STEREO MATCHING PROJECT IN JAPAN

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Abstract: Less time-consuming and high accuracy DTM producing is required for successful management of large scale construction earth works, because efficient control of worth works needs repeated measurement of cut-&-filled terrain shape during execution. This paper describes a newly developed automated measurement system for this purpose. Usual measurement works are replaced by stereo matching calculations by computer. Its basic algorithm is based on a sophisticated coarse-to-fine correlation. The measurement system is realized on general purpose image processing hardwares and linked to an earth work management system that is also newly developed in the unified project. In the paper the outline of hard and soft ware configuration is described as well as matching precision and processing time.

1. INTRODUCTION

Stereo matching techniques have been studied as a powerful tool to speed up photogrammetric works. Among the many strategies proposed so far, area correlation and its sophisticated versions are regarded as most practical and competitive to calculation cost in major application fields.

One of the most challenging applications of stereo matching techniques in photogrammetry is quick measurement of cut-&-filled terrain shape for the construction management of large scale earth works. Usually aerial photogrammetry or conventional ground surveying has been employed for this measurement. But because the construction is forced to stop during surveying, the expensive rent of construction machines prevents sufficient repeated measurement for fine control of cut-&-fill works and the replaning of disposition of construction machines, which are necessary to shorten a construction term. For improving the cost-benefit ratio of the repeated measurement, it is required to speed up photogrammetric works and to shorten feed-back time.

Japan Society of Photogrammetry in cooperation with Ministry of Construction has developed and just released a new image processing system for automatic (or more precisely semi-automatic) DTM production from aerial photographs which is intended especially for the above aim. Measurement of terrain coordinates is replaced by stereo matching calculations by computer. Our basic matching algorithm is based on so-called coarse-to-fine correlation which was recently developed by one of the authors /1/. Terrain coordinates are measured in three steps of coarse-to-fine matching. Its validity was already proved.

In connection with this development the earth work management system has been developed by the MInistry of Construction. It is intended to cover the comprehensive collection and analysis of data associated with the earth work, i.e., a cut-&-fill history, a soil quality map, etc., and to replan the time schedule and machine disposition. These two systems make an integrated control system, but we here discuss only the automatic measurement system and describe the outline of the configuration of hard and soft-wares as well as its system performances and matching precision.

2. HARDWARE CONFIGURATION

Fig.1 shows the configuration of system hardwares, which are general purpose devices for image processing. Since usually several stereo models are required to cover the entire construction area, a gigantic peripheral memory is needed to store image data, we provide the system with a optical disc unit. Each device is outlined as follows;

AD Converter-----This is an image AD converter (Topcon Co.) with a comparator function newly developed to meet the requirement of high speed conversion and high positional accuracy (Fig.2). A film is placed on a carrier sandwiched between two glass plates at a marked position. Every 8.97 mm x6.58 mm portion of the film (called sub-image) is illuminated and its image is focused on an area ccd sensor, the pixel size of which is 11.5x13.5 μm^2. The output 780x488 gray values are temporarily stored in a frame memory, and transferred to an optical disc memory together with the center point coordinates of the sub-image, which are measured by the linear encoders provided along the x and y axes of the carrier. Then the carrier moves to the next digitizing position. The drive of the carrier is controlled by a micro-computer. And scanning is monitored by a B/W TV. Point-by-point coordinate measurement is also possible by meeting the cursor with the point on a screen. Output gray values are calibrated by a KODAK gray scale. The total performances are listed in Table 1.

Image Processor------NEXUS 6510 image processor (Kashiwagi Research Co.)is featured by 4 image memories of 512x480 bytes each in size for R, G, B and Work, and by many useful hardware provisions such as a graphic display function or a coordinate measurement function with a cursor controlled through the graphic digitizer table. These functions are made use of for organizing the system in an interactive way.

Optical Disc Unit----The unit, DU15 (Matsushita Electronics Co.), has two drivers so as to cope with handling a stereo pair. They are controlled by a optical disc controller, NEXUS 68151. A memory volume of a disc is 1.2GB, which can store as many data as 2.5 sheets of photographs. Write-out time from the NEXUS memory to an optical disc is 13 sec a sub-image, while read-in time in the reversed direction is only one sec.

