A STUDY ON REAL-TIME PHOTOGRAMMETRY FOR ARCHAEOLOGICAL SITES USING WIRELESS CCD CAMERA

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ABSTRACT

In general, recording for archaeological sites is performed by plane-table surveying, leveling or section drawing , expending a great deal of time and labor. Digital photogrammetry is expected to become a useful tool in this field. However, time consumed in geodetic surveying for camera calibration is still an issue which needs to be resolved. By using information such as distance which is included in the image as proposed in this paper, time consuming aspects of geodetic surveying can be improved.

This paper describes a real-time photogrammetric system for site recording using a wireless CCD camera .

1. INTRODUCTION

Many archaeological sites are excavated yearly in Japan. The number of archaeological sites amounted to over 8,000 in 1994 and the majority of these archaeological sites are found at the foundational stage of a construction.If archaeological sites are found, construction should be stopped during the excavation for site recording. In general, site recording is a slow process since photogrammetric techniques are not yet widely used in archaeology. Even in the case of photogrammetric techniques for site recording, it takes much time to develop film and to enlarge photos since a still camera is widely used . Consequently, finding archaeological sites become a severe problem not only for requester but also contractor.

For real-time photogrammetry, there are two complicated subjects which have to be resolved. One is real-time camera calibration without any geodetic surveying for control. The second is real-time image acquisition from tethered balloons, kites or model helicopter. Ideally, real-time camera calibration without control points can be performed by using GPS and an optical gyro. Such equipment, however, is not widely used due to unacceptable cost. Reducing control points by utilizing information such as distance which are included in the image are considered as a calibration method that does not depend on this equipment.

2.CAMERA CALIBRATION COMBINED WITH DISTANCE

With regard to film camera, simultaneous adjustment of photogrammetric and geodetic data such as distances , angles, or heights has been developed by the authors(Chikatsu et al,1988,1989). The basic idea for the camera calibration combined with the constraint condition of distance is as follows: first, let the border point on the measured line be control point A and let another border point on the same line be control point B. Similarly, let the border points on another measured line be control points C and D. Second, let the line from point A to point B be the X axis and the perpendicular line at point A be the Y axis. Finally, let the ground coordinate of control point A be $(0,0,0)$ and assume that the distance between point A and B is L.The initial ground coordinate of control point B becomes $(L,0,0)$ and the ground coordinate for points C and D can be calculated from the relationship for the positions on the image between A to C and A to D (Figure 1).

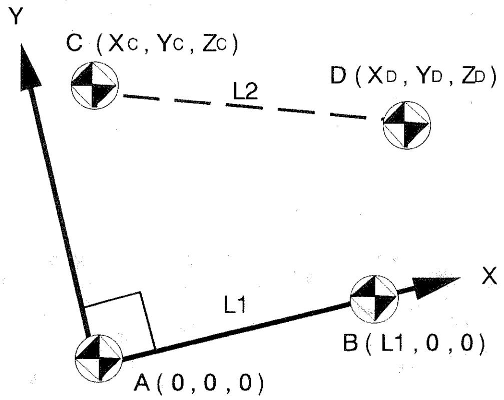


Figure 1 Conception for camera calibration combined with distance

In the case of the CCD camera, the unknown parameters are as follows: exterior orientation parameters (ω, ϕ, κ ,X_0, Y_0 , Z_0), interior orientation parameters { f, x_0, y_0 (principal points), a_1 ,a_2 (scale factor), p_1 (lens distortion)} and ground coordinate for control Points { B(X_B,Y_B,Z_B),C(X_C,Y_C,Z_C),D(X_D,Y_D,Z_D)}.These unknowns can be computed from the following simultaneous adjustments developed in this paper.

