

Rock Image Segmentation

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Abstract

A hybrid approach to rock image segmentation based on thresholding and rock structure knowledge has been developed. This technique furnishes a new rock digital photoanalysis tool for obtaining statistical data of rock fragmentation size effectively. In the proposed approach, a rock image is processed in two major phases. In the first phase, it is presegmented by means of a thresholding method, in which the rock blocks are extracted and the image is transferred into binary one with missed weak boundaries. In the second phase, the missed boundaries are reconstructed approximately based on a set of assumptions on rock structure and the mode matching techniques. The algorithms have been implemented and tested using a set of real rock images. They yield encouraging results.

KEYWORDS: Hybrid Approach, Thresholding, Presegmentation, Structure knowledge, Vertex Modes, Boundary Reconstruction.

1 Introduction

In rock engineering, in order to monitor blasting quality, optimize blast design, and reduce costs and environmental impact, it is important to efficiently measure the size distribution of fragmentation produced by blasting. For years rock engineers have tried to deal with the challenge. Among them are Franklin and Maerz [1], whose "digital photoanalysis" approach which combines image processing and photoanalysis provides a promising technique for measuring the size distribution of rock fragments.

In digital photoanalysis, image segmentation plays an important role because it is at this stage that the individual rock blocks are extracted from an image for subsequent analysis and calculations. During the last two decades, many image segmentation techniques have been developed. They are generally based on one of the two basic properties of gray-level values: *discontinuity* and *similarity*. These belonging to the first category are based on edge detection while those in the second category are based on thresholding and region-oriented methods [2].

For high contrast and noise free pictures, edge segments can be detected using gradient operators. They are then joined to form close boundaries using an edge-linking algorithm. However, this process usually fails when applied to noisy images with fuzzy boundaries or to images containing texture regions. The major difficulties are nonuniformity in the brightness level of objects (high frequency noise) and the loss of contrast (low frequency noise). Though a number of more sophisticated edge techniques have been proposed, they are not effective enough to handle the segmentation problems of complicated pictures. Thus early efforts to segment rock images by edge detection have not been encouraging [3].

Thresholding is a simple and direct method for extracting objects [4]. This approach is based on the assumption that different classes of segments of an image are represented by distinct "modes" in the distribution of suitably chosen features extracted from the image. The technique fails if this assumption were not true. Compared to the edge detection techniques thresholding techniques are less affected by noise. They usually give close boundaries.

The region-oriented approaches include region growing and split-merge methods [5, 6]. The main advantages of these methods are that at any step in the algorithm, it is always possible to obtain closed regions and noise can be effectively suppressed. However, it is not always possible to find a suitable region predicate to complexed images (like the rock images). Basically, all of these region extraction techniques use local information heavily, and are usually computation and memory intensive.

Because of rock images' complexity, i.e. noise, fuzzy boundaries and irregular texture, no single conventional segmentation method is considered adequate. Rock images are currently segmented by manually tracing the edges of rock blocks in an image, which is indeed a slow and tedious procedure.

This paper proposes a hybrid rock image segmentation approach based on thresholding and rock structure knowledge. With this method, a rock image, at first, has a pre-segmentation in which the rock blocks are extracted roughly by using thresholding (Section 2). In this stage, a rock image is transferred into binary one with missed weak boundaries. In the second phase (Section 3), the missed

