Measurements Of Granite Joint Surfaces Using Area-Based Matching And A Surface Model

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ABSTRACT

Surface measurements of joints in rock provide an indication of the roughness of the joint plane. With such information, design engineers will be able to classify the joints and estimate their shear strengths. The common technique adopted in measuring the surface is through the use of a profiler. As such, the mensuration process is sometimes laborious and time consuming. Measurements are normally repeated to obtain a better representation of the surface and this in turn makes the whole exercise lengthy.

This study looks at the suitability of close range photogrammetry technique in measurements of joint surface in granite. In particular, this paper presents the usage of surface models in the image matching process. The image matching approach adopted is the area-based but extended to include information of the surface, i.e. suitable surface models.

1 INTRODUCTION

It is well accepted that area-based matching methods, either single or multi-point, are more precise than feature-based matching for finding corresponding points on digital images. Since it was first introduced, many studies have been conducted in a quest to further improve the accuracy and performance of area-based matching. These studies, which were undertaken either for topographical or non-topographical applications, range from practical improvements of the conventional area-based method to more complex solutions or algorithms that entirely replaced the approach of the conventional method.

The fact that on-going work is still being carried out suggests that limitations still exist at present and further investigations are needed. Amongst the problems that are still current, include (a) geometric model, (b) radiometric parameters, (c) estimation of initial parallax values and (d) the need for expensive hardware to be able to provide accuracies acceptable to the 'real world'. Moreover, conventional area-based methods are suffering from problems such as slow-convergence when the initial data do not contain enough signal, multi-solution (false matching) when areas measured have repeated patterns, and weak or impossible matches.

In an attempt to solve some of the existing problems above and after considering possible avenues for improvement, this paper looks at enhancing the fidelity of the pixel co-ordinate transformation used in area-based matching. This is seen as a means of enabling larger windows to be utilised, thereby allowing the number of redundancies to be increased, so improving accuracy and reliability. As such, this paper proposes a method that modifies the functional model describing the relationship between the windows. The method replaces the approximations made using an affine transformation. It makes use of a surface model and the collinearity conditions in determining the transformation needed. This is because the use of an affine transformation in representing the relationships between the windows means that no information of the object is taken into account. However, if a projective condition such as the collinearity and the object's shape are used, a greater fidelity is involved in the transformation between the windows. Moreover, if some information about the surface to be measured is available then some sensible surface model can be introduced and the problem could be alleviated.

In other words, the problem of precision, accuracy and reliability were overcome by modifying the existing conventional area-based algorithm. Since there is greater fidelity involved in the transformation, it is hypothesised that the improved functional model will allow the use of larger windows for matching and hence improve accuracy.

2 PRESENT APPROACH OF DETERMINING TOPOGRAPHY OF JOINT SURFACES IN GRANITES

Joint surfaces or sometimes referred to as structural discontinuities, are planes of weakness in massive rock such as granite. Joints are identified to be the main cause of rock shear failure. The surface texture or roughness of these joint planes greatly influenced the strength and direction of shear along a joint surface (Hencher & Richards, 1989). Figure 1 (a) and (b) explains the effect of surface roughness on the strength of a joint surface.

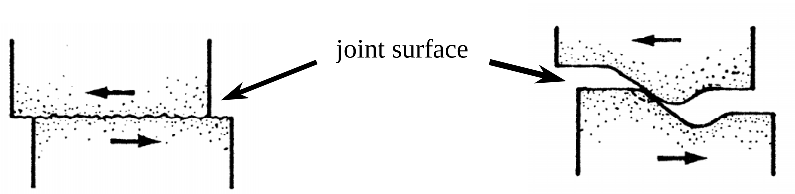

Fig. 1(a) Relatively smooth surface of joint surface results in low shear strength

Fig. 1(b) Rough joint surface means higher shear strength

In order to determine the strength of a joint surface, cross-sections of a sample are obtained by measuring the surface topography at nominated grid points. The height information is then used to calculate the mean height of the joint plane. The strength of the joint surface is then approximated based on the mean height obtained.

Present approach of obtaining the topography of the joint surface is through the use of a profiler (ISRM, 1981). It is basically a hand-held instrument comprising of a bar fitted with a probe that slides along the bar. Cross-sections are obtained by aligning the bar on a selected section on the joint surface and vertical movements of the probe give the heights that are needed. The measurement process is laborious and time consuming.