Host Computer--------All calculation tasks are done by FACOM M170-F (16 MB in memory size), which is connected to the NEXUS through the BMC interface (400 KB/sec).

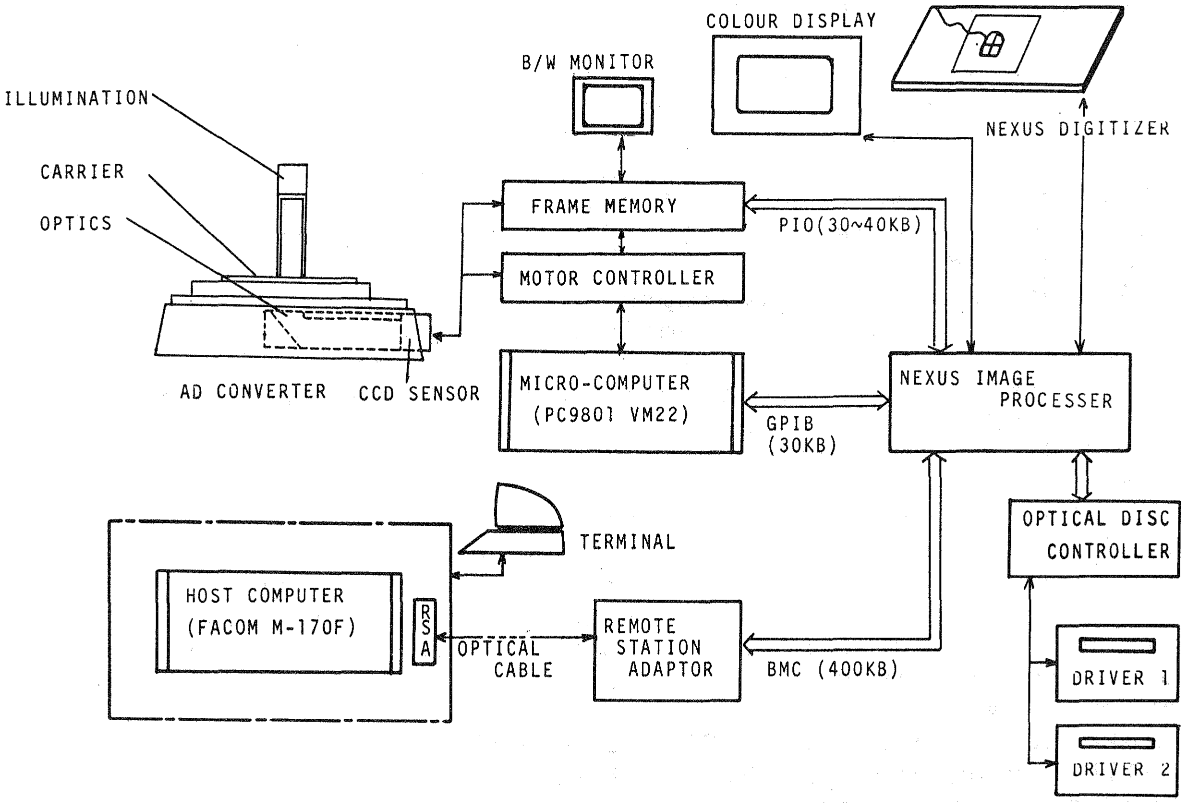


Fig.1 Hardware configuration

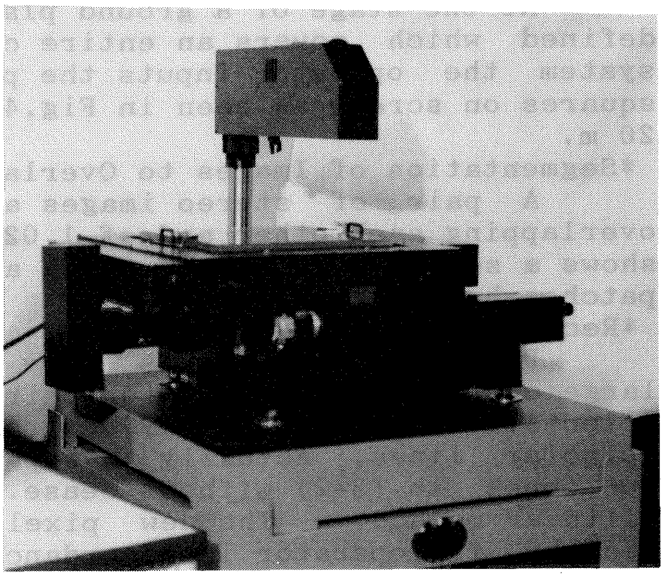


Fig.2 Topcon AD-converter

Table 1 Data about Topcon AD-converter

ITEMS	DATA
maximum film size	230x230 mm^2
size of a field of view	8.97x6.58 mm^2
pixel size	11.5x13.5 μm^2
positional accuracy	less than 3 μm in x and y
axial orthogonality	less than 10"
driving velocity of carrier	20 mm/sec
driving mode	manual or programmed
weight	60 kg
output format	8 bit binary (0-3D)
controller	micro comp. (PC 9800)

3. PROCESSING FLOW OF AUTOMATIC MEASUREMENT

Fig.3 shows a flow of the automatic measurement. It consists of 4 parts; AD conversion of photographs, relative and absolute orientation, automatic measurement and DTM production. A operator runs the program by selecting menus on screen in succession. The each item is illustrated in the following with an example of a typical 43 ha earth work area. This area is covered with 2 models consisting of 3 sheets of 1:5,000 photographs.

(1)AD Conversion of Photographs

Digitized areas are designated (only one rectangle is permitted to cover one side area of a model) by pointing fiducial marks and 4 corner points of the area in a paper print on the NEXUS digitizer table. Digitized images are stored in optical discs in a sub-image mode.

(2)Relative and Absolute Orientation

The system has two alternative choices in coordinating orientation points. One is usual manual procedure with a stereo comparator. The other is a method to find pass and control points in digitized images using correlation, which will be referred in sec.4. In the former choice orientation parameters are input extraneously to run the aerial triangulation program.

