THREE DIMENSIONAL MEASUREMENT OF METAL SURFACE SHAPE BY USING A STEREO PAIR OF SEM PHOTOGRAPHS

Junichi Koseki, Ryuji Matsuoka,
Kojiro Hirai and Takeshi Yamamoto

Survey Department
Kokusai Kogyo Co., Ltd.
6-1, Asahigaoka 3 Chome, Hino
Tokyo, Japan

Commission V, Working Group V/3
ISPRS Kyoto 1988

ABSTRACT

This paper describes analytical and digital photogrammetric methods of a stereo pair of scanning electron microscope (SEM) photographs.

Analytical method was applied to a triplet of stereo SEM photographs of an impression left by the diamond indenter of Vicker's hardness tester. The height error of the three dimensional measurement was ±5% and the precision is sufficient for surface shape analysis.

Digital image processing method was applied to metal surface analysis. A pair of stereo SEM photographs were digitized and stereo matching process was executed to obtain three dimensional surface shape.

INTRODUCTION

Now the Scanning Electron Microscope (SEM) is widely used, because SEM has a capability to allow ultramicrostructures of specimens to be observed as three dimensional images. However three dimensional measurement using a pair of stereo SEM photographs is not so popular.

This paper describes analytical and digital photogrammetric methods of a stereo pair of SEM photographs to obtain three dimensional surface shape of metal specimens without conventional photogrammetric instruments.

The Objectives of the study are as follows:

1) To evaluate accuracy of three dimensional measurement using stereo SEM photographs.
2) To development the digital image processing system to obtain three dimensional information using stereo SEM photographs.

MATHEMATICAL MODEL OF SEM PHOTOGRAPH

Strictly speaking a mathematical model of SEM photograph is a central perspective projection. However when magnifications are high, the difference between the perspective and the parallel projection can be ignored. In this study, the following parallel projection model is adopted as a mathematical model of SEM photograph.

(X, Y, Z) and (x, y) represent the specimen and the photographic coordinate system respectively. X-axis of the specimen coordinate system is parallel to the tilt axis of the specimen holder and Z-axis is parallel to the principal electron axis. The ith photograph of the specimen with tilt angle θ_i are taken from the projection center (Xo_i, Yo_i, Zo_i) with rotation angle around the Z-axis α_i and scale of photograph is s_i. Subscripts i and j refer to the jth specimen point on the ith photograph.

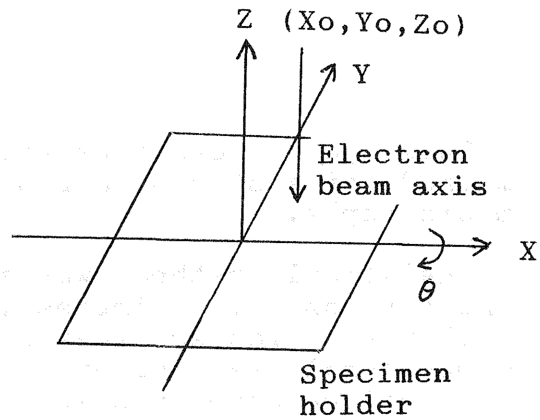


Figure 1 Geometry of SEM photograph

$$x_{ij}=s_i[(X_j-Xo_i)\cos\alpha_i-\{(Y_j-Yo_i)\cos\theta_i-(Z_j-Zo_i)\sin\theta_i\}\sin\alpha_i] \quad (1)$$

$$y_{ij}=s_i[(X_j-Xo_i)\sin\alpha_i+\{(Y_j-Yo_i)\cos\theta_i-(Z_j-Zo_i)\sin\theta_i\}\cos\alpha_i] \quad (2)$$

In this study parameters Xo_1, Yo_1, Yo_2, θ_i, s_1 are assumed constant and the others are treated as unknown parameters.