$$G_1 = \left\{ \begin{array}{r} \left[p_1\left(\Delta x_i^2 + \Delta y_i^2\right)\right] + \left[p_2\left(\Delta D_{ij}^2\right)\right] + \left[p_3\left(\Delta X_i^2 + \Delta Y_i^2 + \Delta Z_i^2\right)\right] \\ + \left[p_4\left(\Delta\omega^2 + \Delta\phi^2 + \Delta\kappa^2\right)\right] + \left[p_5\left(\Delta f^2\right)\right] \end{array} \right\} \quad \cdot\cdot\cdot\cdot (1)$$

where, [ ] ; summation, p_i weight

The most advantageous points of this method are the ability to simplify the geodetic surveying for camera calibration by utilizing initial ground coordinates for points B,C and D which are calculated from location opposite A on the image and by increasing the constraint condition; for example, three rotation angles ω, ϕ, κ; three exposure station coordinates X_0, Y_0, Z_0 ; focal length f and principal points x_0, y_0. The above combined calibration depends strongly on the verticality of the camera because the initial approximate values for ground control points are calculated from relationship of the positions on the image between A to C and A to D. This is the weakest point in this method. The initial approximations for three rotation angles assume that images were taken as vertical photographs and three exposure station coordinates are computed under the assumption that the object plane is flat, where the two dimensional projective transformation is available. Regarding other initial approximations, nominal value for focal length and center coordinate of image for principal points are adopted.

3. EXPERIMENT

For flexibility,experiments were performed for the following three cases,

case 1; two distances are given.

case 2; two distances and height for each control point are given.

case 3; two distances and 3D coordinate for control points are given.

Figure 2 shows the stereo image for the test site which was taken from 1.4 m height and base-height ratio 0.1. Table 1 shows components for this experiment. On the left image, the lower left black and white target is assumed as control point A. Similarly the lower right point is B, the upper left point is C and the upper right is D. Other black circle points are check points for calibration accuracy. The length for A to B and C to D is 204mm and height opposite A are 17mm(B), 0.0mm(C),2.5mm(D).

Table 1 Experiment components

CCD camera	XC-75(SONY,768H × 494V)
Lens	VCL-16Y-M(SONY,f=16mm)
A/D converter	FRM2-512(PHOTORON)
TV monitor	PVM-1454Q(SONY)
PC	PC9801BX(NEC)

The following weights were adopted: $p_1 = 2.0, p_2 = 2.0, p_3 = 0.5, p_4 = 0.5, p_5 = 2.0, p_6 = 0.5, p_7 = 0.01$ in the case 1),2) and $p_1 = 1.0, p_2 = 2.0, p_3 = 2.0, p_4 = 2.0, p_5 = 2.0, p_6 = 0.1$ in case 3).

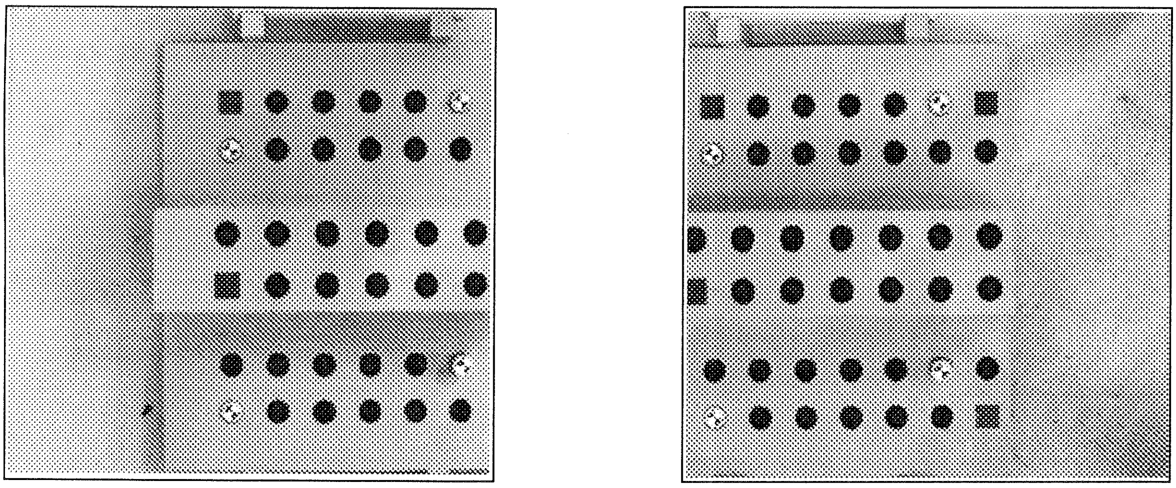
Table 2 R M S E for check points

	X,Y	Z
case1	±1.5 mm	±8.7 mm
case2	±1.3	±6.1
case3	±0.3	±4.0
equation(2)	±0.26	±2.6

