DEVELOPMENT OF A DIGITAL-IMAGE-BASED-PLOTTER AND ITS APPLICATION TO GROUND DISPLACEMENT MEASUREMENT IN THE KOBE EARTHQUAKE

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ABSTRACT

This paper describes a digital image-based plotter, GOKUU. GOKUU operates on UNIX and a window system, X11 and supports fundamental functions of aerial photogrammetry. Especially it is implemented with the least squares correlation for semi-automatic matching of orientation points. It is modified to extend the small convergence domain (one pixel) to ±5 pixels by extracting strong edge corners using the LoG filter and the Sobel filter. GOKUU was applied to the ground displacement measurement in the Kobe earthquake, and its measurement ability was tested. The result suggests that the dynamic range of CCD sensors of film scanners used and the current quantization level, which is usually one byte (256 stages), and the dynamic range of display monitors are not sufficient to compete with clear observability of film-based analytical plotters. Thus unavoidably the actual measurement project was completed by an analytical plotter. The paper compared the measurement precision with GOKUU and the analytical plotter, followed by the brief explanation of the measurement work and results of ground displacement.

1. INTRODUCTION

Digital photogrammetry is expected to replace the current film based photogrammetry in the near future. We have recently developed a simple DP, GOKUU on a low level workstation for education and training of photogrammetry, especially linked to GIS. The OS (Operating System) is UNIX and the window system is X11R5. Only the standard equipments of a workstation is assumed to run it.

For semi-automatic measurement of orientation points coordinates, the least squares correlation (LSC) is implemented. A major shortcoming of the LSC is its small convergence domain. We stretched it using the Laplacian of Gaussian (LoG) filter and Sobel filter. This is called hereafter MLSC (Modified LSC). GOKUU adopts the screen split method for stereo view with a simple reflectance mirror scope.

In Jan. 17, 1995, a disastrous earthquake broke out centered at the Kobe district, West Japan, which claimed 45,000 lives. In March, 1995, "the committee on damage evaluation for the Kobe earthquake" was formed headed by the Geotechnical Society. Dr.Okamoto was named to the leader of a WG for the measurement of the ground displacement. Its objective was the measurement by aerial photogrammetry using large scale photographs taken before and after the earthquake, to which we tried to apply GOKUU.

The damaged area was about 30km*80km wide. It was apparently impossible to measure all the area by the end of 1995. We selected Ashiya-city, one of the most damaged city, as a pilot area for measurement. We first planned to apply GOKUU to this project entirely. To identify the corresponding points in the photographs before and after the earth-quake, cooperative observation on the screen by two operators was thought to be the most effective to avoid mis-identification. But in the course of experiments, many shortcomings came out. Some were due to the design of GOKUU, and others were due to current limit to digital photogrammetry.

In spite of incessant improvements of GOKUU, the time limit to the dead line of report and required high precision of measurements, we changed the plan to the use of an analytical plotter in November, 1995. The measurement was completed in February,1996 and the achievement was published in a report (Okamoto et.al.,1996).

This paper describes the constitution and functions of GOKUU including the MLSC, and discusses the experimental results of measurement, when applied to the measurement work in the earthquake.

2. THE CONSTITUTION AND FUNCTIONS OF GOKUU

To be portable with as many as computers, GOKUU is programmed on UNIX using X11R5 as a window system. Though GOKUU has its own simple CAD program, it is connected to AutoCAD r12 to edit graphics and link the data to GIS. For this purpose OS is confined to Sun Solaris 2.x but when AutoCAD is detached, GOKUU runs on most of UNIX machines. And only 10MB is necessary to run GOKUU stand-alone. GOKUU has the following basic functions for aerial photogrammetry.

(1)MANAGEMENT of jobs and images
(2)image coordinate measurement (stereo COMPARATOR MODE)
(3)ORIENTATION of one model
(4)adjustment for AERIAL TRIANGULATION
(5)RECTIFICATION of a stereo pair
(6)plotting and editing of graphics (PLOTTER MODE)

GOKUU does not include film scanning. COMPARATOR MODE is only for the orientation of one model, and not intended to measure many supplementary GCPs for aerial triangulation.