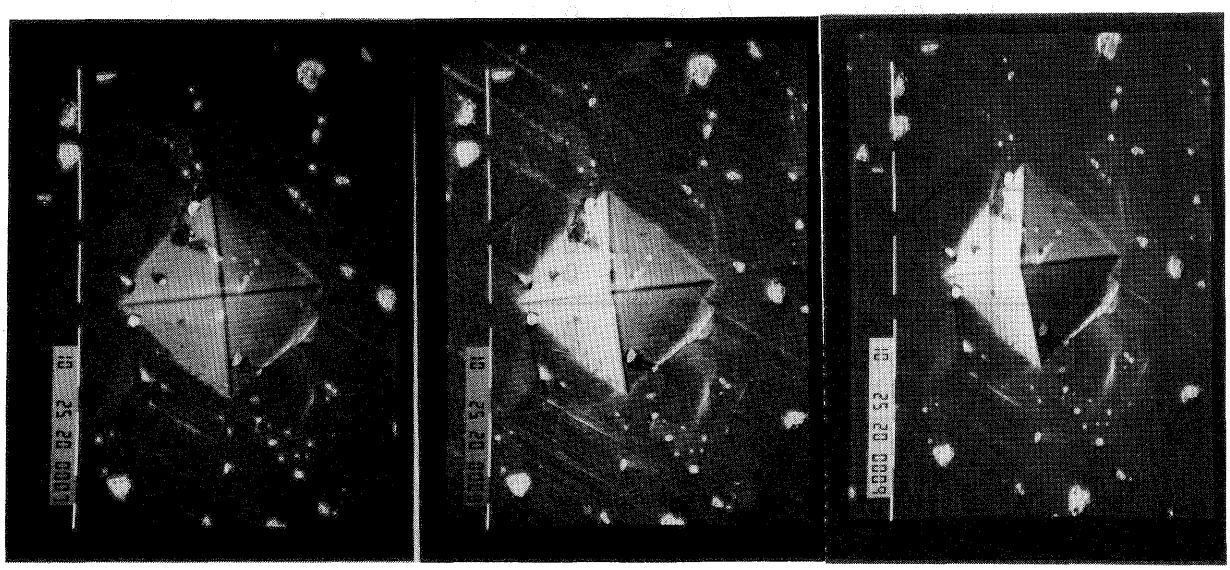
ANALYTICAL METHOD

1. SEM Photographs

Five triplets of SEM photographs of impressions left by the diamond indenter of Vicker's hardness tester with different loads shown in Table 1 were used. Figure 2 shows one of triplets of SEM photographs. Each triplet of SEM photographs were taken at tilting angle 0°, 15° and 30°. Photograph scales were between 750:1 and 2000:1.

Table 1 SEM photographs of impressions of Vicker's tester

Specimen No.	Load (g)	Control points	Photograph No.	Photograph scale	Tilting angle(°)
1	25	11	0001 0002 0003	2000:1 2000:1 2000:1	0 15 30
2	50	11	0004 0005 0006	2000:1 2000:1 2000:1	0 15 30
3	100	11	0007 0008 0009	1500:1 1500:1 1500:1	0 15 30
4	200	13	0011 0012 0013	1000:1 1000:1 1000:1	0 15 30
5	300	11	0014 0015 0016	750:1 750:1 750:1	0 15 30



0° 15° 30°

Figure 2 Triplet of SEM photographs of Vicker's impression

2. Observations

Photographic coordinates of micron markers and control points were measured by the tablet digitizer (minimum reading unit = 0.020 mm) on the twice enlarged positive prints. 11 or 13 control points were selected on the photographs for each specimens as shown in Table 1. 5 control points of them were vertexes of the impressions and the others were used only for orientation.

3. Results

The following results were obtained with respects to 5 specimens shown in Table 1.

1) Mean and maximum residuals of the photographic coordinates of control points are shown in Table 2.

Table 2. Mean and maximum residuals of photographic coordinates

Specimen No.	Photograph No.	Residuals (mm) (Photograph) Mean	Residuals (mm) (Photograph) Maximum	Residuals (mm) (Model) Mean	Residuals (mm) (Model) Maximum
1	0001 0002 0003	0.16 0.09 0.11	0.42 0.14 0.29	0.13	0.42
2	0004 0005 0006	0.10 0.15 0.09	0.23 0.39 0.18	0.11	0.39
3	0007 0008 0009	0.13 0.16 0.15	0.25 0.29 0.26	0.15	0.29
4	0011 0012 0013	0.13 0.12 0.20	0.22 0.20 0.29	0.14	0.29
5	0014 0015 0016	0.12 0.15 0.20	0.20 0.25 0.39	0.16	0.39

