Digital Surface Modeling for Assessment of Weathering Rate of Weathered Rock in Stone Monuments

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ABSTRACT:

This study presents method for self-calibration of the SEM (Scanning Electron Microscope) stereo image using the standard microprobe with same grid pattern and using parallel projection equation. The maximum error of 3D coordinates acquired by the method did not exceed 5 μm, and DSM (Digital Surface Model) for three dimensional measurement of the rock sample was generated by the digital photogrammetric technique. This result can be used for quantification of micro scale change of shape and analysis of the micro morphology of rock due to weathering.

1. INTRODUCTION

DSM (Digital Surface Model) of microprobe can be acquired by combination of the digital photogrammetric technique and SEM (Scanning Electron Microscope) stereo image (Hemmleb and Albertz, 1996; Stampfl et al., 1996). The 3D visualization and positional information of microstructure can be also acquired from combination of those (Minnich et al., 1999).

Stone monuments are often endangered due to the deterioration (i.e. weathering process) in nature. To monitor the speed of such deterioration, it is necessary to have DSM of stone surface in micro scale. In this study, SEM is used to acquire the stereo images of the stone surface. SEM stereo images are used to generate DSM by the digital photogrammetric technique. And it is also required to develop a reliable and more accurate method for acquisition of digital surface image of weathered stone which has caused durability problems on stone monuments. For this, self-calibration method of the SEM stereo image is presented using the standard microprobe with same grid pattern and using parallel projection equation.

Using an algorithm, DSM is acquired and further analysis on the rate of weathering due to several factors can be conducted, after the stone surface has been artificially weathered by dry & wet cycles and freezing and thawing cycles.

2. METHODS

2.1 Self Calibration of SEM Image

SEM image have various distortions (scale and tilt angle distortion, radial and spiral distortion, etc.), and image distortion is corrected using the standard microprobe with same grid pattern (Ghosh and Nagaraja, 1976; Maune, 1976). Self calibration method (for correction of image distortion) can be applied parallel projection equation (Fig. 1 and Eq.1, 2).

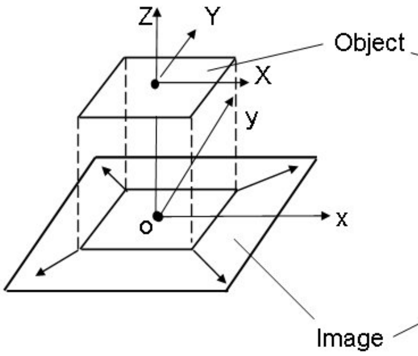


Figure 1. Parallel projection

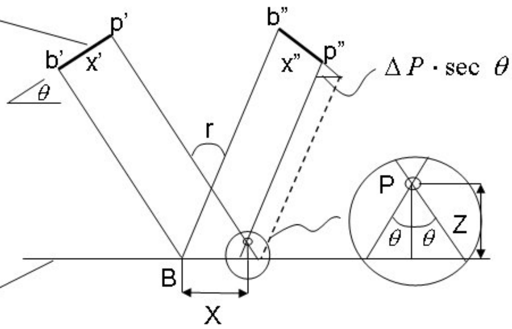


Figure 2. Intersection geometry (Ghosh, 1988)

$$x + \Delta x = Mx[m1X + m2Y + m3Z]$$
$$y + \Delta y = My[m4X + m5Y + m6Z] \qquad (1)$$

$$\Delta x = D_1 x^3 + D_2 xy^2 + S_1(x^2 y + y^3)$$
$$\Delta y = D_3 y^3 + D_4 x^2 y + S_2(x^3 + xy^2) \qquad (2)$$

Where, x, y and X, Y, Z ; image coordinate and 3D position of standard microprobe

M_x, M_y and m1···m6 ; scale factor in X, Y direction and coefficients of parallel projection equation

D_1 □□□ D_4 and S_1, S_2; radial distortion and spiral distortion coefficients

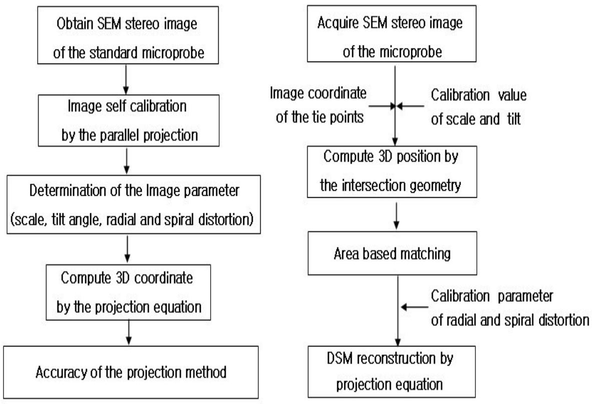
2.2 3D Positioning

3D coordinates of microprobe surface in the SEM imaging system are computed by the intersection geometry (Fig. 2 and Eq.3) using tilt angle (θ) and scale factor of stereo image on the parallel projection.

$$Z = (x' - x'')/(2 \cdot Mx \cdot \sin\theta)$$
$$X = (x' \cdot \sec\theta)/Mx \qquad (3)$$
$$Y = y'/My = y''/My$$

3. TEST AND RESULTS

Model name of SEM system is Phillips XL-20, and image resolution of that is maximum 3.5nm. And the standard microprobe is constructed same grid pattern (one-square size is 100 × 100 micrometer in X and Y direction, height is 5 micrometer). Overall processing for acquisition of DSM of rock sample is described in Figure 3. Figure 4 and 5 show working using SEM system and left and right image of standard microprobe acquired from this system. And Figure 6 shows 36 control points were selected by using the ERDAS IMAGINE software (ver. 8.4). Control points have image coordinates and 3D coordinate for self-calibration of SEM image. Figure 7 shows left and right image of rock sample, acquired condition of those correspond to condition of standard microprobe image



