Digital Image Processing for Rock Joint Surface Studies

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ABSTRACT: The presence of a jointed rock mass in an excavation may lead to the ultimate failure of an engineered foundation/opening if the properties of the rock joint surfaces are not well understood. The intent of this paper is to introduce the possible applications of digital image scanning and processing to the study of joint surface roughness and other relevant properties. An Eikonixscan 78/99 image digitizer camera scanned the image of a rock joint surface directly into a computer with a radiometric resolution of 256 grey levels. The digital joint surface image was later processed by a Comtal/3M processor. Several image processing functions were tested. An image combination technique was found to best delineate asperity contact areas, and a directional filtering method was able to enhance the linear features such as trend of cracks and paths of shearing in the image.

INTRODUCTION

JOINTS, mechanical discontinuities of geological origin, exist within almost all near-surface rock masses. Construction and excavation in a jointed rock mass may lead to unexpected strata deformation if the mechanical strength of the discontinuous rock mass is not properly understood. The mechanical strength of a rock mass is often governed by the presence of joint systems within it. The most significant effects of a joint system intersecting a rock mass are to reduce the tensile strength of the rock mass to an extremely low level and to lower its shear strength to a residual magnitude. Additionally, the existence of joints induces anisotropy of strength as well as of many other properties in the rock mass.

During the past two decades, a number of researchers in the rock engineering discipline have conducted various laboratory and field investigations on the influence of joint systems on the mechanical strength of rock masses (Barton *et al.*, 1974; Bieniawski, 1974; Deere, 1964). From their studies, three rock-mass classification systems and corresponding support design criteria were introduced based upon a numerical assessment of the rock mass quality using different parameters. Although the classification parameters used in each method are each different from the other, their criteria are relevant to the measurement of the shear strength of a rock mass, the active stress acting on a discontinuity, and the properties of the joint surfaces.

Properties of joint surfaces include orientation and continuity, dimension and extent, spacing and separation, roughness and waviness, degree of alteration and filling, and number of joint sets. Usually, field measurement and rock-core study will permit reasonable estimates for certain of the properties mentioned. Practicing engineers often use photographic methods and visual identification to assess the joint conditions and their contribution to the rock mass characteristics. However, current digital image processing technology provides a promising method of describing and quantifying the conditions of joint surfaces.

Since the advent of digital image technology, it became evident that many tasks which require data extraction from images by manual interpretation can be performed with the aid of a computer. In recent years, the digital computer and modern image sensors have assisted the image interpretation process in many ways such as digitizing images of objects, removing image distortion, stretching tonal contrast, and manipulating data to produce desired information. Image processing methods have been widely used in the exploration of mineral deposits in remote areas, the management and inventory of natural resources, the assessment of environmental impact, and the study of geological and terrain features. The application of digital image processing to rock engineering (in particular, joint surface characterization) has not been much investigated, however, mainly due to the lack of understanding of the potentials and the processing procedures. Any significant improvement in understanding and acceptance of this new approach of joint condition assessment would require extensive research in its application. In this paper, the authors present the results of a pilot study which utilized an image scanner to directly scan and digitize an artificial joint surface. This information was then processed by routine functions.

ARTIFICIAL JOINT PREPARATION

The rock joint surface utilized in this study was artificially created by testing a fine-grained quartz diorite rock sample for uniaxial compressive strength in a compression testing machine. The rock specimen was selected from a surface exposure at the University of Alaska's Silver Fox experimental mine near Fox, Alaska. A block of sample was transported from the mine to the laboratory where it was cored with an NX-sized (5.08 cm/2 in. diameter) diamond rock bit. The sample was free of natural discontinuities.

After drilling, the quartz diorite rock core was prepared and tested in accordance with ASTM D2938, "Standard Method of Testing for Unconfined Compressive Strength of Rock Core Specimens." Both ends of the core sample were first cut and flattened by grinding to a maximum relief of no more than 0.02 mm (0.001 in.). Both ends were also ground so as not to depart from perpendicularity to the specimen axis by more than 0.05 mm (0.002 in.). Because the length-to-diameter ratio of this core specimen was somewhat less than the optimum ratio of 2.5 to 3.5, the measured compressive strength was corrected to produce an equivalent uniaxial compressive strength at the preferred ratio. The equivalent compressive strength of this sample was 49.6 MPa (7196 psi).