The above (2),(4),(5) and (6) are briefly described in the following.

(2)COMPARATOR MODE (see Fig.1) measures the image coordinates of fiducial marks and orientation points (GCPs and supplementary GCPs). For sub-pixel measurement, the operator has an alternative of either manual measurement with four times enlarged images, or semi-automatic measurement by the MLSC. The accuracy in either method is 1/3 pixel, which is detailed in section 3.

Three 300*300 pixel windows below the screen in Fig.1 are the index windows. Small scale whole images are used for indexing. The third window is prepared for connection of triplet images for a small triangulation. Above two large windows are the stereo windows for coordinate measurement, size of which is 400*400 pixels. For image retrieval GOKUU uses the tiling method. Original image portions of 1200*1200 pixels are retrieved in a time. To ease off heavy overhead for image access, the data are stored in blocks of 64*64 pixels. But since this method is less convenient to roam over a wide area, we consider seamless roaming is necessary in the next generation. Images are displayed with 64 gray value levels. According to preliminary tests, display with more than 64 levels does not show any difference in image quality even with the best quality monitor we can ever have, e.g., MITSUBISHI Diamondtron.

Stereo view is realized by the screen split method with a simple mirror scope, like Leica DVP (Nolette,1992), because of economy . The operator roam the images and measure point coordinates at mess-marks in the center of the screen. The control of image roaming is done with a mouse and a keyboard.

(4)AERIAL TRIANGULATION executes the bundle adjustment with optional self-calibration. It includes the calculation of the estimates of ground coordinates of each supplementary GCP as well as of conventional parameter. This function is necessary to evaluate the strength of a network, when high precision is required like the ground displacement measurement.

(5)RECTIFICATION (see Fig.2) makes y-parallax free images by eliminating the distortions due to rotation of a camera axis. Fig.2 shows the screen to check the residual y-parallaxes. Since this process takes much time, it can be skipped, as long as stereo view is possible, i.e. rotation angles are small. For this, PLOTTER MODE provides two modes of image control.

(6)PLOTTER MODE (see Fig.3) plots graphics on a stereo model and edits drawn graphics. The screen design is similar to that of COMPARATOR MODE, it is not referred to here. GOKUU has its own simple CAD (hereafter called 3-D CAD) for the edition of graphics. Drawn graphics are left superimposed on the images. The 3-D CAD is connected to AutoCAD r12, which is shown right below in Fig.4. The two CAD programs communicate by use of the shared memory system and semaphore in UNIX. For identification of graphics data. every graphics is tagged with an ID number.

The control of image roaming is just the same as in analytical plotters. The operator controls a ground point $P(X_G,Y_G,Z_G)$, then the computer calculates the pair of corresponding image points. We first tried to fix the images and moved the mess-marks, but it was proved to fatigue eyes in the presence of large x-parallaxes like buildings in an urban area. X_G,Y_G are controlled by the mouse and Z_G is controlled by the key board.

3. MODIFIED LSC IN COMPARATOR MODE

3.1 Matching Precision with the LSC

The LSC (Ackermann,1984) is a matching method to consider the linear distortion of image coordinates. Let the left and the right image function be L(x,y) and R(X,Y) respectively. Between the left and right coordinates, a linear relation is assumed,

$$\left.\begin{aligned} &L(x,y)+n(x,y)=R(X,Y)\\ &\begin{bmatrix}X\\Y\end{bmatrix}=\begin{bmatrix}a_1 & a_2\\ a_4 & a_5\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix}+\begin{bmatrix}a_3\\a_6\end{bmatrix}\end{aligned}\right\} \quad (1)$$

where n(x,y) is a noise and a_1 through a_6 are unknown coefficients. The unknown parameters are determined so as to minimize $\Sigma\ n(x,y)^2$. Eq.(1) does not include the correction to intensity level difference between L(x,y) and R(X,Y). It is removed before correlation by local averaging the pixel values over the correlation area. Sub-pixel values of R(X,Y) are interpolated for differentiation by the 1-D bi-linear spline (Press,1992).