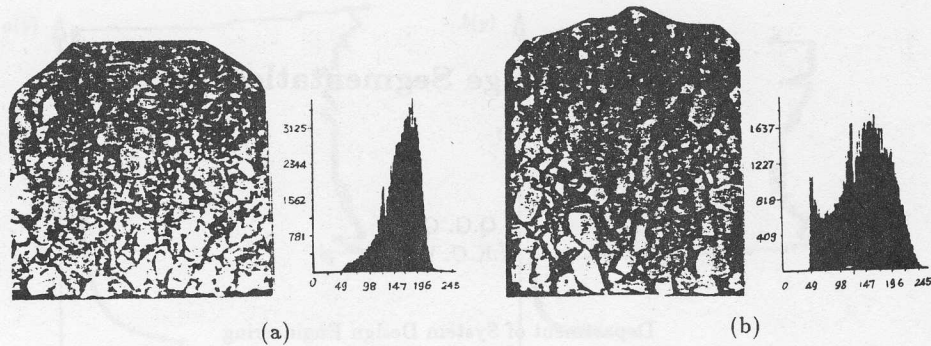


Figure 1: Two rock images and their histograms. (a) Image I. (b) Image II.

boundaries are reconstructed approximately based on a set of assumptions on rock structure, mode matching and intersection pair searching techniques. The algorithm has been implemented and tested using a set of images. Segmentation results of two rock images are presented in Section 4.

2 Pre-Segmentation by Thresholding

Two typical rock images and their histograms are given in Figure 1. The rock image histograms are usually unimodal with an approximate Gaussian curve on the light side. On the dark side, the peak tends to display either a shoulder or down slope. The histograms also contain a smaller but narrow and distinct peak in the middle of the gray level range.

From the above observation and after testing a number of rock images, we found that a rock image histogram can be generally classified into three regions (see Figure 2): (I) a pixel population distributing inside rock blocks; (II) a pixel population distributing in the areas near to boundaries; (III) a pixel population distributing inside shadows;

Figure 3 (a) and (b) show two pre-segmentation results by taking thresholds $T = t_1$ and $T = t_2$ respectively. In the first result (Figure 3 (a)), obviously, the rock blocks missed a number of pixels which lie on or near the boundaries. The result get big improvement when segmentation the blocks with region I and II together from the shadows (Figure 3 (b)). That indicates if $T = t_2$ can be located, the block areas can be nicely extracted in pre-segmentation. According to the above analysis, we can set up simple object/background model for rock images: A rock image consists of two types of regions: (1) rock blocks (object) with a population of approximate Gaussian distribution; (2) shadows (background) with the complementary population.

Based on the above image model and statistics an appropriate threshold T is available since rock block areas possess the property of Gaussian distribution.

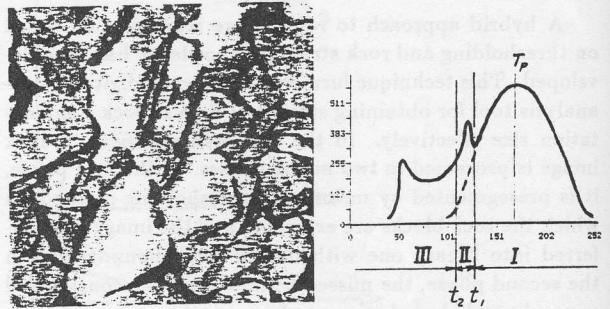


Figure 2: A test rock image and its histogram with three regions.

Algorithm 1: Thresholding evaluation

1. Read in an image;
2. Smooth histogram and locate the peak T_p of a Gaussian curve;
3. Calculate μ and σ based on the right side of the gaussian curve;
4. Estimate threshold $T = T_p - k\sigma$;
5. End of Algorithm.

Where μ and σ are the mean and standard deviation respectively. k is standard score.

The result obtained using Algorithm 1 when taking $k = 2$ match t_2 quite well (Figure 3 (c)). More results can be found in Section 4.

In the first phase of the hybrid approach, a rough segmentation, termed pre-segmentation, is obtained in which the rock image is transformed into a binary image. In this stage, however, most of the blocks cannot be extracted completely because weak boundary information becomes missing after the thresholding process. In the second phase of the hybrid approach, the lost block boundary information is reconstructed, and the rock image segmentation is completed.