After strength testing, the now fractured rock specimen was then mounted in plaster of paris (Figure 1) so that an imaginary flat plane touching the highest asperities along the fracture plane would be perpendicular to the vertical view of the image scanner. In order to produce a manual characterization of the roughness of the joint surface resulting from the shearing during the compressive strength test, the mounted sample was placed below a vertically supported dial gage (Figure 2) and a contour map of the joint surface topography was developed utilizing a grid system of sample points on one quarter of an inch centers. The elevation of the average relief of joint asperities was arbitrarily chosen as the reference plane. Points above this refer-

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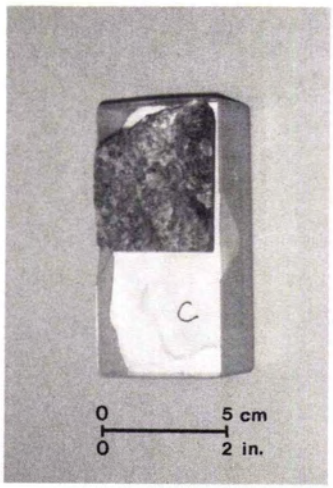

FIG. 1. Fractured rock specimen mounted in plaster of paris.

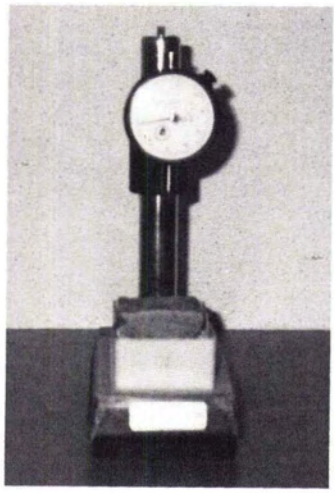

FIG. 2. Dial gage for measurements of the joint surface roughness.

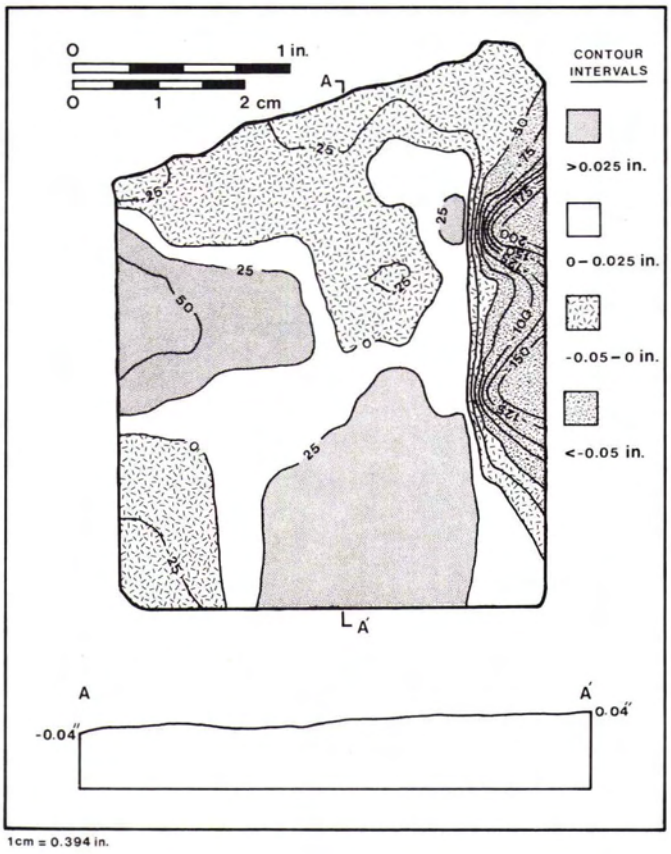

FIG. 3. Contour map of the joint surface topography (contour interval: 0.064cm/0.025 in.).

ence elevation were labeled with positive contour intervals. Negative intervals were assigned to points below the average relief plane. The map of the joint surface topography was later divided into four zones with their corresponding interval ranges (Figure 3). Also shown in Figure 3 is a cross-section view of the joint surface in the loading direction. The average joint surface inclination angle was approximately 2.2°. A joint roughness coefficient (JRC) of less than 5 was assigned by matching the profile of the joint surface with the JRC system established by Barton and Choubey (Figure 4). The sample was then transferred to the digital image processing laboratory for scanning.