Table 2 shows the root mean square error for check points(24 points) and theoretical accuracy which were calculated with the following equation,

$$\sigma_{xy} = \left(\frac{H}{f}\right)\sigma_p \qquad \cdot\cdot\cdot\cdot (2)$$
$$\sigma_z = \left(\frac{H}{f}\right)\left(\frac{H}{B}\right)\sigma_p$$

where, H ; altitude of camera, B/H ; base-height ratio, f ; focal length, σ_p; pointing accuracy



(a) Left image

(b) Right image

Figure 2 Stereo image for test site

As a matter of course, calibration accuracy depends on pointing accuracy of image coordinates. Furthermore, most importantly automated targeting is required for real-time photogrammetry. Therefore, the following image processing procedure for this purpose was developed . Though a pointing accuracy less than 0.1 pixel is expected under good conditions (low noise and target size)(Schaefer and Murai,1988), 0.3 pixel (≒0.003mm) was adopted as σ_p in this paper. The basic steps of this image processing procedure are shown in figure 3.

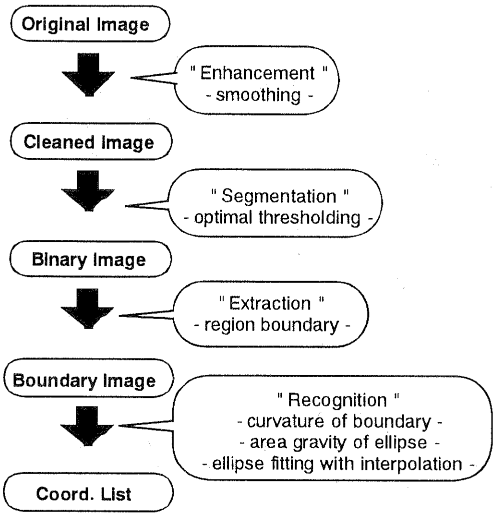


Figure 3 Flow of automated targetting

It may be seen from the results of this experiment that,

1) with regard to 2D, accuracy of 1/1000 for camera altitude were obtained in case 1.

2) accuracy for height improved 30% in case 2.

3) accuracy for 2D and height improved 80% and 50% respectively in case 3.

From these results, it is confirmed that the camera calibration method proposed in this paper is effective in reducing the geodetic surveying for control.

As noticed above this method depends strongly on the verticality of a camera. For improvement on this point, the following are considered:

1. Height for control points are given.

2. Beginning with two distances and the parallel type in form, the following three additional types are adopted :Box , Cross and F types (Figure 4).

The box type means utilization of 4 distances.The cross type adds one control point compared with the box type.Thus two more collinearity condition equations can be obtained. The F type is developed from the cross type. The remarkable difference in this improvement compared with case 2) in the first experiment is that the initial 3D ground coordinate for control points can be calculated using distance and height because control points are linked to each other.