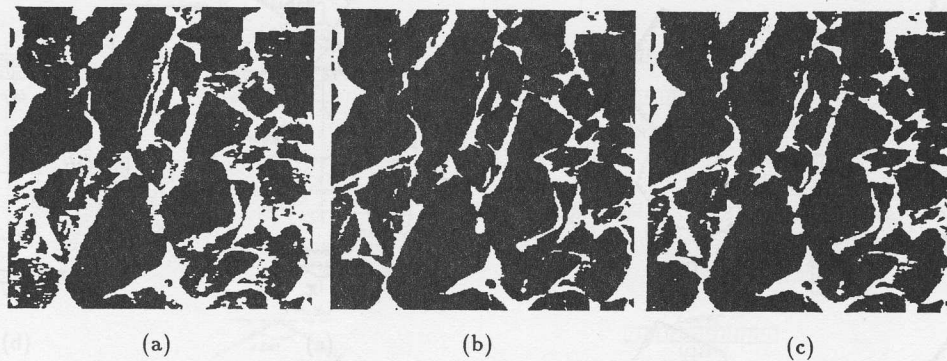


Figure 3: Segmentation based on thresholding. (a) $T = t_1$. (b) $T = t_2$. (c) Using Algorithm 1.

3 The Reconstruction of Missing Boundaries

The three principal factors by which human beings recognize a complex scene are the boundaries of objects; region information, such as uniformity in intensity, color and texture; and knowledge (or previous experience) of the scene. When boundary and uniformity information is insufficient to obtain complete segmentation, scene knowledge often plays an important role in making a correct judgement. In this section, algorithms for rebuilding the missing boundary segments are developed based on a set of assumptions regarding rock structure, mode matching and intersection pair searching techniques.

3.1 The Analysis of Rock Structure

A set of rules regarding rock structure can be formulated based on observation and basic geometric principles.

1. An assumption about the profile of a rock block

From observations, we can see that most rock blocks possess a profile which is an approximate convex polyhedron. Hence we propose the following assumption concerning the 2-D profile of a rock block.

Assumption 3.1: *The 2-D projection of a 3-D contour of a rock block is a convex polygon.*

2. An observation about convex polygons

An observation from basic geometric principles of convex polygon is made:

Observation 3.1: *If α is an arbitrary interior angle of a convex polygon and β is an arbitrary exterior angle of a convex polygon, then $\alpha < \pi$ and $\beta > \pi$ (Figure 4).*

3. Knowledge about the connection and overlap of blocks

An example of connected and overlapped rock blocks with missing boundary segments is given in Figure 5. Obviously, if a non-convex polygon is found in a binary image (Figure 5 (a)), we can make a judgement according to assumption 3.1: this non-convex polygon must consist of two blocks which may be connected (Figure 5 (b)) or partially

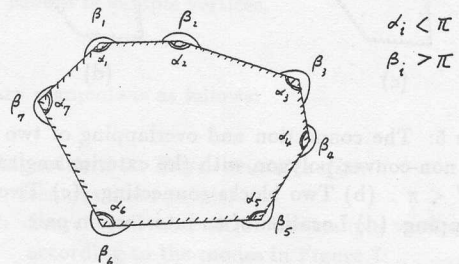


Figure 4: A convex polygon assumption of 2-D rock structure and geometry properties of a convex polygon.

overlap each other (Figure 5 (c)). In both cases, there is a missing boundary part between v and v' . In another word, a polygon with two exterior angles less than π (i.e. $\beta < \pi$ and $\beta' < \pi$) must be composed of two neighboring blocks which are either connected or partially overlap each other as shown in Figure 5. According to observation 3.1, we define vertices with exterior angle $< \pi$ as *intersection points*. The rebuild process then searches for suitable pairs of intersection points, called *intersection pairs* (such as v and v' in Figure 5), and connects them by a line that separates the block.

In practice, not all intersection points can provide enough information to justify a decision concerning a reconstruction operation since block boundary segments are not ideal straight lines. For the purpose of increasing the accuracy of the operations, the concept of sample vertices is developed.

Definition 3.1: *An intersection point with $\beta \leq (2/3)\pi$ defined as a sample vertex.*

We can set up a searching rule based on the above observation.