SCANNING AND PROCESSING DEVICES

The intent of this study was to develop an applicable procedure of image scanning and processing of joint surface images. Shapes and patterns of joint surface features resulting from shearing are commonly observed in images as gently curved or linear trends or as scattered high/low points. Such patterns may be inferred as trends of asperities or fracture planes. The Eikonixscan 78/99 digitizer camera system and Comtal/3M image processor at the Digital Image Processing Laboratory at the University of Alaska Fairbanks were used to perform the scanning and processing tasks. The following summarizes the specifications of each device and its respective functions.

SCANNING CAMERA

The Eikonixscan 78/99 camera (Figure 5a) is a digitizing device which is capable of scanning a photograph of a joint surface or an undisturbed joint surface and converting it directly into a digital form. The scanning system consists of two components: the scanner head and the electronics unit. The image scanner at the laboratory consists of an array of 1728 photodetectors spaced 15 micrometres (0.0006 in.) apart. During a scan, the array moves incrementally in a direction perpendicular to its length. In each scan, up to 2048 steps can be taken. While receiving the reflectance from the joint surface, each photodiode developed a voltage which was converted into a digital representation of the light. The number of bits per pixel can be adjusted up to 12 bits. A maximum of 4096 grey levels may be obtained by software control.

The digitizer system described above was connected to a DEC VAX 11/750 host computer. The purpose of the VAX computer is to capture, process, and store the digital value sensed by the

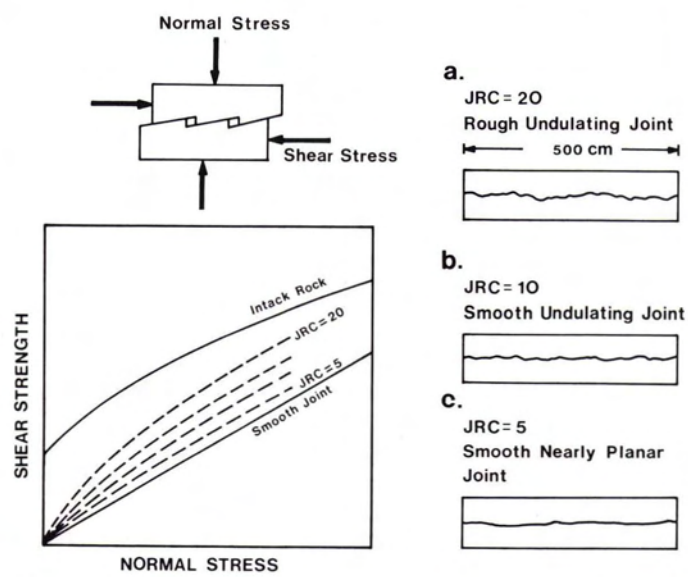

FIG. 4. Classification of joint surface roughness and prediction of shear strength for non-planar rock joints (modified after Barton and Choubey, 1977).