(3)Automatic Measurement (Stereo Matching)

(3-1)Preprocessing and Preparation

*Reading in a Planned Grid

At the stage of a ground planning a basic planned grid is defined which covers an entire construction area. In this system the operator inputs the planned grid by daubing grid squares on screen as seen in Fig.4. Its grid width is usually 20 m.

*Segmentation of Images to Overlapping Patch Pairs

A pair of stereo images are segmented to patch pairs overlapping each other and of 1,024x1,024 pixels each. Fig.5 shows a screen display in patch allocation. The operator daubs patches he wants to match.

*Rectification of a Patch Pair

Digitized sub-images are sent to FACOM to merge to a large one. Then every patch pair are rectified with relative orientation parameters by rearranging pixel arrays along epipolar lines. Actually this patch-by-patch process directly continues to (3-2) without cease. Resampling is made by the bilinear method. The new pixel size is flexible and assigned by the operator in accordance with the required matching precision and allowable calculation time. The standard new pixel size is 50 μm x50 μm. The rectified images are stored again in optical or magnetic disc files.

(3-2)Stereo Matching

The details are described in sec.5. Matching is executed for every patch pair independently. If necessary, the right patch is shifted in the x direction to come to the appropriate position by referring to the average ground height of a neighboring patch that has been matched.

(4)DTM Production

Matched points are distributed in a semi-random mode in the ground coordinate system. And their density is usually too high (about 2 m spacing in the ground with 1:5,000 photographs and 50μm sized pixels used). Therefore obtained terrain