2) Observed diagonal length d_o and depth h_o of the Vicker's impression are shown in Table 3. Calculated depth h_c of the Vicker's impression and Vicker's hardness value Hv in Table 3 are calculated by the following equation (3) and (4) respectively. P in equation (3) means load.

$$h_o = d_o / (2\sqrt{2}\tan 68^\circ) \quad (3)$$

$$Hv = (2P\sin 68^\circ)/d^2 \quad (4)$$

Table 3 Results of three dimensional measurement of impressions

Specimen No.	Diagonal length d_o(um)	Depth			Hardness Hv
		Obs. h_o(um)	Cal. h_c(um)	h_o/h_c	
1	18.13	2.59	2.59	1.000	141
2	25.26	3.33	3.61	0.922	145
3	35.38	4.85	5.05	0.960	148
4	54.04	7.01	7.72	0.908	127
5	61.94	8.46	8.85	0.956	145

4. Conclusions

From these results shown in Table 2 and 3 the following conclusions were obtained.

1) Maximum height error of the three dimensional measurement was 9% and average height error was 5%.

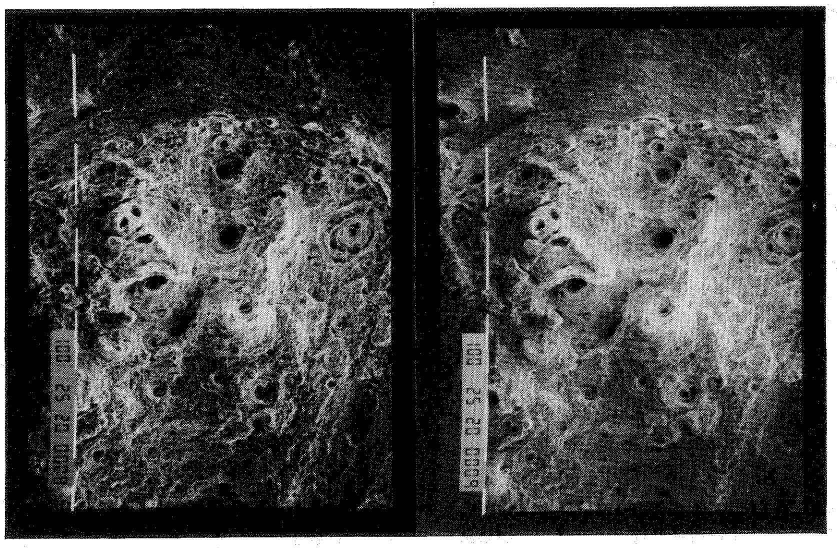
2) The precision of the three dimensional measurement of specimen No.4 shows rather bad. The reason of this fact could be that the quality of the photograph No.0013 was not good and control points were not observed clearly.

3) The height error of the three dimensional measurement using a stereo pair of SEM photographs can be about 5% and the precision can be sufficient for surface shape analysis when the quality of photographs is good.

DIGITAL IMAGE PROCESSING METHOD

1. SEM Photographs

A stereo pair of SEM photographs of the surface of stainless specimen broken in tension test shown in Figure 3 were used. These SEM photographs were taken at tilting angle 0° and 10° and photograph scale was 150:1.



0° 10°

Figure 3. Stereo pair of SEM photographs of stainless specimen

2. Digital Images of SEM Photographs

These two stereo photographs were digitized through the drum scanner with pixel size of 0.050 mm by 0.050 mm.

3. Orientation

112 control points were selected at intervals of 100 pixels and 100 lines on one image. Photographic coordinates of control points on the other image was obtained by image matching method.

Mean and maximum residuals of the photographic coordinates of control points are 0.031 mm and 0.060 mm respectively. Mean and maximum residuals of two bundles intersection are 0.219 um and 0.602 um respectively.

4. Stereo Matching

Multi-stages area correlation method using cross correlation coefficients are adopted as stereo matching method. Three dimensional coordinates of 11,921 points(91 points by 131 points) at intervals of 10 pixels and 10 lines were calculated.