A B

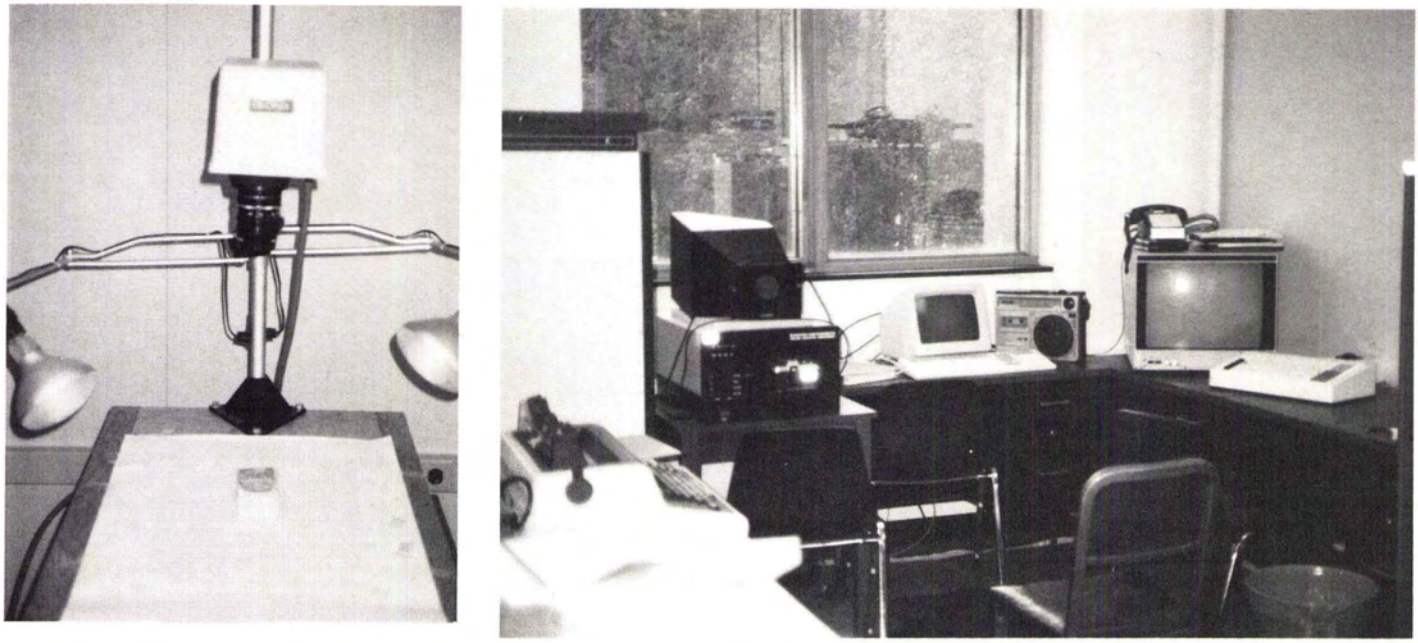

FIG. 5. (A) Ekonixscan 78/99 camera for digitizing image of the joint surface; (B) Comtal/3M image processing system at the University of Alaska Fairbanks.

photodetectors. In this study, the Eikonixscan camera, through the control of computer, was set to scan an image of 512-by-512 pixels with an 8-bit radiometric resolution. The fractured rock surface was placed directly beneath the 55-mm Nikon Micro-Nikor lens and scanned with proper illumination from one direction. Primary color filters were used as well to perform color separation. During the entire scanning process, the exposure level and time were set at the highest level.

IMAGE PROCESSOR

The set of color filtered, digitized images were loaded onto the four image planes of a Comtal/3M Vision One/20 system (Figure 5b). The processing system, a complete system providing an interactive processing and control capability, was also interfaced with the DEC VAX 11/750 computer. The processing system produced an image with spatial and radiometric resolutions compatible with the image scanned. The system configuration consists of a fully integrated LSI-11 processor, image processing electronics, refresh memory, and application hardware and software. Control is accomplished by means of the system keyboard and trackball through a terminal connected to the host computer. In this study, all of the routine processing was performed interactively and in real time.

IMAGE ANALYSIS AND RESULTS

The identification of joint surface roughness and asperity contact area have an important implication in determination of frictional strength of a fractured rock mass. Bandis *et al.* (1981) conducted a comprehensive investigation of the shear behavior of rock joints. From the study, they found that a reduction in peak shear strength was associated with a decrease of joint roughness and an increase of actual asperity contact area. Barton and Choubey (1977) suggested that the contact area ratio of a joint might be closely related to the ratio of joint-wall compressive strength to effective normal stress acting on the joint surface.

As described earlier, the intent of this project was to search for a workable procedure which can be utilized to identify the distribution of asperities and degree of joint roughness. In this section, the authors summarize the methods used during the investigation.

CONTRAST ENHANCEMENT

Figures 6A to 6D show histograms of the original images of the rock specimen joint. Figure 6A presents the brightness distribution of the joint surface without the use of color filters, and the remainder were that of primary color filtered images. The image scanned with the red filter (Figure 6B) illustrates a much brighter image and a wider albedo variation than the green- and blue-color filtered images (Figures 6C and 6D). The reflectance variation in Figure 6A has a shape similar to that shown in Figure 6B. Saturation of the unfiltered image occurred during the scan. This could be eliminated by control of the lighting or software. The arrows shown in the diagrams of Figure 6 present the median reflectance values of the quartz diorite specimen at the tested spectral ranges. The information indicated that the average albedo of the red color component image was about 3 to 5 times stronger than that of the green and blue color component images.