3 JOINT SURFACE RECONSTRUCTION USING AREA-BASED IMAGE MATCHING AND SURFACE MODELS

As mentioned earlier, area-based image matching is capable of yielding high accuracy in three-dimensional surface reconstruction when compared to feature-based matching. The area-based matching procedure adopted in this study is an approach that makes use of suitable surface models. The mathematics involved in area-based matching are well documented in many publications (e.g. Grün 1996) and will not be described here. It may be sufficient to point out that area-based matching utilises a least squares solution of observation equations written for each of the pixels within the window. The observation equation for any one pixel involves the difference in image intensity between that pixel and a corresponding pixel on the other image. In this study the position of the corresponding pixel is obtained through an iterative least squares adjustment using information of the camera orientations, projective geometry and suitable surface models.

The basic area-based observation equation, which gives a relationship between the radiometric values of corresponding pixels in the left and right image, can be written as follows :-

$$I_L(x_L, y_L) + n(x,y) = I_R(x_R, y_R) \tag{3.1}$$

where,

I_L, I_R	are the intensities of the left and right pixel respectively
x_L, y_L	are the image coordinates of the left pixel
x_R, y_R	are the corresponding image coordinates on the right image
n(x,y)	is the difference caused by noise at the point (x_L,y_L) on the left image.

If the relationship between image coordinates on the left (x_L,y_L) and (x_R,y_R) on the right is traditionally given by assuming an affine transformation exists between the images, then matching has to be done using only those pixels in those sub-areas of the images in which the affine relationship still holds between the two images.

On the other hand, introducing a suitable surface model to modify Eqn. 3.1 means that projective transformation (i.e. collinearity equations) is involved thus ensuring that a better transformation is obtained across the image. Using the collinearity equations also means that three additional parameters, (X,Y,Z) will be introduced. Supposing that the six relative orientation parameters of the cameras or sensors are precisely known, then a simpler relationship of the points used that relates to the object coordinates (X,Y,Z) can be obtained through the epipolar constraint. To do this, a deterministic mathematical model is adopted for the surface, such that the relationship between the coordinates of any one point on the surface, say (X_p,Y_p,Z_p), and the point to be matched (X_o,Y_o,Z_o) on the surface can be determined. Assuming that the refined image coordinates (i.e with corrections to lens distortion applied) of the point to be matched on the left image is given by (x_L,y_L), then, through the use of the collinearity conditions, the following applies :-

$$x_L = f_{x_L}(X_o,Y_o,Z_o) \quad (3.2a)$$

$$y_L = f_{y_L}(X_o,Y_o,Z_o) \quad (3.2b)$$

where,

x_L,y_L	are the known coordinates of the central point on the left image
X_o,Y_o,Z_o	are the corresponding object space coordinates of the point to be matched
f_{x_L} , f_{y_L}	are the collinearity conditions

The object space coordinates (X_o,Y_o,Z_o) are not known, but can be estimated. If the neighbouring are represented by shifts $(\Delta x_L, \Delta y_L)$ from the point to be matched in *x* and *y* directions respectively, then Eqn. 3.2 (a) and (b) can be written as :-

$$x_L+\Delta x_L = f_{x_L}(X_o+\Delta X,Y_o+\Delta Y,Z_o+\Delta Z) \quad (3.3a)$$

$$y_L+\Delta y_L = f_{y_L}(X_o+\Delta X,Y_o+\Delta Y,Z_o+\Delta Z) \quad (3.3b)$$

where ΔX, ΔY and ΔZ are the differences between the central point coordinates (X_o,Y_o,Z_o) and (X_p,Y_p,Z_p) in the X, Y and Z directions respectively.

Supposing that matching is to be done for a flat surface, then a planar (first order) surface model can now be introduced across the window to represent the surface. The change of elevation (ΔZ) at any point on the surface is given by :-

$$\Delta Z = \frac{\partial Z}{\partial X}\Delta X + \frac{\partial Z}{\partial Y}\Delta Y \quad (3.4)$$

where (∂Z/∂X) and (∂Z/∂Y) are the gradients of *Z* in *X* and *Y* directions respectively. These gradients define the model surface and they are to be evaluated in the solution. If the changes in *X* and *Y* are expressed as ΔX and ΔY as a function of the corresponding shifts on the left image, Δx_L and Δy_L respectively, then Eqn. 3.4 can be written as :-

$$\Delta Z = \frac{\partial Z}{\partial X}\left(\frac{\partial X}{\partial x_L}\Delta x_L + \frac{\partial X}{\partial y_L}\Delta y_L \right) + \frac{\partial Z}{\partial Y}\left(\frac{\partial Y}{\partial x_L}\Delta x_L + \frac{\partial Y}{\partial y_L}\Delta y_L \right) \qquad (3.5)$$

The above discussion only serves to provide a brief outline of the functional model used for the image matching. Detailed discussion of the mathematics involved can be found in Mustaffar (1997), Mitchell & Mustaffar (1997).