Searching rule 3.1: *One point of a suitable intersection pair must be a sample vertex and another can either be a sample vertex or an intersection point.*

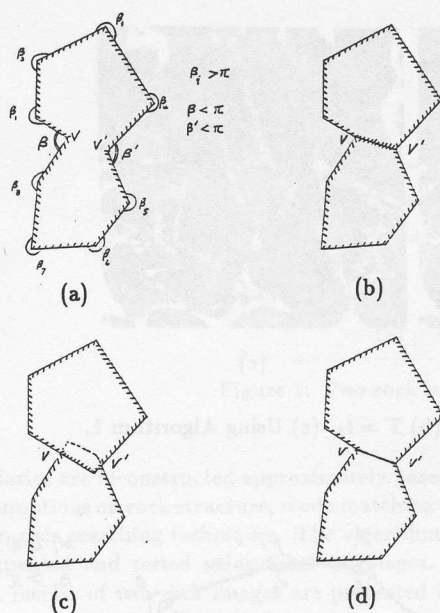


Figure 5: The connection and overlapping of two blocks. (a) A non-convex polygon with the exterior angles $\beta < \pi$ and $\beta' < \pi$. (b) Two blocks connecting. (c) Two blocks overlapping. (d) Location of an intersection pair.

3.2 The Vertex Structure Modes

The structure modes of intersection points and sample vertices can be set up based on Section 3.1.

1. Modes of Intersection Points

According to the definition of intersection points and local structural knowledge, the modes of the intersection points can be described as below. If $f(i, j) = 0$ is an exterior point of a polygon, then it is considered to be a mode of intersection point if its neighbors' pixel values inside the polygon are 1 and satisfy certain constraint conditions. We classify the intersection points into four modes according to their location in a block (Figure 6).

Upper intersection point:

$$f(i, j) = 0; \quad \left[\sum_{k=-5}^5 f(i-1, j+k) \right] + f(i, j+1) = 12. \quad (1)$$

Right intersection point

$$f(i, j) = 0; \quad \left[\sum_{k=-5}^5 f(i-1, j+k) \right] + f(i, j+1) = 12. \quad (2)$$

Lower intersection point:

$$f(i, j) = 0; \quad \left[\sum_{k=-5}^5 f(i+k, j-1) \right] + f(i-1, j) = 12. \quad (3)$$

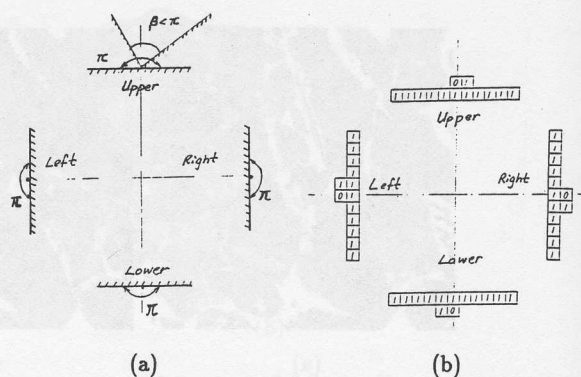


Figure 6: Definitions and modes of a set of intersection points: (a) Definitions, (b) Modes.

Left intersection point:

$$f(i, j) = 0; \quad \left[\sum_{k=-5}^5 f(i+1, j+k) \right] + f(i, j-1) = 12. \quad (4)$$

2. Modes of Sample Vertices

In a similar fashion, the sample vertices are also classified into four modes according to the definition of sample vertices and local structural information (Figure 7). If a sample vertex $f(i, j) = 0$ is an exterior point of a polygon, its neighbors inside the polygon must be $f_{neighbors}(i, j) = 1$. The four different direction modes are:

Upper sample vertex:

$$f(i, j) = 0; \quad \left[\sum_{k=-5}^5 f(i+k, j-1) \right] + f(i+1, j) + f(i-5, j+2) + f(i+5, j+2) = 14. \quad (5)$$