A wide variety of processing routines were tested for contrast enhancement. In order to remove unwanted marginal areas from the image, a small area image technique was invoked by tracing the outline of the joint surface on a graphic plane. The final contrast enhanced images were derived by fitting the original histograms to normal distribution curves between the limits of the dynamic range of the display monitor (Figures 7A to 7D). A true color composite image (Figure 8) was recreated from the primary color images. The improvement of the image contrast and spatial resolution of the color composite image was not

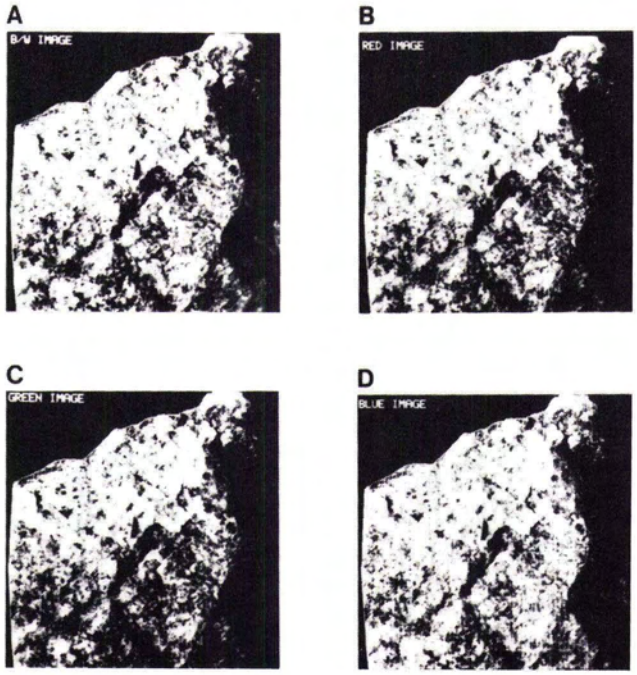

FIG. 6. Brightness distribution of the joint surface images. (A) unfiltered image, (B) red-color filtered image, (C) green-color filtered image, and (D) blue-color filtered image.

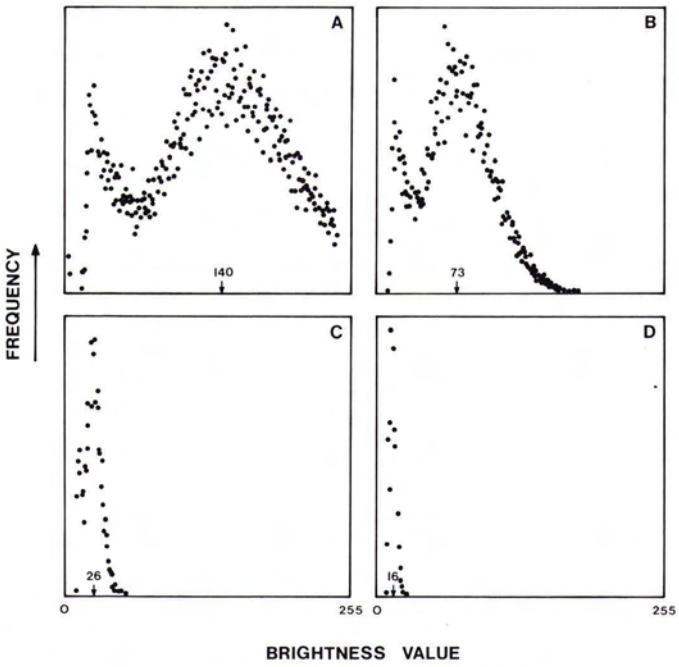

FIG. 7. Contrast enhanced images of the joint surface. (A) unfiltered image, (B) red-color filtered image, (C) green-color filtered image, and (D) blue-color filtered image.

significant. This was perhaps due to the relatively uniform color of the rock surface.