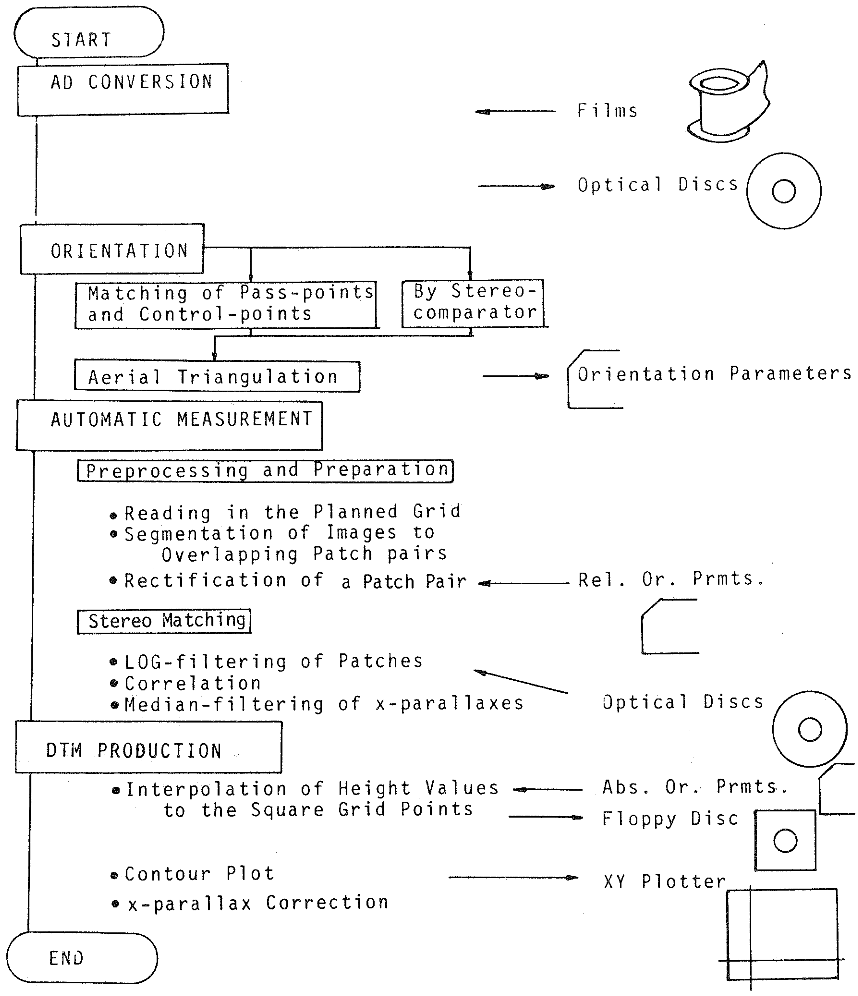


Fig.3 Flow of the automatic measurement

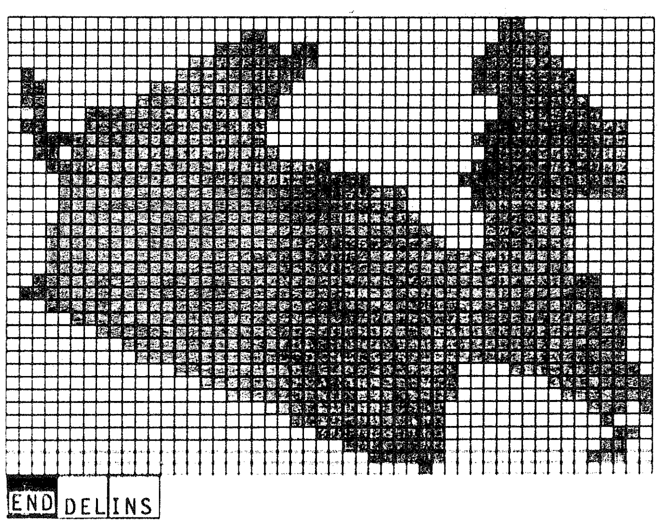


Fig.4 Screen input of a planned grid

data are interpolated to any specified grid points by a simple weighted mean.

Fig.6 shows an example of a contour map for the earth work area, plotted from the planned-grid-based DTM interpolated from the matched terrain data, in which the rectified images with 50μm sized pixels are used.

(5)x-parallax Correction

In many applications matching errors of 2-3 m in height appear at occlusions like both sides of buildings. As far as earth volume evaluation is concerned, these errors make little effects. In case, however, the operator wants to get more precise DTMs, false matchings can be corrected in such a way he points out suspectedly mismatched areas in the print set on the digitizer table to call the image area on screen, and correct mis-matchings with a cursor.

4. FINDING ORIENTATION POINTS BY CORRELATION

The operator can obtain alternatively orientation points coordinates by correlation instead of extraneous input, if he chooses in Fig.3 'Matching of Pass Points and Control Points' in 'Orientation'. Its basic way is Gruen's adaptive least square correlation /2,3,4/.

