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RESEARCH OF MATCHING AND/OR SEARCHING METHODS OF IDENTICAL POINT ON STEREO AERIAL IMAGES AND ITS APPLICATION

by

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ABSTRACT

In the field of topographic surveying and mapping from aerial photographs, researchs touching upon technical improvement which constructs digital terrain models easily and efficiently using a drum-scanner and a computer system instead of a stereoplotter are being advanced by many photogrammetry workers.

This paper describes about four methods for matching and/or searching pixels corresponding to identical point on stereo aerial images, and reports the results of these applications to photographs.

In this research, stereo vertical photographs were decomposed into digital images using a drum-scanner. By performing relative orientation between digital images, we reconstructed a pair of numerical rectification images. On these images, we found the corresponding pixels to identical ground point, and its digital terrain model was finally made.

1. INTRODUCTION

The process which constructs the topographic maps from a pair of photographs is considerably complicated. Photogrammetry workers have been used the specialized machines such as the optical rectifier, the orthophotoscope , the stereoplotter and others for this process. The operations of these machines, however , stand in need of high techniques in addition to skills and labors. Recently another approarch has been under developement in completion with these methods [T.J.Blachut(1976), J.M.Zarzycki(1978)]. This research, at first, replaces photographs with digital images using a drum-scanner. Computer software performs the numerical rectification and plots the contour map from these images. If we succeed in this research, this image processing would eliminate both distortions due to defective lens and rough surface of film altogether, and it is expected in the near future that image processing will be superior to the former method in terms of economy and efficiency [R.Orth(1976)].

In this research, a pair of photographs are decomposed into digital images which are capable of computer processing. These photographs actually include various kind of geometric distortions according to flight conditions. In order to eliminate geometric distortions from digital images, we perform relative orientation and reappear the real situation of both photographs. Given these relative orientation elements thus obtained , computer software constructs the numerical rectification images that are corresponding to nadir photographs. On these images, the elevation differences cause the differences of parallaxs in the case that there are ups and downs in the ground surface of photographed object. In other words, the elevation can be represented as a function of parallax . We automatically find the corresponding pixels on two numerical rectification images in order to measure the amount of parallax. Then, the elevation of the object point which is projected through these pixels is calculated and the digital terrain model is constructed.

Several methods for searching the corresponding pixels by using a computer are known [R.E.Kelly(1977)]. This paper describes following four methods : Correlation, SSDA, Correlation using FFT, and Phase-Delay using FFT. These methods are applied to images which are extracted from aerial photographs. The discussion about the performance on each method are mentioned from these applied results.

2. THE PRINCIPLE OF STEREOSCOPIC MEASUREMENT

On the rectification images, the relative height of a object point , that is, the elevation differences Δh between two points P and Q appears the distance differnces (See Fig.1). On account of these properties, the elevation of P can be determined from the locations of corresponding pixels on the images. Now this section explains the numerical relation between the distance differences Δp and the corresponding relative height Δh.

Let us assume that an object has been photographed stereoscopically from the points O_1 and O_2 respectively, where the camera axes parallel and perpendicular to the length of base b, as shown in Fig.1. The camera constant is c, and the flying height is h.

The distance differences Δp between the corresponding pixels pairs are termed horizontal parallax differences p - q. They are directly dependent on the relative height Δh of the corresponding object points. From similarity it is clear that a simple relation exists between Δp in the image and ΔP in the photographed object, namely,

$$\Delta P = \frac{\Delta p \cdot (h - \Delta h)}{c} \quad \cdots\cdots (1)$$

From similar triangles, Δh is given by

$$\Delta h = \frac{\Delta p \cdot h^2}{b \cdot c} \cdot \left(1 - \frac{\Delta h}{h}\right) \cdots\cdots (2)$$

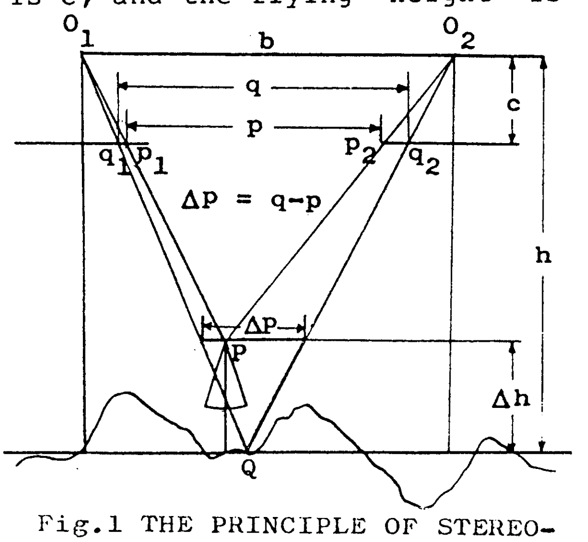


Fig.1 THE PRINCIPLE OF STEREOSCOPIC MEASUREMENT

If the length of base b can be measured in the image as b', we have b = b'·h/ c and Eq.2 finally becomes

$$\Delta h = \Delta P h / b' \cdot (1 - \Delta h / h) \quad \cdots\cdots\cdots \quad (3)$$