JOINT SURFACE CHARACTERIZATION

The color composite image was divided into four zones of different relief based upon the distribution of brightness, shading,

FIG. 8. Image with four zones of joint surface roughness.

and surface textures (Figure 8). The zone labelled as "L" indicated a low relief area where the rock was chipped away during the unconfined compressive test. The L-area was easily identified because the brightness values were low. As compared with Figure 3, the low area approximately followed the area enclosed by contour line of -0.127 cm (-0.050 in.). The area labelled as "H" on the image (Figure 8) indicated the high elevation contact area of the joint surface. This area when also compared with the contour map, more or less coincided with the area with elevation higher than 0.064 cm (0.025 in.).

The Il and I2 areas were zones with intermediate relief. The textural and tonal differences between these two zones were less evident on the image. As noted in Figure 3, the relief in these two zones ranged from -0.127 cm (-0.050 in.) to 0.064 cm (0.025 in.) which was very close to the average asperity elevation value. Besides the small magnitude of elevation change, the direction of lighting may have also prevented the authors from differentiating the actual boundary between I1 and I2 zones. Although these difficulties existed, the two zones were traced according to brightness variation and observed linear features which indicated the trends of high and low contact points.

JOINT SURFACE IMAGE PROCESSING

Upon the completion of manual characterization of the joint surface roughness, several routine processing techniques were carried-out to automate the characterization task. The methods used include density slicing, supervised classification, convolution process, and image combintion. Among those methods, image combination was more favorable in matching the processed image with the boundaries of the relief zones.

The image combination process involved arithmetic manipulation of two images. The displayed image showed the grey level in each pixel which was determined by the applied algorithm. In this study, image addition, subtraction, division, and multiplication were tested. The displayed images were further enhanced interactively by changing the offsets and scale factors of the mathematical model. Figure 9 illustrates an enhanced

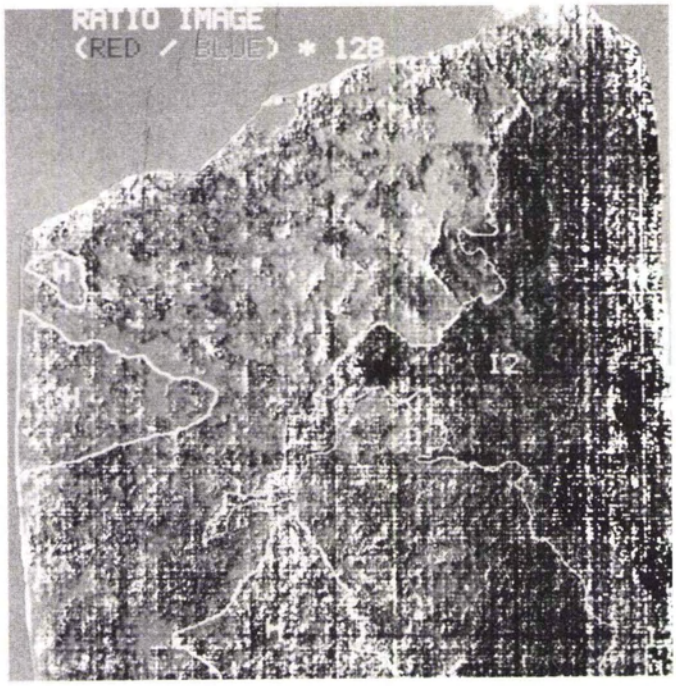

FIG. 9. Contrast enhanced ratio image of the red-color filtered image to the blue-color filtered image.

ratio image of the red-color filtered image to blue-color filtered image. From the ratio image, the areas labeled as "H" shown in Figure 9 lost detail as a result of the relatively high scale factor used in this case. The data were much more informative in areas where the original pixel brightness values were low. The lesser variation in the differences of reflectance in the I2 and L zones between the red component and blue component images was not only applicable for joint surface roughness characteristization, but also useful for distinguishing between mineral types which were not visible in the previous figures.

The convolution process which produced banding on the image, enhanced the linear features such as fractures and trends of asperity points. Several 3-by-3 filters were passed across the original red component image to enhance linear features in the shear direction. Figures 10A and 10B illustrate how the directional filters enhanced suitably oriented joint surface features. In Figure 10A, the filter (0 0 -1 0 3 0 -1 0 0) enhanced a set of three fracture lines which cut across the joint surface in a NW-SE trend and a number of other smaller linear features. A trend of the asperities surrounding the high relief areas was also observed. The filter (−1 0 0 0 3 0 0 0 −1) indicated in Figure 10B enhanced the fracture lines running in the NE-SW direction. These two sets of fracture lines make an angle of approximately 30° from the loading direction.