6 image areas of 2 cmx 2 cm in size including pass points candidates for every photograph are digitized and stored in an optical disc. The operator selects hopefully matchable candidates on screen. They are matched to the right points by the adaptive least square correlation. Point pairs are designated by the operator on the screen. But since the designation is usually rude, three steps of coarse-to-fine are used for safe convergence. In the first and second correlation sampled images at every 4 and 2 pixels are employed respectively. The window size is usually set to 31 pixels but can be changed according to image or terrain conditions. After the correlation converges, the operator visually checks the matching accuracy. Matching of control points is done in a similar way. Different points are (See Fig.7);

*Standard templates are ready in advance.

*An image pair in windows are binarized to remove noises before correlation.

5. STEREO MATCHING ALGORITHM

The following is a mere outline. For details refer to Hattori/1/. Since each step consists of similar processes, we don't refer to the step number.

(1) LOG Filtering of Patches

A pair of patches are filtered with the Laplacian of Gaussian filters of different 3 scales. The LOG filter is the most narrow band-pass that can be realized without a wind-up effect.

(2)Reduction of Images

The filtered images are reduced by resampling at every 4 and 2 pixels for the 1st and 2nd steps. No information loss is assured by the well-known sampling theorem.

(3)Grid Points Allocation and Correlation

To keep matching precision high, this system adopts the two-way search, i.e., independent searches from the left patch to the right and from the right to the left. First the corresponding square grids with 8 pixel spacing are set on both the

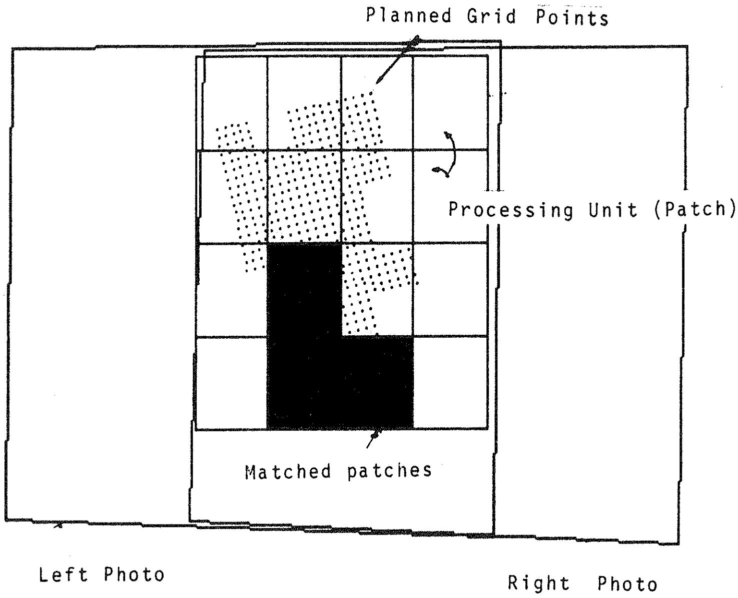
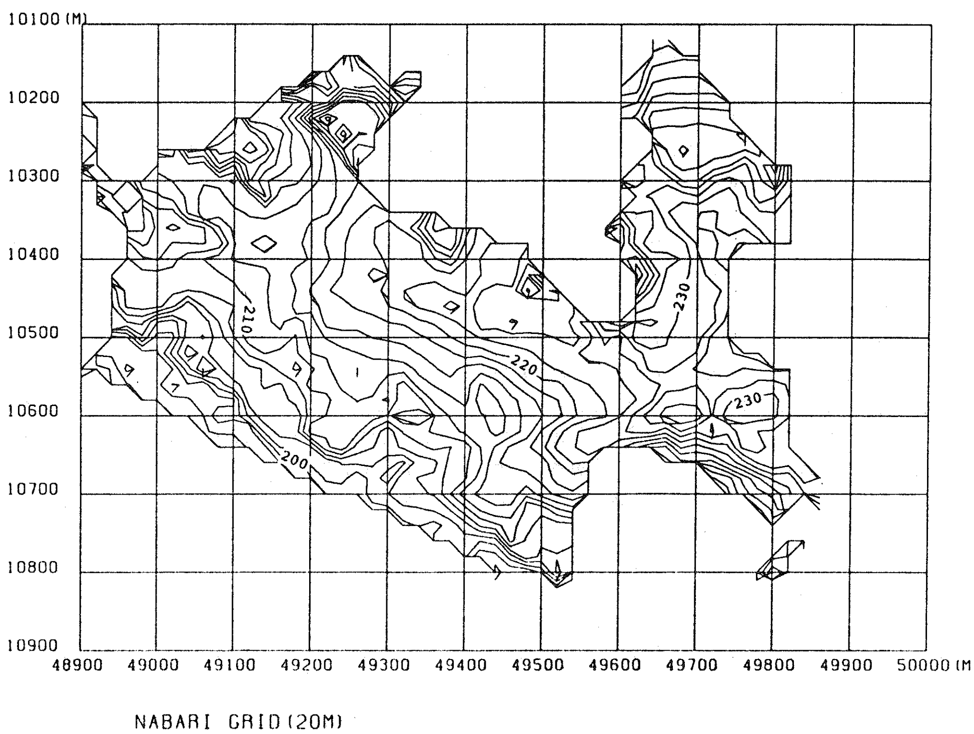