4 TESTS CONDUCTED

Preliminary tests on the suitability of the proposed approach on joint surface measurements were performed on a plaster cast of a typical granite surface. A 15mm grid was marked on the sample's surface and the nodes of the grid intersections represent points of interest on the surface. Apart from providing well-defined marks on the surface, the grid also provides good texture in the matching process. (see Fig. 2)

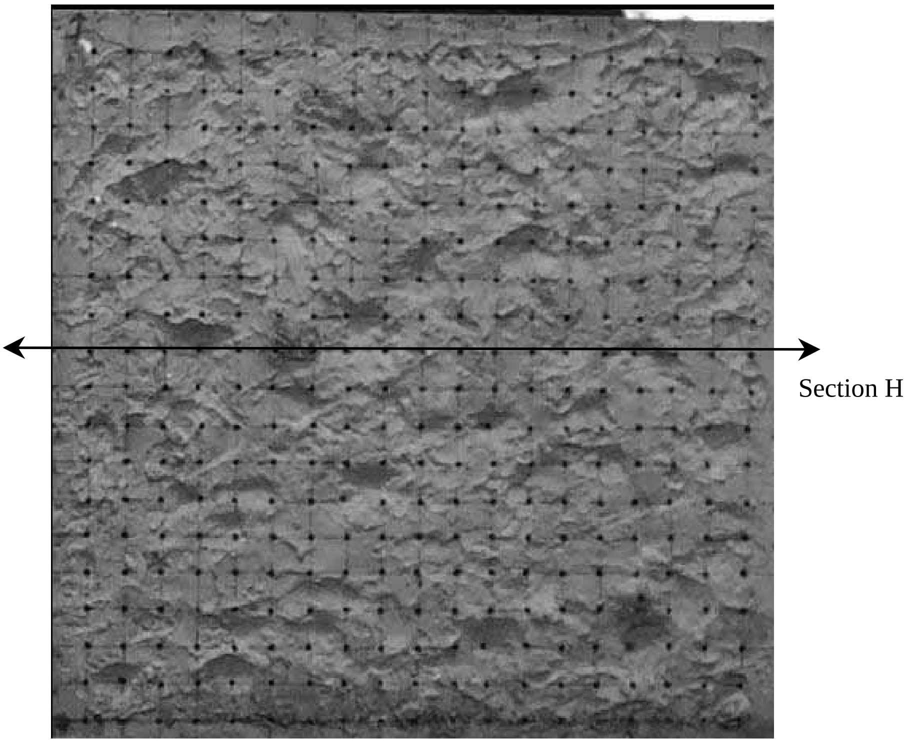

Fig. 2 Plaster cast of a typical granite joint surface with 15mm grid. Section *H* denotes the cross-section selected for the test.

The camera used in this project for the purpose of image acquisition is a DC240 Kodak digital camera which gives a resolution of 1280 × 960 pixels. The dimension of the sensor was found to be 4.1µm in *x* and 4.5µm in *y*. The camera is fitted with a 6 - 18mm zoom lens which is equivalent to 39 – 117 mm lens in 35mm photography. Image of the plaster cast was captured at focal length setting of 6mm. It should be noted that, as this is a preliminary study, calibration of the camera was not done but will be performed at a later stage of the study. Figure 3 shows an example of the camera used.

Fig. 3 An example of the Kodak DC240 digital camera used for image acquisition

For comparison purposes, the plaster cast was measured using the profiler at the same grid nodes used in the photogrammetric approach. Table 1 lists the heights obtained at cross-section *H* as shown in Figure 2. This section was selected due to the fact that it lies in the centre of the shear plane.

Distance along cross-section (mm)	0	15	30	45	60	75	90	105	120	135
Heights using profiler (mm)	0	0.90	-0.88	-0.46	0.75	-3.50	-0.60	4.68	2.87	1.28
Heights using Photogrammetry (mm)	0	0.25	1.92	1.97	1.48	4.09	-0.47	3.42	3.72	2.10

Distance along cross-section (mm)	150	165	180	195	210	225	240	255
Heights using profiler (mm)	2.69	2.47	3.47	2.34	1.61	2.33	0.62	0.29
Heights using photogrammetry (mm)	3.36	3.19	3.80	3.87	2.27	2.49	1.23	1.44

Table 1. Heights along cross-section obtained using the profiler and photogrammetry.