A second experiment was performed under nearly the same conditions as in the first case. Unknown parameters were computed from the following equation,

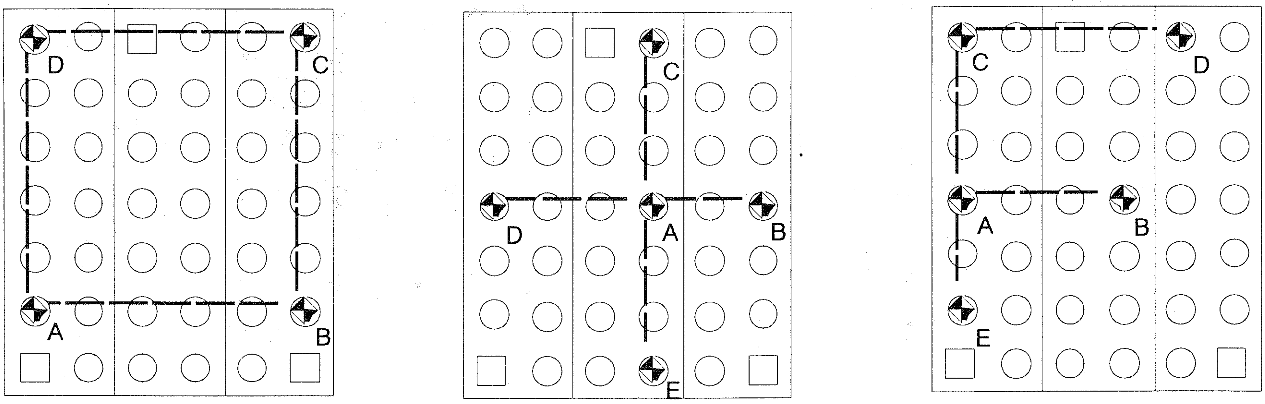
$$G_1 = \left\{ \begin{aligned} &\left[p_1\left(\Delta x_i^2 + \Delta y_i^2\right)\right] + \left[p_2\left(\Delta D_{ij}^2\right)\right] + \left[p_3\left(\Delta X_i^2 + \Delta Y_i^2 + \Delta Z_i^2\right)\right] \\ &\qquad + \left[p_4\left(\Delta X_0^2 + \Delta Y_0^2 + \Delta Z_0^2\right)\right] + \left[p_5\left(\Delta x_0^2 + \Delta y_0^2\right)\right] \end{aligned} \right\} \qquad \cdot\cdot\cdot\cdot (3)$$

Calibration became quite stable since it was possible to get high quality initial approximations. Consequently, the weights adopted in equation (3) were of equal value(=1). Table 3 shows the results for the developed types.

Table 3 R M S E for developed types

	X,Y	Z
Box type	±0.28 mm	±3.05 mm
Cross type	±0.33	±2.77
F type	±0.42	± 4.85
equation(2)	±0.26	±2.63

Accuracy, except the F type, nearly coincide with the values which were calculated from equation 2). Furthermore, considering the field condition, the cross type has the advantage of setting the control points. Then, in order to reduce any geodetic surveying in site, 5 control points with a given height and 4 pipes with a known length were previously prepared (Figure 5).



(a) Box type (b) Cross type (c) F type

Figure 4 Types developed from parallel type

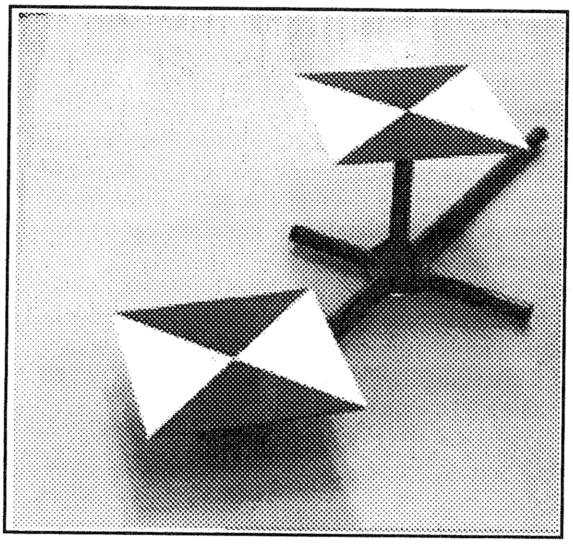


Figure 5 Control points linked with pipe

4. DIGITAL PHOTOGRAMMETRIC SYSTEM FOR SITE RECORDING

In order to acquire real-time images, a wireless CCD camera(FR CD-5C; 768 × 494) (Figure 6) and wide angle lens (f =4mm) were adopted. This wireless CCD camera with a transmitter mounted on top can take high quality images from 300m away using 1.2 GHz micro wave and BS tuner. The weight with lens is 165g and the size is 34.5 × 35.2 × 52.0mm. The CD-5C becomes a very useful tool when the image is taken from tethered balloons, kites or model helicopter.