Fig. 5 Patch allocation
A pair of the images and patches are displayed on a screen. Matched patches are designated by daubing.

Fig.6 Example of a contour map output
The contour interval is 2m. The grid spacing is 20m. The contour is plotted from DTM data associated with the planned grid.



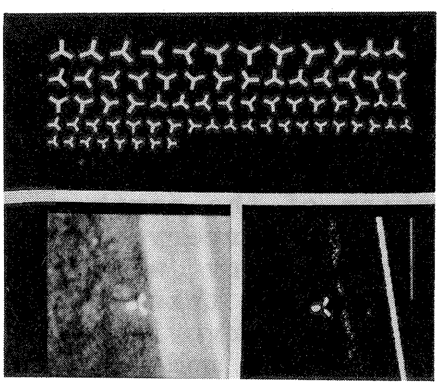


Fig.7 (upper) Automatically produced templates
(lower left) Original image
(lower right) Binarized image

patches, on the assumption the terrain is flat. Then the right conjugates to the left patch points are searched for. Secondly the same search is done from the right to the left. The correlation window size is 15x15 pixels (4 octaves). Thus we obtain two independent x-parallax sets.

(4)Median-Filtering of x-parallaxes

These two sets are median-filtered with a 3x3 window respectively to remove gross matching errors, and yet not to hurt abrupt x-parallax changes at cliffs or so. After this filtering occluding points are found by checking geometrical consistency on x-parallax arrays line by line in the x direction. According to some examinations, occluding terrain tends to be reconstructed in a bit smoothed shape. But their matching errors are trivial for the earth volume evaluation.

(5)x-parallax Elimination from the Patch Pair

Along every grid line the terrain surface lines are estimated by connecting matched points as shown in Fig.8. A dotted line is drawn through matched points by the 'left-to-right' search, while a solid line is by the 'right-to-left' search. Then a new grid is set on the X Y model datum, which doesn't make a square grid, but has equal spacing only in the X direction in the model coordinate system, and has equal spacing in y in the image coordinate system. The height values of new grid points are evaluated as simple means of two independently interpolated terrain values.

The pixel arrays of both patches are rearranged to eliminate x-parallaxes and make the new grid pair square on both the image planes respectively. Note that after this process the new grid lines in the Y direction on the model datum are not straight lines any longer.

(6)Coarse-to-fine Convergence and x-parallax Output

The processes from (1) to (5) are repeated in any step. The density of grid points are doubled in x and y at the beginning of the next step. After the three steps finish and all the grid point pairs are identified, 88x112 points out of 97x121 are left and the others on the boundary of a patch are abandoned because of less reliability. As patches are already rectified, the reliability in x can be regarded higher than in y and more points are left in x.

6. SYSTEM PERFORMANCES

The system performances should be assessed from view-points of total consumed time, precision and manageability. We must confess that the first version of the system has some shortcomings in these respects.

Table 2 lists the processing time required for a typical case. The bottle neck is at Log-filtering which is executed with FFT. As many as 8 FFTs of 1,024x1,024 pixels are needed to make 6 kinds of filtered images for a patch pair. We think this process had better be replaced by the Fast Convolution.