We judged the precision by residual y-parallaxes. A pair of aerial film (1:10,000 scale) was scanned with a scanner, VEXCEL VX3000PLUS, with the pixel size of 25μm*25μm. This scanner was also used for measurement of ground displacement (see Section 4). The film distortion was assumed negligible. We picked up 53 orientation points at strong edges on flat places like traffic marks on roads uniformly over the overlapped area. With eye observation on the original scale images, the residual y-parallax(rms) was 0.68 pixel, and on the four times enlarged images it was 0.40 pixel. This was assumed the best, because on more enlarged images, y-parallaxes got large. Table 2 shows the residual y-parallaxes for some measurement conditions. Tested pixel sizes were 5*5 and 11*11 (larger ones gave the same precision). Besides eq.(1) also tested the form

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} x+a_3 \\ y+a_6 \end{bmatrix} \quad (2)$$

The best result was obtained for eq.(1) with the window size of 11 pixels. According to the error propagation theorem, 0.4 pixel y-parallax(rms) corresponds to 0.4/1.414=1/3 pixel error in image coordinates. It should be noted this best precision is the same as the best obtained by the eye observation.

3.2 Modified LSC

The convergence domain with the LSC is usually one pixel. GOKUU extends it by the following way.
(1) Edges are extracted from the left image by LoG filtering. The LoG filter is defined as

$$\nabla^2 \exp(-(x^2+y^2)/2\sigma) \quad (3)$$

where σ is a scale parameter. It is set to 2, which scales the filter with an influence area of ±5pixels. The filtering produces countless small edges. Then corners are extracted by the following algorithm (see Fig.6);

```
if( not less than 3 edges are found in 8 pixels
around pixel O)    O is a corner; /*Fig.(a)*/
else if ( the edge passing through O is a straight
    line)   O is not a corner;   /*Fig.(b) */
else {
 if( not less than 3 edges in 8 pixels around A or
    B)      O is a corner;       /*Fig.(c) */
 else if ( ∠COD <=135° ) O is a corner;/*Fig.(d)*/
 else O is not a corner;
}
```

Then the Sobel filter (Iannino,1979), a differentiation filter with a light smoothing, is applied to the area. This filter produces the intensity gradient at every pixel. In 11*11 pixels around the approximated corner point, the corner with the maximum intensity is picked up as an orientation point. By conventional correlation this orientation point is matched to the right image up to one pixel, then the LSC is applied. If the terrain is flat in a 21*21 pixel area, convergency is almost assured in a 11*11 pixel area.

4. THE MEASUREMENT OF GROUND DISPLACEMENT IN THE KOBE EARTHQUAKE

4.1 Aerial Photographs and Control Surveys

We selected Ashiya-city as a pilot area, which is as wide as 2-3 km east to west and 8-9km north to south. It faces the Seto Inland Sea in the south where reclaimed land spreads.

Table 2 shows the data on the aerial photographs, GCPs and the result of aerial triangulation used for the measurement work. One set of the photographs were taken before the earthquake (hereafter pre-photos) and the other taken after that (post-photos). The city is covered with about 50 models for each set of photographs. The scales of the photographs are 1:40,000 and 1: 40,000-1:50,000 respectively. There is a gap of three years in two flights, and the flight directions differ by 90 degrees. These make the identification of the same points less easy.

The flight for pre-photos was for a map production for the sewerage management. The ground control survey was done by triangular and traverse surveying, with the estimated precision of 3cm (in planimetry) and 1cm (in height). The direct levelling was also conducted, with the estimated precision of 1cm.

The control survey for the post-photos was conducted in September, 1995 by GPS surveying. The measurements were adjusted with Trimnet (Trimble Corp.). The precision is estimated to be 3cm (in planimetry) and 1cm (in height).