(a) (b)

Figure 3. Flow chart of the self-calibration using the standard microprobe(a) and the DSM reconstruction(b)

Figure 4. SEM system

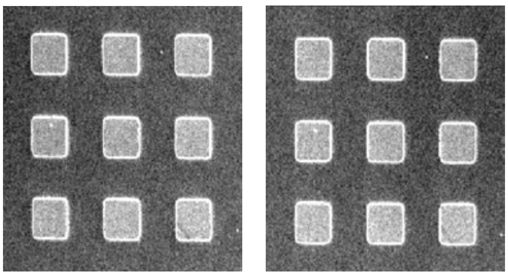


Figure 5. Stereo image of the standard microprobe acquired from this system (Scale factor: 39, Tilt angle: Left image -6°, Right image +6°)

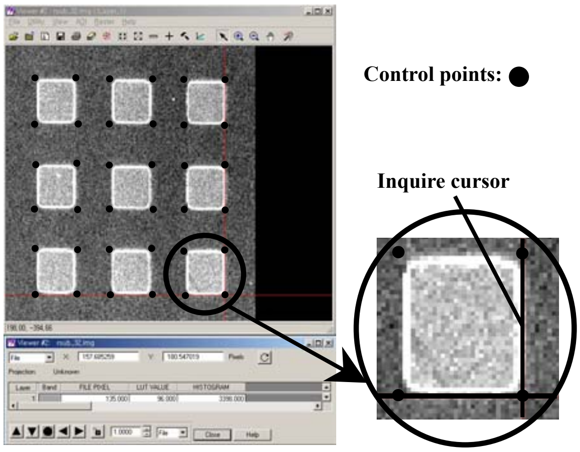


Figure 6. Control points for self-calibration using the parallel projection

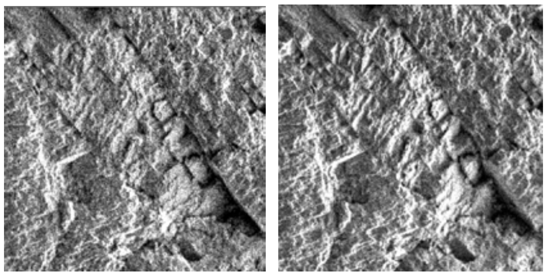


Figure 7. Stereo image of the rock sample acquired from SEM system (Scale factor: 39, Tilt angle: Left image -6°, Right image +6°)

4. DISCUSSION

In this study, image distortion coefficients are determined by self calibration using stereo image of the standard microprobe and parallel projection equation (Table 1), and 3D positions of control points are computed by Figure 3(a) processing (Table 2).

Table 1. Distortion parameters of the SEM image

Parameters \ Projection		Parallel	
		Left image	Right image
Tilt angle		7° 12’ 00”	7° 11’ 24”
Scale	X	35.17	35.49
	Y	40.11	40.11
Radial distortion	D1	-5.97e-09	-5.12e-08
	D2	3.60e-08	3.25e-08
	D3	-2.60e-08	-2.47e-07
	D4	-2.99e-08	6.82e-08
Spiral distortion	S1	3.03e-08	-9.58e-09
	S2	5.72e-09	4.38e-09

Table 2. 3D positional error of control points generated from parallel projection (unit μm)

Coordinates	X		Y		Z	
Error	RMSE	Max.	RMSE	Max.	RMSE	Max.
Parallel (36 points)	1.93	3.45	2.14	3.80	0.15	0.33

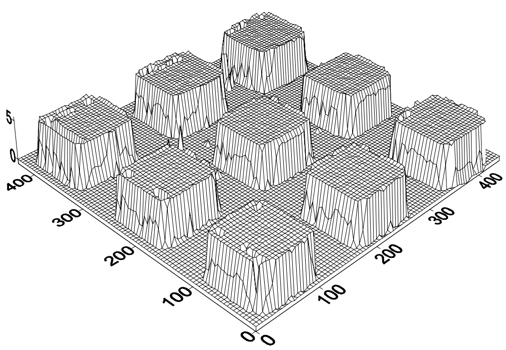


Figure 8. DSM of the standard microprobe (space: 10μm)

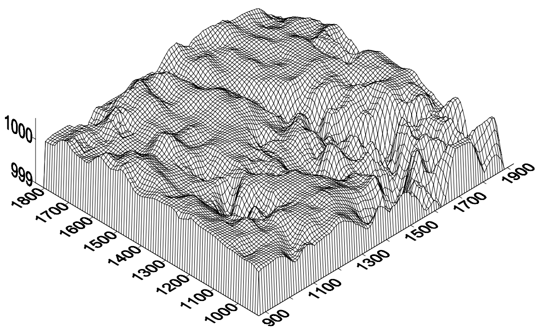


Figure 9. DSM of the rock sample (space: 10μm)

As shown in Table 1, the highest distortion is scale of X direction. The maximum error of 3D positioning of control points did not exceed 5μm (Table 2). DSM of object probe was reconstructed by Figure 3(b) processing method. Figure 8 and 9 show DSMs of the standard microprobe and the rock sample.

5. CONCLUSION

1. Self calibration technique of SEM system for acquisition of microprobe DSM is presented in this study, using the standard microprobe and parallel projection equation.
2. The maximum error of 3D positions acquired by parallel projection did not exceed 5μm, and DSM for three dimensional measurement of the rock sample was generated by the digital photogrammetry.
3. This result can be used for quantification of micro scale change of shape and analysis of the micro morphology of rock due to weathering.

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