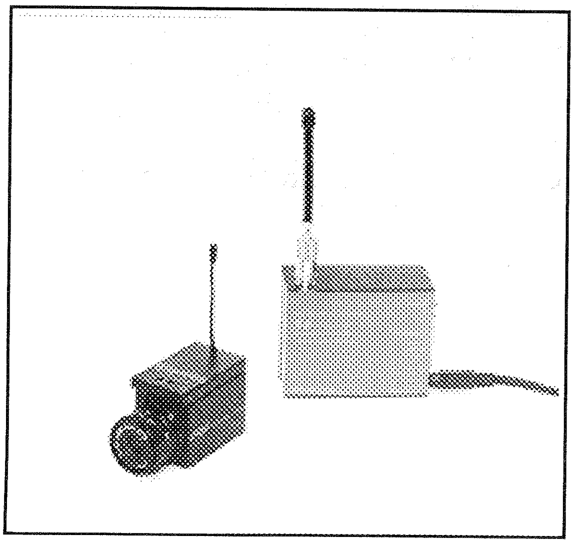


Figure 6 Wireless CCD camera and BS tuner

For the estimation of CD-5C, camera calibration for CD-5C and XC-75 were previously performed by using the same test site as in the first experiment where stereo image for XC-75 was taken from 1.61m height and base-height ratio 0.12 .Similarly, CD-5C were taken from 0.59m height and base-height ratio 0.33.

Tables 4 and 5 show the calibration results with 9 control points and the root mean square error for check points .

Table 5 R M S E for XC-75 and CD-5C

	X,Y	Z
XC-75	$\pm 0.12^{\mathrm{mm}}$ (±0.30)	$\pm 1.14^{\mathrm{mm}}$ (±2.49)
CD-5C	$\pm 0.21^{\mathrm{mm}}$ (±0.34*)	$\pm 0.90^{\mathrm{mm}}$ (±1.03*)

where, ( ) means computed values from equation (2)

* ; as pointing accuracy for CD-5C, 0.002 mm was adopted.

Experiment results were expected to show better values than the theoretical values because these experiments used 9 control points and only circle targets. Results for XC-75 are better than theoretical values in expectation. Results for CD-5C are nearly equal to theoretical values contrary to expectation. The natural reason may be that the images using CD-5C were taken with a wide angle lens.

However, it is concluded that a wireless CCD camera is still a useful tool for the purpose of real-time image acquisition from tethered balloons or kites.

5. APPLICATION IN THE ARCHAEOLOGICAL SITES

Tests were performed at an actual archaeological sites using the cross type, and a stereo image was taken from about 9 m height using a CD-5C wireless camera(Figure 7).

Figure 8 shows a stereo image and Figure 9 shows the configuration of real-time photogrammetric system used in this test.

Table 6 shows calibration results for a stereo image.

Table 4 Calibration results with 9 control points

		X_0	Y_0	Z_0	ω	ϕ	κ	x_0	y_0	f	a_1	a_2	$p_1 \times 10^{-7}$
XC-75	left image	mm 12.482	mm 81.983	mm 1714.864	0° 28′ 09.4″	0° 55′ 22.5″	0° 09′ 31.3″	pixel 248.527	pixel 241.499	mm 16.183	100.638	0.006	1.00
	right image	207.494	80.039	1718.701	-1 34 27.7	1 43 32.4	0 47 47.6	280.703	274.447	16.267	100.580	-0.002	1.00
CD-5C	left image	mm 44.746	mm 84.026	mm 588.362	1° 07′ 45.5″	2° 09′ 16.3″	1° 04′ 04.5″	pixel 285.049	pixel 220.798	mm 4.143	131.020	0.322	5.00
	right image	236. 397	82.212	583.328	2 00 54.8	1 13 12.7	0 58 44.9	281.350	211.210	4.121	131.139	0.152	7.00