Figure 4 shows the cross-sections obtained by both methods plotted using values tabulated in Table 1. Assuming that the data obtained from the profiler represent the correct profile of the section, it can be seen, apart from the region between distances 0 to 90mm, that both methods produce a similar profile of the cross-section. The maximum difference in height is approximately 1.5mm and the standard deviation is approximately 0.7mm. This is a good indication of the suitability of close-range photogrammetric technique in the determination of surface roughness of granite joints.

A possible explanation why the profile of the section obtained by both methods differ significantly between distances 0 to 90mm (maximum difference in height approximately 7.5mm) could be attributed to the fact that camera calibration was not performed. Since, heights needed are in the order of millimetres, it is felt that slight changes in the camera interior orientation will affect the results.

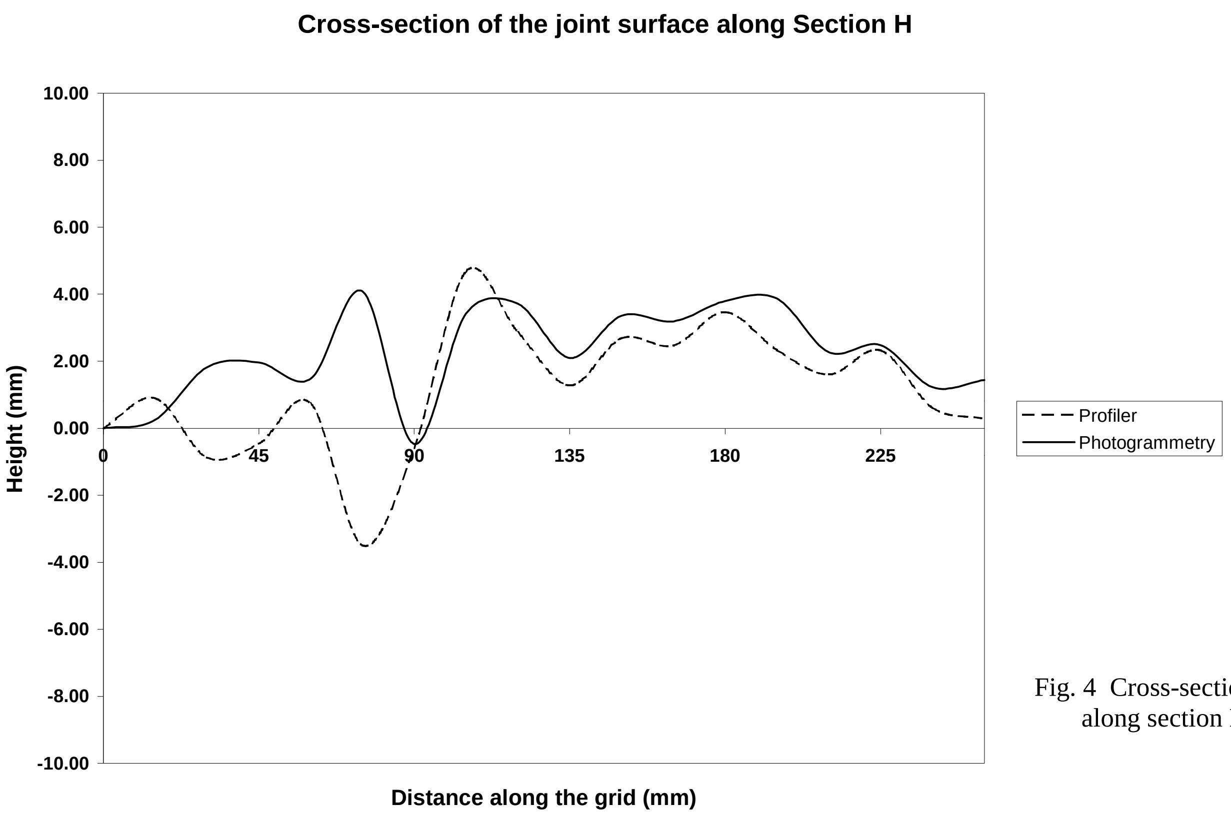

Fig. 4 Cross-section along section H

5 CONCLUSION

It has been shown in this preliminary study that close-range digital photogrammetry and in particular, area-based matching using surface models has a future in surface measurements of rock surfaces. However, the possibility of replacing the conventional method with photogrammetry is not conclusive since further studies and tests on real and variety of samples are needed.

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