3. THE THEORY OF MATCHING AND/OR SEARCHING METHODS

3-1 Correlation method and SSDA

To search the corresponding pixels from left and right images, an criterion which indicates their similarity between two pixels is needed. In order to compare with two pixels, the two sub-images $f_W(x,y)$ and $g_W(x,y)$ are setted so that each pixel is located in the center of them, respectively. They are termed the matching windows and have size and shape in common. Then the similarity of two dimensional density patterns between two matching windows is calculated as the similarity between two pixels. As the criterion of similarity between these windows, Correlation method adopts the two dimensional crosscorrelation coefficient $R_{fg}(\xi,\eta)$, which is represented by Eq.4 [S.E.Masry(1974), T.J.Keating(1975)]. On the other hand, SSDA (Sequential Similarity Detection Algorithm) adopts the summation of absolute differences between both matching window densities $D_{fg}(\xi,\eta)$, which is expressed by Eq.5.

$$R_{fg}(\xi,\eta) = \frac{\iint_W f_W(x,y)g_W(x+\xi,y+\eta)dxdy}{\sqrt{\iint_W f_W^2(x,y)dxdy}\cdot\sqrt{\iint_W g_W^2(x+\xi,y+\eta)dxdy}} \qquad (4)$$

$$D_{fg}(\xi,\eta) = \iint_W \left| g_W(x+\xi,y+\eta) - f_W(x,y) \right| dxdy \qquad (5)$$

It is expected that the density patterns between both matching windows are more similar each other, the former criterion is higher and the latter one is lower.

3-2 Correlation method using FFT

This method calculates the crosscorrelation function value by using FFT (First Fourier Transform) in the frequency domain [H.Stark(1982)]. At first the rectangular sub-images $f_P(x,y)$ and $g_P(x,y)$ are setted from both images, respectively. They are termed the patches and have size and shape in common. In this method, the crosscorrelation function $C_{fg}(\xi,\eta)$ which is defined by Eq.6 can be utilized to examine the similarity between two patchs.

$$C_{fg}(\xi,\eta) = \iint_P f_P(x,y)g_P(x+\xi,y+\eta)dxdy \qquad (6)$$

And crosscorrelation coefficient $R_{fg}(\xi,\eta)$ of Eq.4 is rewritten as Eq.7 by using the crosscorrelation function.

$$R_{fg}(\xi,\eta) = \frac{C_{fg}(\xi,\eta)}{\sqrt{C_{ff}(0,0)}\cdot\sqrt{C_{gg}(0,0)}} \qquad (7)$$

According to the assumption that f (x,y) and g (x,y) is a periodic function of x and y, $C_{ff}(0,0)$ and $C_{gg}(0,0)$ are constant values. As the result, the calculation of R_{fg} is acquired from the C_{fg}. On the other hand, the cross-spectrum S(u,v) can be defined by

$$S(u,v) = \frac{1}{P}\iint_P C_{fg}(x,y)e^{-2\pi j(ux+vy)}dxdy. \qquad (8)$$

and it corresponds to Fourier transform of the crosscorrelation function. Then the two dimensional Fourier transforms of two patches are expressed by

$$F(u,v) = \frac{1}{P}\iint_P f_p(x,y)\, e^{-2\pi j(ux+vy)} dxdy, \quad (9)$$

$$G(u,v) = \frac{1}{P}\iint_P g_p(x+\xi, y+\eta)\, e^{-2\pi j\{u(x+\xi)+v(y+\eta)\}} d(x+\xi)d(y+\eta). \quad (10)$$

Thereupon, the cross-spectrum S(u,v) can be represented as the product of the complex conjugate of the spectrum F (u,v) with the spectrum G(u,v), that is

$$S(u,v) = F^{*}(u,v)\cdot G(u,v), \quad (11)$$

where the asterisk denotes the complex conjugate.

Consequently, the value of crosscorrelation function is calculated by performing inverse Fourier transform to S(u,v).

$$C_{fg}(\xi,\eta) = \iint_P S(u,v)\, e^{2\pi j(u\xi+v\eta)} d\xi d\eta \quad (12)$$

When the function indicate maximum value $[Rfg(\xi,\eta)]_{max}$, ξ and η represents the displacements between two patches in x-direction and y-direction, respectively.

3-3 Phase-delay method using FFT

The Fourier transform of the image represents the amplitude and the phase of the various frequency components making up the image. This method performs the Fourier transform of two rectangular patches f_p (x,y), and g_p (x,y) and calculates the phase-delays between frequency components of both patches. Then, the distance-delays between both sub-images based upon these phase-delays can be acquired.