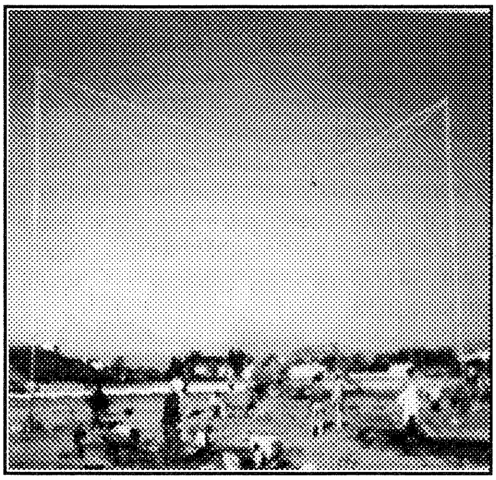


Figure 7 Test at archaeological site

The accuracy for 8 check points on the image is ± 27.6mm(X,Y) and ±139.8mm(Z) .This may be because,

1. the center of the target is not clear due to halation.
2. arrangement of control points are not uniform.

However, considering 50mm error is admitted even if plane-table surveying were performed with 1/100 scale using 0.5 pencil,a photogrammetric system with wireless CCD camera is still considered satisfactory for the purpose of this paper.

Figure 10 shows a display for semi real-time stereo matching for site recording and the results are shown in Figure 11. It took 10 seconds per point for stereo matching. Consequently Figure 11, which consist of 180 points, required 30 minutes.

(a) Left image

(b) Right image

Figure 8 Stereo image for archaeological site

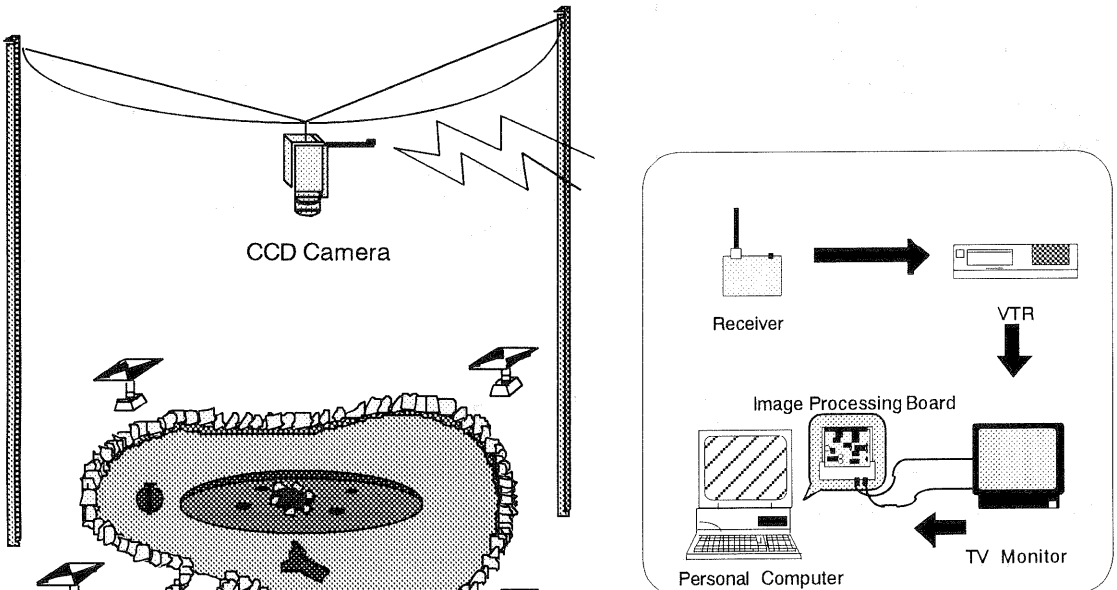


Figure 9 Configuration of real-time photogrammetric system for archaeological site

