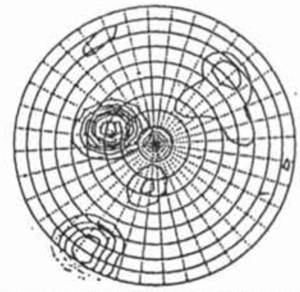
2) An examination of automated edge grouping on a rock surface model

An examination of automated edge grouping in which a rock surface model shown in Fig.8 is used has been executed. The result shows that the algorithm can extract, measure, and infer joint surfaces in 90 % accuracy.

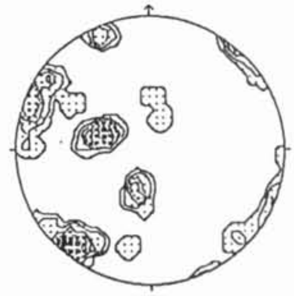
3) An examination of automated joint set modeling on existent rock

An examination on existent rock surface shown in Fig.1 has been executed. The result shows that edge extraction has been performed in 80 % accuracy in case of step-edges. And in case of line-edges, 60 % accuracy has been done. In practical operation, it is noticed that some kinds of noise such as shadows, saturation of image level, etc., prevent edge extraction from complete processing. Consequently, further enhancement of noiseless edge extraction algorithm is needed.

The result also shows that edge matching in EPM and edge grouping have been performed in 12 % accuracy. The errors of edge matching and grouping are not only caused by occlusion in a stereo-photo image but also by broken line-segments which make different projection in EPM.



(1) Distribution of joint set calculated by the algorithm



(2) Distribution of joint set measured in field research

Fig.7. An analysis of dominant direction of joint set

Fig.8. A model of rock surface

Conclusion

From the result of a simulation and an examination using a rock surface model, it is quite possible to conclude that the algorithm based on an edge-base stereo matching can treat 3-D joint parameters.

To attain better accuracy in edge extraction on existent rock, further enhancement of noiseless edge-detection is needed. And it is considered that knowledge-based processing will be effective against edge-like noises, such as shadows.

In case of edge matching, information derived from raster stereo matching will improve matching accuracy, because it can restricts the number of possible matching pairs of line-segments.

In estimating joint surfaces, the edge grouping algorithm allows appropriate approximation on a rugged rock surface. In case of rock whose surface has little undulation, however, it is hardly operative. Consequently, the grouping algorithm should be improved in preparation for application to several types of rock surface.

References

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