A precision check was done in a test site shown in Fig.9, about 200m x200m in area, which is a portion of the earth work area used in section 5. A conventional ground surverying with a distancemeter and a conventional photogrammetry with the Planicomp C-100 as well as the measurement with this system were executed at the same time. In the ground surveying terrain points were taken about every 3 m in a random mode. In the

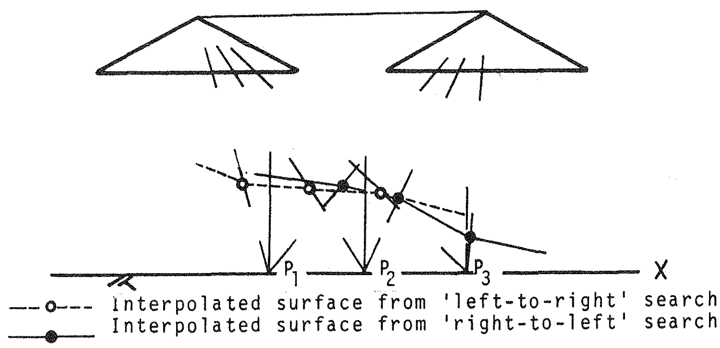


Fig.8 Schematic diagram for the 2-way search
o is a matched point by the 'left-to-right' search. ● is by the 'right-to-left' search.
P_1, P_2, P_3 are model grid points with equal spacing.

ITEMS	PROCESSING UNIT	TIME
AD Conversion	10x11 sub-images	ca. 30min. (with 2 veryfy-check)
Merging and Transfer	10x11 sub-images	ca. 40 min.
Rectification	1 patch	6.3 min. in CPU
Matching	1 patch	
·LOG Filtering		13.3 min. in CPU
·Correlation		3.6 min. in CPU
DTM Production	6 patches (62x49 grid points)	4.5 min. in CPU

Table 2 Consumed time for a typical case
10x11 sub-images cover the one side of a model image pair.

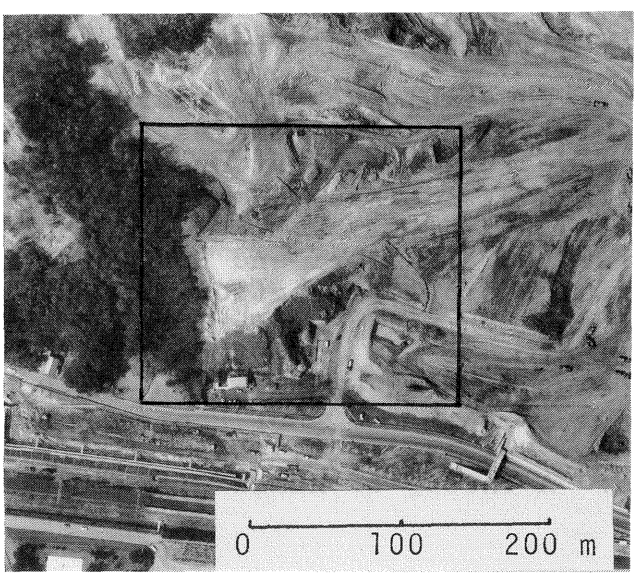


Fig.9 Test site for matching precision check

photogrammetric work, the heights of square grid points with 2.5 m spacing were measured. In the automatic measurement image data were rectified with 20 um sized pixels, and matched terrain data are interpolated to the same grid as above. Fig.10 (a),(b)and (c) are respective contour maps. In Fig.10 (c) no corrections are made. The large errors in stereo matching broke out only at forests and a building. In other areas there appear no significant errors and the precision is enough for earth volume evaluation. The errors in forests occur because if trees are sparse, these become noises to make correct matching impossible, and if trees are dense, matching is done on the top of trees different from the custom in human plotting in which operators trace the ground.

7.CONCLUSION

This automatic measurement system is a first realization in Japan to be intended for earth work management. The basic matching method is area correlation. Through some preliminary tests matching precision is proved sufficient for this purpose.