4.2 Aerial Triangulation

Aerial triangulation was executed by GOKUU. Table 3 includes the results. The standard deviations of errors in observed coordinates of image points were assumed 7μm for both pre- and post-photos.

The horizontal error of supplementary GCPs was 5cm for both photos, so the combined horizontal displacement measurement error was estimated 8cm. The vertical error was 8cm for the pre-photos and 14cm for the post-photos. The latter large error was caused by the incomplete models produced along the seashore. Without these, the combined vertical displacement error was estimated to come within 15cm.

4.3 Scanning photos

For the experiment two sheets of pre-photos and three post-photos were scanned with two scanners. One is VEXCEL VX3000PLUS with the nominal precision of 3μm and the other is ZEISS PhotoScan (by courtesy of Geographical Survey Institute) with the precision of 2μm. These photographs cover a common area of about 500m*800m.

Since the required measurement precision was 10cm or higher, 10 μm pixel size (4-5cm on the ground) was thought necessary. It produces image data of about 600MB/film. Though the scanning time was only 30min, it took 4-5 hours/film to write out the data to DAT(Digital Audio Tape). Eventually with VX3000PLUS the images were scanned with 10μm pixel size, but with PhotoScan, 15μm pixel was used because of the limit of exclusive use. In this case the volume was reduced to only 200MB/film.

The second difficulty was a small dynamic range of CCD sensors. Fiducial marks were thinner imaged. When the sensitivity was adjusted to fiducial marks, details of scenes become hardly recognized and looked nearly binarized. In this experiment, the image quality of fiducial marks were sacrificed to the extent of the border. But the densitometric range of obtained digital images was still short.

4.4 Orientation and Measurement

The practical measurement was done with an analytical plotter WILD BC-1. GOKUU could not attain the precision of BC-1 in inner, relative nor absolute orientation. The errors with GOKUU in interior orientation were 1/5-1/4 pixels and the residual y-parallaxes in relative orientation were 1/3-1/2 pixels by the MLSC for the three models, while with BC-1 the interior and relative orientation errors were both 2-3 μm.

Errors in absolute orientation varied largely with image quality. The orientation points (GCPs and supplementary GCPs) had been marked on one side of a pair of photographs by a pricking device. But 50% of points were invisible at orientation with GOKUU, because these points had been taken on poorly textured flat places, e.g., on bare soil or paved roads. Though these pricked holes could be observed stereo-optically clearly with BC-1, it was hardly seen on the display. This implies that not only the dynamic range of CCD sensors is short, but the quantization level of 1 byte is also insufficient. The absolute orientation with GOKUU gave the error of 8-9cm(rms) both horizontally and vertically, while with BC-1 the residuals were as half as or less with GOKUU as shown in Table3. The effect of pixel size was concealed by the variance of image quality of orientation points.

For keeping the orientation precision from degradation we took again supplementary GCPs which were clearly identifiable on the display for the three models, and then each set of the photographs were adjusted at once by the bundle adjustment including these points. The corresponding points identified for displacement measurement were also included as supplementary GCPs.

To identify corresponding points in the pre- and post-photos with GOKUU, two operators observed the images on two displays cooperatively. These points include corners of lines of pedestrian crossings, stop lines, letters (STOP, 50KM etc.) and corners of grid lines in parking lots. Since there are three years' gap between two flights and the flight direction differ by 90 degrees, careful observation was necessary. Lines or letters might be often rewritten. Roads might be repaved. But most of them were easily discernible by changes in tone or shapes of lines.

The same points were also measured with BC-1. Fig. 6 shows the differences of observed ground coordinates between the two plotters for one pair of the pre-photos. The differences are accredited point measurement errors coupled with orientation errors of images. The difference of horizontal errors is estimated to reflect the pixel size. The points with a more than 30cm error are probably mis-identified. These figures show GOKUU can not compete with BC-1 at present.