Right sample vertex:

$$f(i, j) = 0; \quad \left[\sum_{k=-5}^5 f(i-1, j+k) \right] + f(i, j+1) + f(i+2, j-5) + f(i+2, j+5) = 14. \quad (6)$$

Lower sample vertex:

$$f(i, j) = 0; \quad \left[\sum_{k=-5}^5 f(i+k, j-1) \right] + f(i-1, j) + f(i-5, j+2) + f(i+5, j+2) = 14. \quad (7)$$

Left sample vertex:

$$f(i, j) = 0; \quad \left[\sum_{k=-5}^5 f(i+1, j+k) \right] + f(i, j-1) + f(i-2, j-5) + f(i-2, j+5) = 14. \quad (8)$$

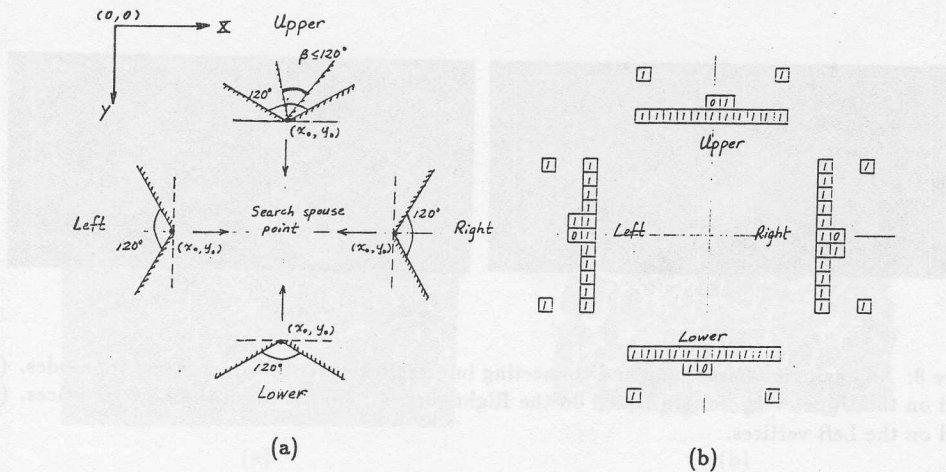


Figure 7: (a) Definition of sample vertices. (b) Modes of sample vertices.

We can see the matching results of the structure modes of the test image from Figure 8.

3.3 Searching of Intersection Pairs

The search for the intersection pairs is conducted over the set of sample vertices and the set of intersection points. The procedure is first to locate a sample vertex then search for another point (say, the sample vertex's *spouse point*) belonging to the same intersection pair based on the following assumption.

Assumption 3.2: *If a sample vertex exists, the distance between the sample vertex and its corresponding spouse point from the other vertices will be minimum.*

This assumption is based on rock structure analysis and the definition of sample vertices in Section 3.1.

According to Definition 3.1, after locating a sample vertex, its spouse point can be identified based on the following rule.

Searching rule 3.2: (Figure 7 (a))

- For the Upper_sample_vertex:
search its spouse point from $y > y_0$,
- For the Right_sample_vertex:
search its spouse point from $x < x_0$,
- For the Lower_sample_vertex:
search its spouse point from $y < y_0$,
- For the Left_sample_vertex:
search its spouse point from $x > x_0$.

3.4 The Rebuilding of Missing Boundary Segments

The missing boundary segments are approximately reconstructed by filling straight lines between the sample vertices and their spouse points. An algorithm for rebuilding the

boundary segments is as follows:

Algorithm 2: Edge_reconstruction

1. Remove noise points;
2. Search and save all of the sample vertices according to the modes in Figure 7;
3. Search and save all of the intersection points according to the modes in Figure 6;
4. Find the spouse point for each sample vertex in stack list;
5. Reconstruct the missed boundary segments by using a line filling algorithm.