We are now improving the system in a point of processing speed and manageability. We expect the system to be applied to the measurement of objects other than cut-&-filled terrain, which must be speedy and automatic, but is allowed to be less highly precise. Especially automatic map production from satellites, we think, is the most promising and straightfoward application.

In fact we may need AI based matching strategies for measurement of objects required of the highest matching precision, or objects with poor textures incompetent to correlation /5/. We also plan to develop those methods to incorporate in the system in the near future.

Lastly we would like to appreciate the collaborators; Mr. Y. Kometani, K. Uda and O. Uchida. for burdendsome computer programming and researches.

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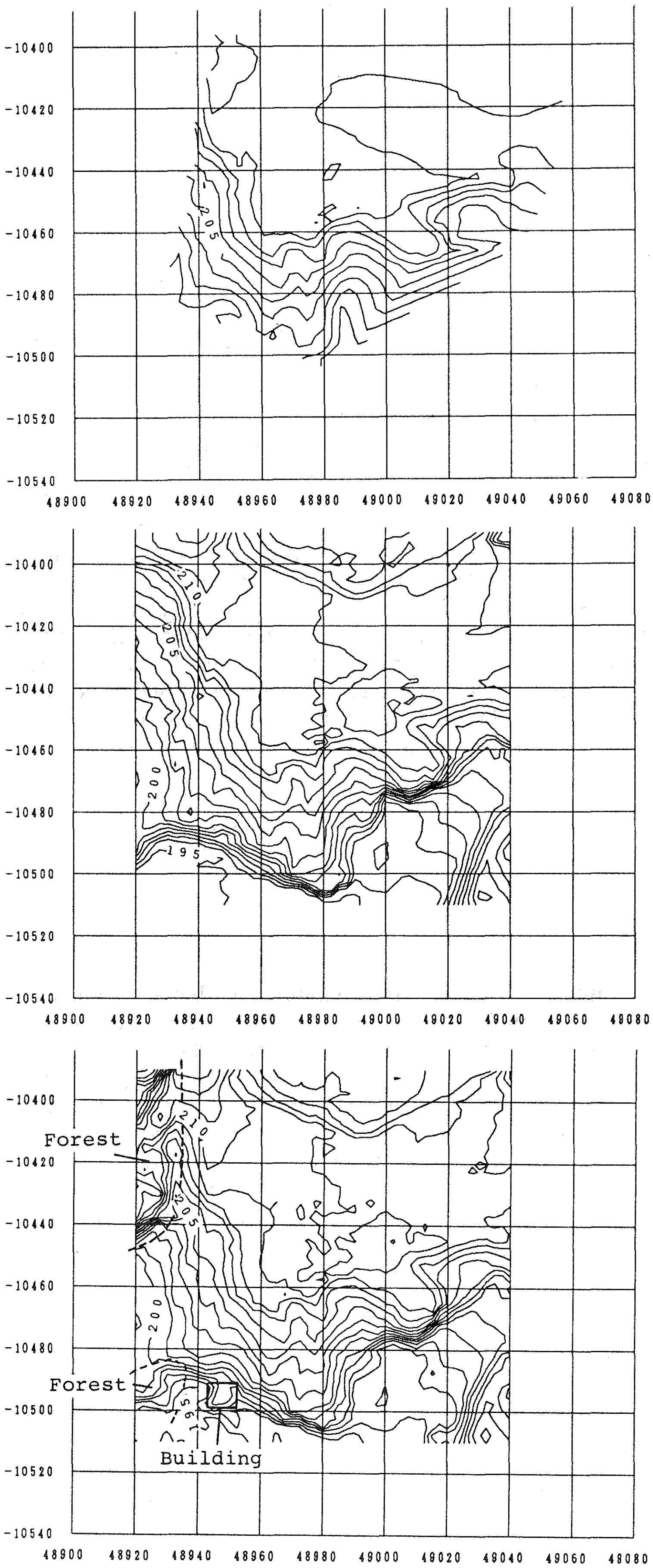

Fig.10 Contour Maps from three kinds of measurements
The contour interval is 1 m.

(a) Ground surveying in a random mode

(b) Photogrammetry with Planicomp C-100 in a grid mode of 2.5m spacing

(c) Automatic Measurement
Matched terrain data are interpolated to the same grid as (b).