Table 6 Calibration results for stereo image of archaeological site

	X_0	Y_0	Z_0	ω	ϕ	κ	x_0	y_0	f	a_1	a_2	$p_1 \times 10^{-7}$
	mm	mm	mm				pixel	pixel	mm			
left image	-1192.14	1574.47	9233.15	4° 33′ 15.1″	3° 08′ 19.6″	-2° 59′ 30.9″	256.009	256.013	4.055	131.413	-2.747	4.00
right image	3517.22	940.60	8711.11	0 42 23.1	-1 59 9.1	0 58 27.2	256.005	255.981	4.078	132.447	1.774	8.00

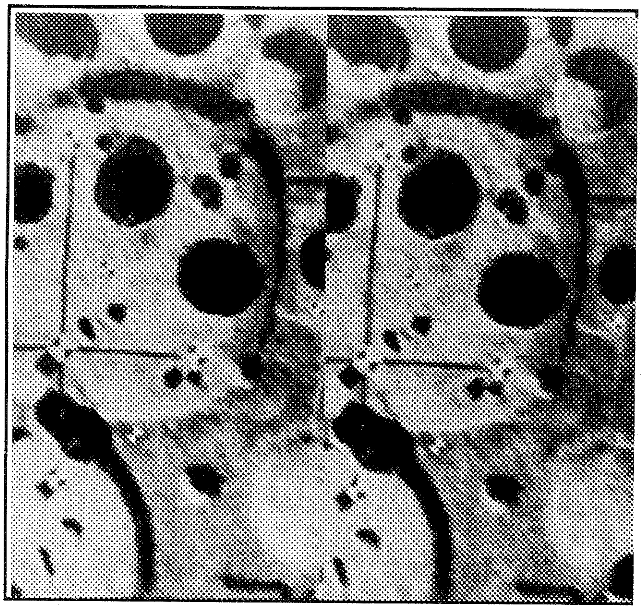


Figure 10 Display for real -time stereo-matching

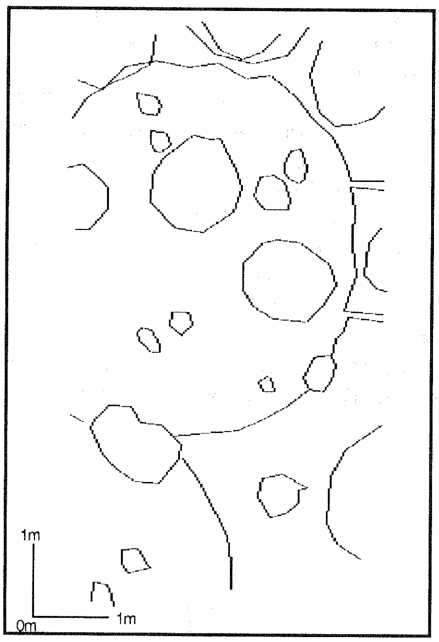


Figure 11 Site recording (scale 1/100)

6. CONCLUSION AND FURTHER WORK

In this paper, two issues on a real-time photogrammetric system for site recording were discussed. One is a camera calibration method to simplify geodetic surveying for control and the other is real-time image acquisition from tethered balloons or kites.

The camera calibration method without any geodetic surveying for control has been established by utilizing information such as distance and height which are included in the image. In order to develop this camera calibration, 4 types (Parallel, Box, Cross and F type) have been investigated. It has been shown that the cross type which improved the parallel type has the advantage of setting the control points and accuracy aspects.
With regard to the second issue, it is concluded that the wireless CCD camera is a useful tool for the purpose of real-time image acquisition from tethered balloons or kites.
The real-time photogrammetric system for site recording has been demonstrated. There are , however, some issues which need to be resolved before real-time photogrammetry may become operational. These problems include, how to take aerial images, automated stereo matching and accuracy. It is assumed that the method of taking aerial images is the most severe issue since balloons and kites take considerable time to prepare.

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