5. MEASUREMENT OF THE GROUND DISPLACEMENT IN ASHIYA-CITY with BC-1

In November, 1996 we determined to change the plan of all the measurement with GOKUU to that with BC-1. About 10-15 supplementary GCPs were included in each model. To avoid mis-identification of points between a pre-photo and a post-photo, we looked for the identifiable corresponding points (or their candidates) on double enlarged prints of the pre- and post-photos. And all the points were sketched.

About 700 points in totality were measured. The points were taken near the lattice of 100-200 m width. This measurement work took for two operators about three months.

Though roots of electric poles or manhole lids could be easily found everywhere, they were intentionally excluded, because the center of a root of an electric pole is difficult to find and manhole lids are not clearly imaged. In some places with no signs on roads or parks, however, those points were unavoidably included.

Since, unlike with GOKUU, simultaneous observation is impossible with BC-1, the judgment on whether signs on roads had been redrawn or not was in some cases difficult. The operator excluded such points as have very different displacements from the trend of surrounding points. But we are still afraid of some points being mis-identified. Fig.7 and 8 show a part of obtained horizontal and vertical displacement maps respectively.

6.CONCLUSION

This paper describes the constitution and functions of a digital-image-based plotter GOKUU with a special interest on the modified least squares correlation for matching orientation points. GOKUU's measurement performance was presented in the experimental application to the project of measurement of ground displacement in the Kobe earthquake. The measurement precision was compared with an analytical plotter, BC-1. According to an experiment, both the positional and densitometric resolutions were shown to be insufficient for precision measurement. But in turn GOKUU was proved far advantageous in simultaneous and comparative observation of images by operators to identify corresponding points in the photographs taken before and after the earthquake.

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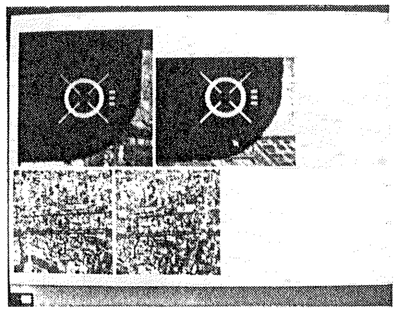