Figure 8 shows an example in which the intersection pairs are found and connected according to Searching rule 3.2. A final segmentation of the test image with size 256×256 is given in Figure 9.

4 Results

In this section, we show the experimental results of two real rock images of size 525×480 .

4.1 Results of Image I

The experimental results of Image I are given in Figure 10 to Figure 13. The segmentation results (Figure 13) showing the size distribution of image I obtained through using the hybrid method is quite close to the data obtained through manual tracing.

4.2 Results of Image II

Figure 14 to Figure 17 show the experiments results of Image II. For image II segmentation, some errors occur in the range of small size distribution (Figure 17). Improvement is possible by using preprocess technologies before pre-segmentation.

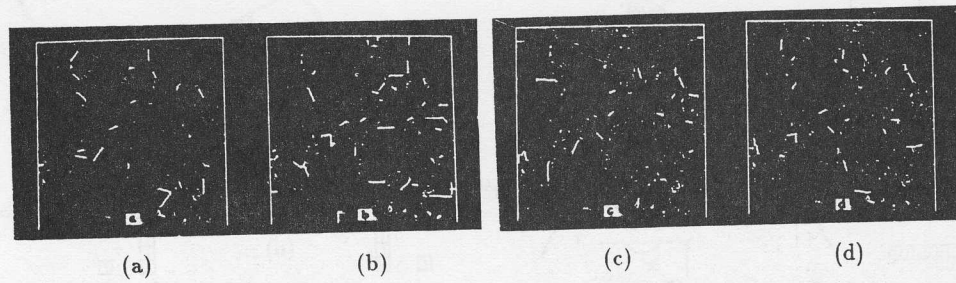


Figure 8: An example of searching and connecting intersection pairs based on structure modes. (a) Based on the Upper vertices. (b) Based on the Right vertices. (c) Based on the Lower vertices. (d) Based on the Left vertices.

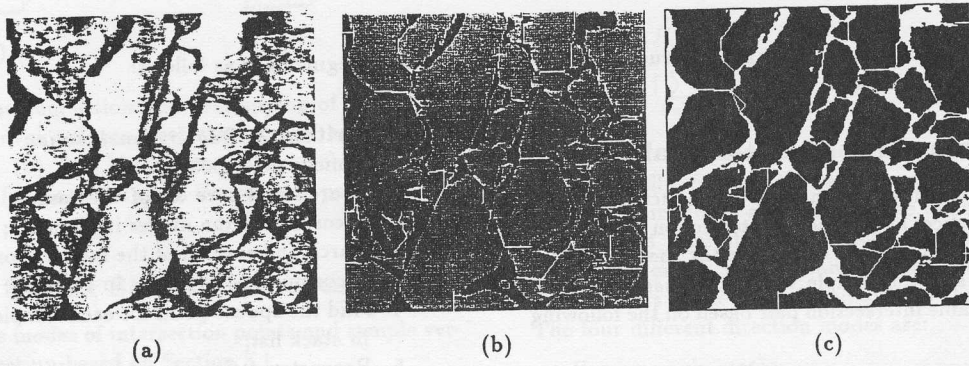


Figure 9: The segmentation result of an image with 256×256 . (a) The original image. (b) After pre-segmentation and boundary reconstruction. (c) Final segmentation.