CONCLUSIONS

The main conclusion drawn from this pilot study is that the image scanning technique may be utilized for digitizing the fine details of joint surfaces created during the deformation of rock or other solid materials. Utilizing various directions of illumination can supply additional information in relation to the degree of joint roughness.

Routine image processing methods are able to enhance contrast variations of joint surfaces. Image ratioing, as compared with other processing methods, is a more promising technique to automate the identification of joint asperity and mineral distribution. The filtering process allows viewers to better identify existing fracture patterns and further estimate the shearing paths of rock under load.

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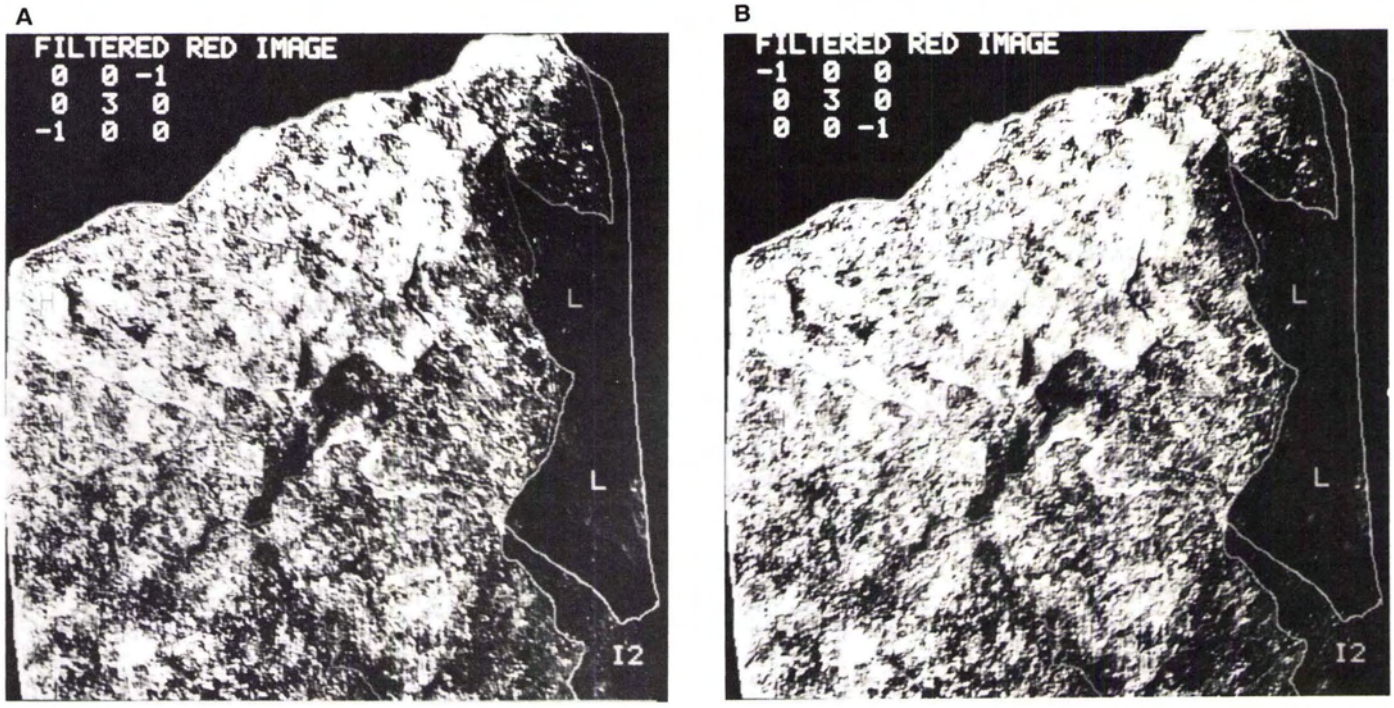

FIG. 10. Directional filtered rock joint surface images (A) with NE-SW filter (0 0 −1 0 3 0 −1 0 0) and (B) with NW-SE filter (−1 0 0 0 3 0 0 0 −1).

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