Fig.1 Screen Design of COMPARATOR MODE

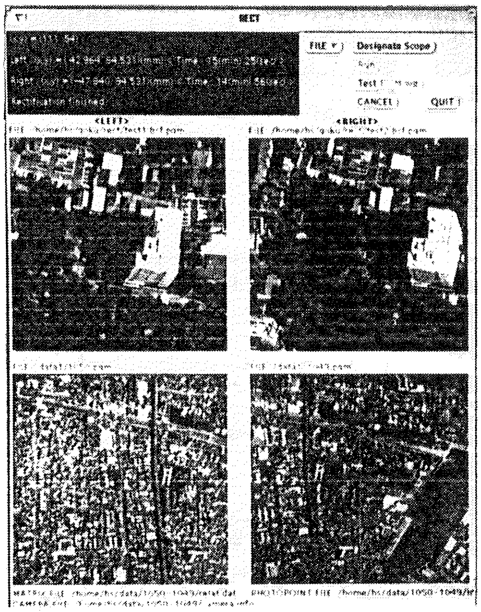


Fig.2 Screen Design of RECTIFICATION

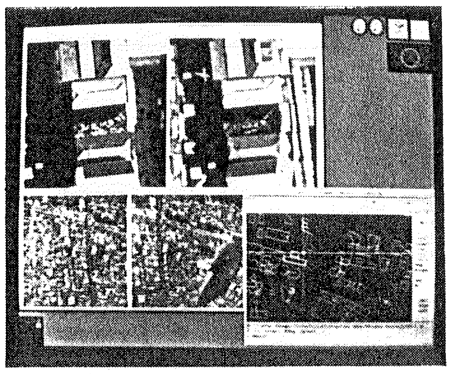


Fig.3 Screen Design of PLOTTER MODE

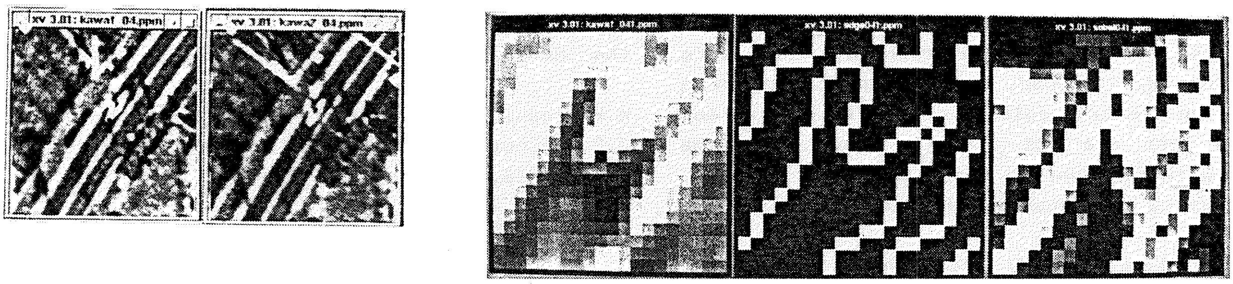
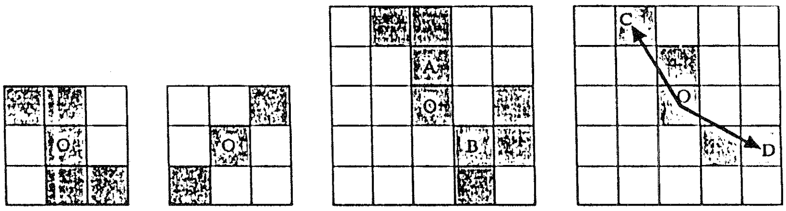
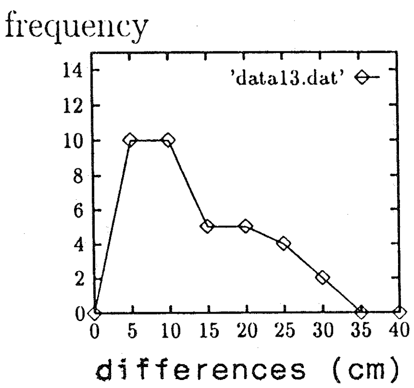


Fig.4 Extraction of an Orientation Point in the MLSC
The left two images show a pair of stereo (100*100 pixels). The right three show the effects of LoG and Sobel filtering. The most left of the three shows an enlarged left image of the stereo around the center.

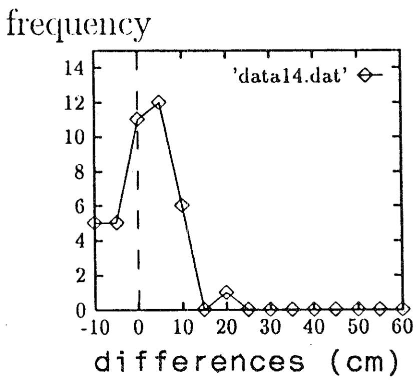


(a) (b) (c) (d)

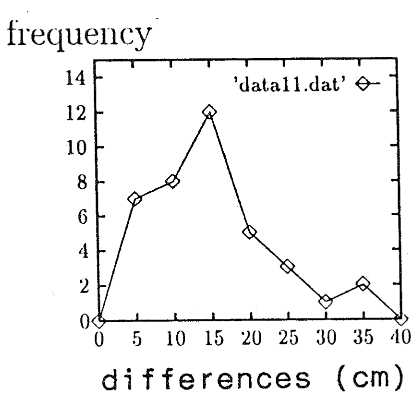
Fig.5 Corner Extraction Process in the MLSC