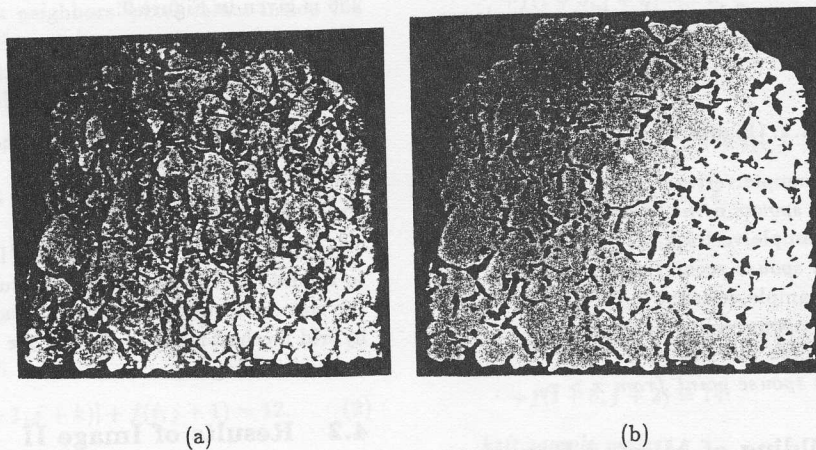


Figure 10: Image I: (a) The original Image. (b) The pre-segmentation result.

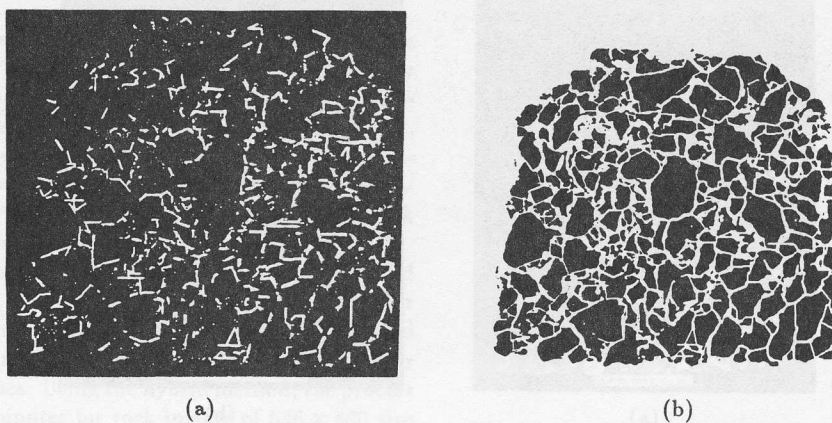


Figure 11: Edge reconstruction processing of Image I: (a) The reconstruction result of Fig. 10 (b). (b) The segmentation result of Image I.

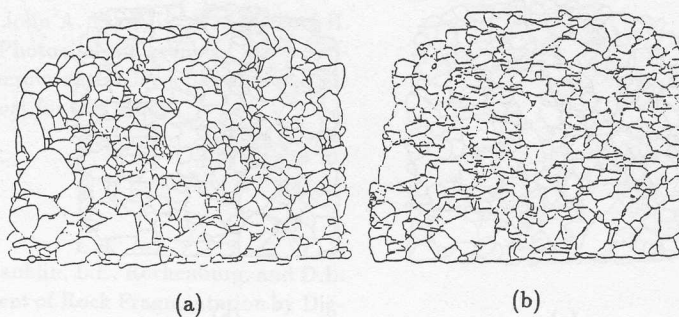


Figure 12: A comparison of block profile after skeletonization of Image I: (a) The segmentation by using a manual tracing method. (b) The segmentation by using the hybrid approach.

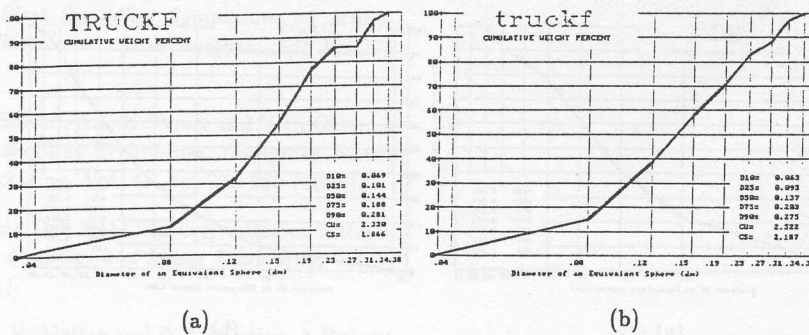


Figure 13: A comparison of cumulative mass distribution: (a) The result by using a manual tracing method. (b) The result by using the hybrid approach.