5. Results

The three dimensional surface shape of the specimen was obtained. Figure 4 shows bird-eye views calculated from this result.

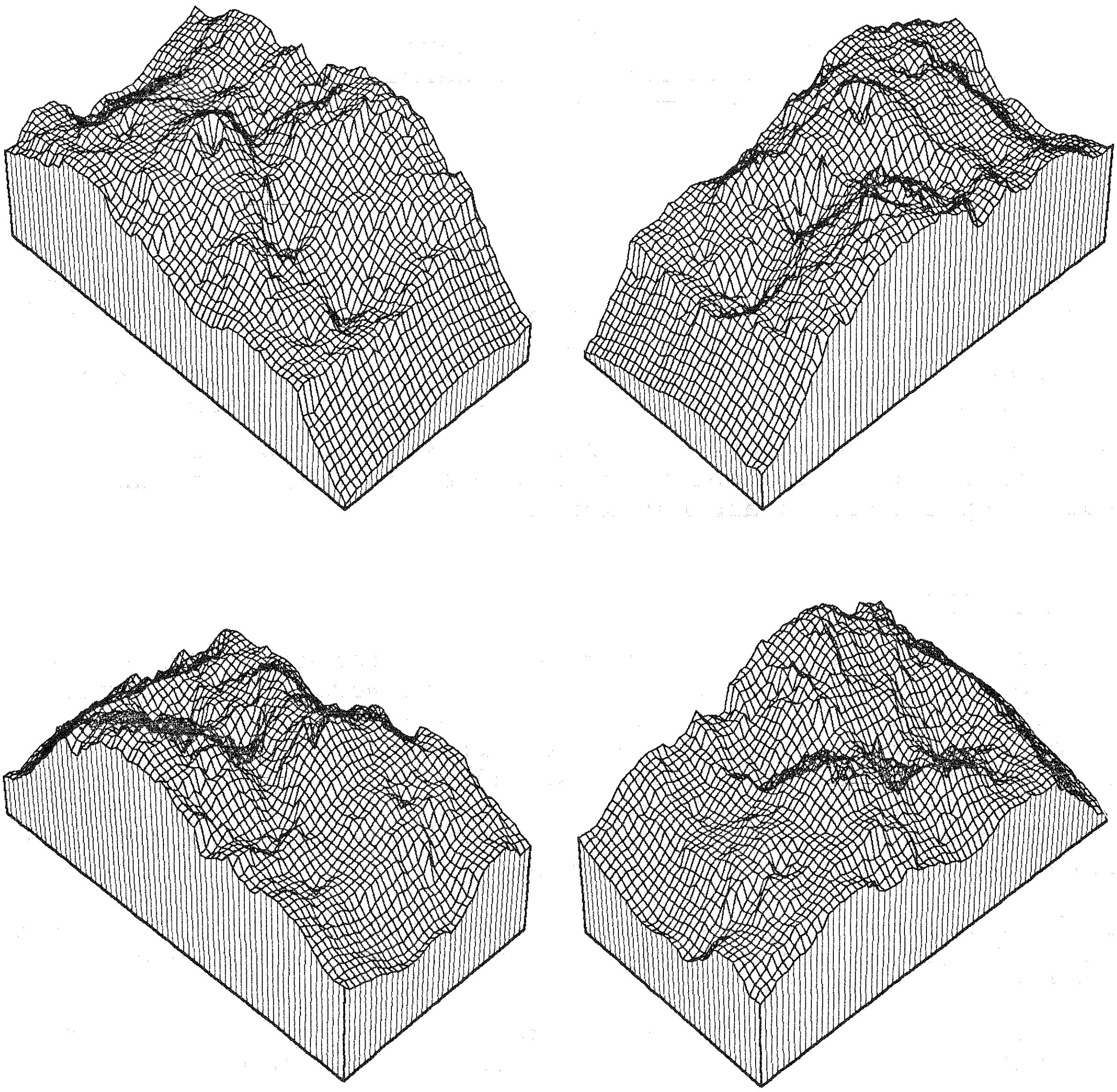


Figure 4. Birds-eye views

6. Conclusion

From these results it was concluded that the digital image processing method to obtain three dimensional information using stereo SEM photographs has been developed and this system can be useful to metal surface shape analysis.