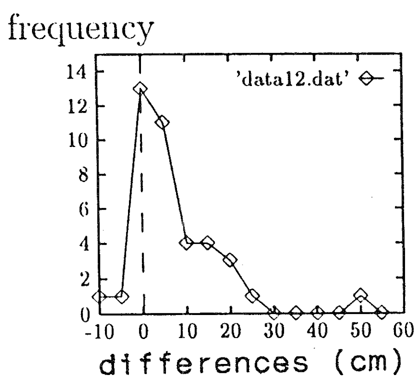
(a) Horizontal dif. (VX3000PLUS with 10μm)



(b) Vertical dif. (VX3000PLUS)



(c) Horizontal dif. (PhotoScan with 15μm)



(d) Vertical dif. (PhotoScan)

Fig.6 Differences of Ground Coordinates Measured with GOKUU and BC-1
difference = coord. with GOKUU - coord. with BC-1. Values are rounded off to 5cm.

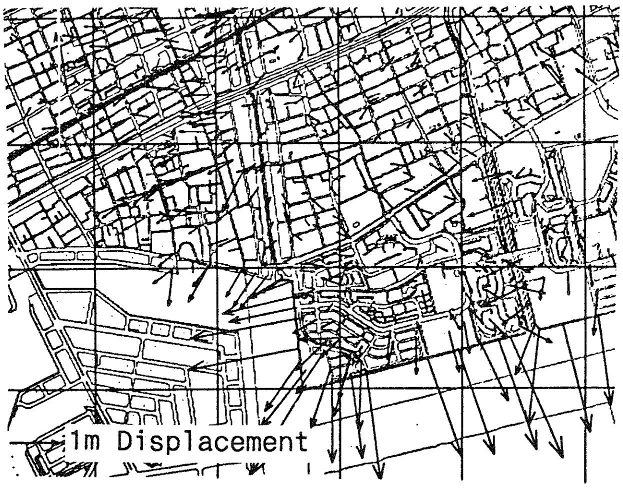


Fig.7 A Part of Horizontal Displacements Map
in Ashiya-City
The grid width is 500m

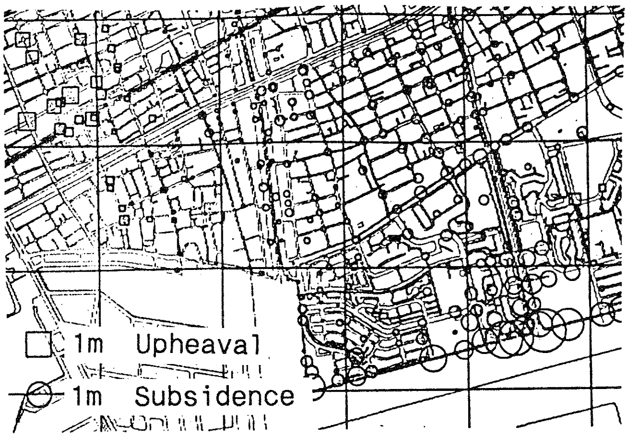


Fig.8 A Part of Vertical Displacements Map
in Ashiya-City

Table 1 Residual y-parallaxes
in Relative Orientation Using the LSC

Eq.	Correlation Window Size ($pixel^2$)	RMS of Residual y-parallaxes (pixels)
(1)	5*5	0.48
(1)	11*11	0.40
(2)	5*5	0.76
(2)	11*11	0.44

Table 3 Absolute Orientation
Errors on the average with BC-1

pre-photos	post-photos
5.0cm (H) 3.8cm (V)	7.4cm(H) 4.1cm(V)

Table 2 Data of Photographs, Ground Controls and Aerial Triangulation

	pre-photograph	post-photograph
Number of Photos	51	45
Scale of Photos	1:4,000	1:4,000 -1:5,000
Number of GCPs	11(H),22(V)	11(H),40(V)
Number of Supplementary GCPs	311	212
Std.Dev. of Errors in Photo Coords	7.1µm	7.5µm
Std.Dev. of Errors in Supplementary GCPs	4.5cm(H) 8.6cm(V)	5.4cm(H), 13.4cm(V)