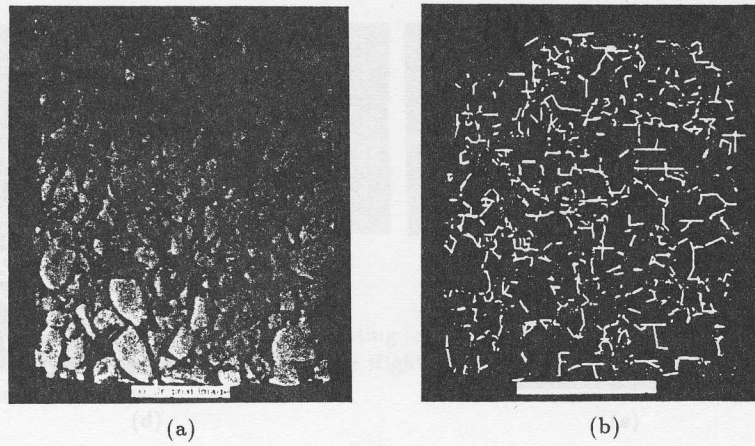


Figure 14: Image II: (a) The original Image. (b) After presegmentation and boundary reconstruction

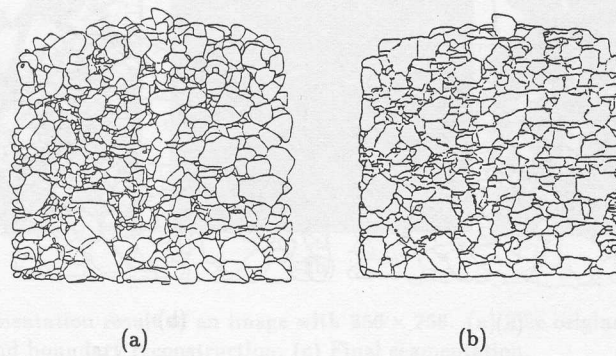


Figure 15: A comparison of block profile after skeletonization of Image II: (a) The segmentation using a manual tracing method. (b) The segmentation by using the hybrid approach.

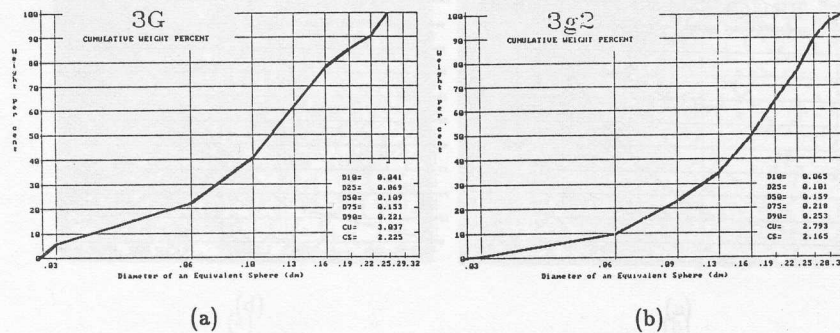


Figure 16: A comparison of cumulative mass distribution: (a) The result by using a manual tracing method. (b) The result by using the hybrid approach.

5 Concluding Remarks

Rock image segmentation is a difficult task because of the complexity of the rock pictures which are characterized by noise, fuzzy boundaries and irregular textures. Any single conventional segmentation method, either edge-based, thresholding or region-based, is not effective to give a solution. This paper presents a new hybrid approach to rock image segmentation which is based on thresholding and rock structure mode matching techniques.

Since rock images do not simply consist of object and background, weak boundary information is often lost after thresholding. We reconstruct the missing boundaries based on rock structure analysis, mode matching and spouse pair searching techniques. Using the hybrid method, the process time is about 2 minutes for rock images of 526×480 size compared with 2-3 hours using the manual tracing method. Experimental results have proved that the hybrid approach is an exceedingly promising technique for rock image segmentation.

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