At first, two patches are transformed to the spectrums F(u,v) and G(u,v) by FFT. Since these spectrums are normally complex type, they are devided into the real part K(u,v) and the imaginary part Q(u,v), respectively. For the two spectrums F and G, the phase θ(u,v) can be expressed by

$$\theta_f(u,v) = \tan^{-1}\left(\frac{Q_f(u,v)}{K_f(u,v)}\right), \quad \theta_g(u,v) = \tan^{-1}\left(\frac{Q_g(u,v)}{K_g(u,v)}\right), \quad (13)$$

And the difference between two phases which is given by

$$\theta_{fg}(u,v) = \theta_f(u,v) - \theta_g(u,v)$$

indicates that two vectors F(u,v) and G(u,v) rotate around the origin altogether with $2\pi/u$ period in u-direction and $2\pi/v$ period in the v-direction, keeping the constant diferrence of phase angles θfg at each frequency component u and v.

Consequently, T_x, the phase devided by u and T_y, the phase devided by v indicate the distance-delays, in other words, displacements between two patches in x-direction and y-direction, respectively, that is,

$$T_x(u,v) = \frac{\theta_{fg}(u,v)}{u}, \quad T_y(u,v) = \frac{\theta_{fg}(u,v)}{v} \quad (14)$$

4. APPLICATION TO AERIAL PHOTOGRAPH

4-1 PRE-PROCESSING

Aerial image processing includes the processes of relative orientation and numerical rectification, besides the process searching for the corresponding pixels. These processes are summarized in Fig.2. This section describes the abstracts of these processes at each stage in the order shown in Fig.2.

[1] Digitization of aerial photographs

Since aerial photographs are not directly amenable to computer analysis, they must be converted to digital images of numerical forms by making use of a drum-scanner before processing. This conversion is the process what we called digitization. The sampling pixel size is 100 μm in line and column. At each location, the photograph density is sampled and quantized. When this digitization process has been done for all pixels, the photograph is represented by a rectangular array of integer. This is the digital image and is stored magnetic tape.

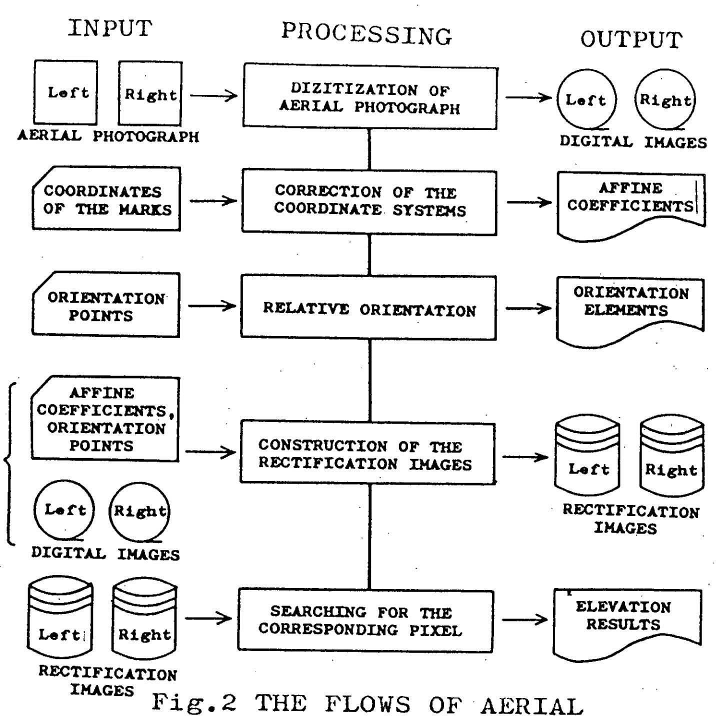


Fig.2 THE FLOWS OF AERIAL IMAGE PROCESSING

[2] Correction of the coordinate system

To the digital image which is made by using a dram-scanner, a image orthogonal coordinate system of line and column is adopted. This coordiate system can not linearly correspond to the source coordinate system of the photograph, because of film curvature in digitizing. In order to eliminate these influences and correct the correspondence between two coordinate systems, the affine coefficients are calculated from the coordinates of four fiducial mark points. By affine coefficients, the coordinate of line and column have connection with source coordinate.

[3] Relative Orientation

In a pair of vertical photographic images, the small rotations or motions of the platform and a difference of flying heights may bring about various geometric distortions. Consequently, relative orientation is necessary to correct them [B.Hallert(1960)]. If the relative rotations between these images are reconstructed by relative orientation, their numerical rectification images can be made.

Assuming two images which are taken with about 60% overlap, a tridimensional orthogonal coordinate system is adopted in Fig.3, where X-axis is horisontal and parallel with the length of base b. The Y-axis is horizontal and perpendicular to X-axis, and the Z-axis is perpendicular to the XY-plane. A image of the positive plane adopts a coordinate system x,y,z. Each perspective center is the point O_1 and O_2, and two positive images and their perspective plane are exactly parallel, where the camera constant is c, and the flying height is h.

In the Fig.3, the pair of corresponding pixels in two positive images are normally be projected in two different points on the perspective plane. The distance between the two projected points P_1, P_2 is defined as the total parallax P_{xy}. This parallax may be devided into two components. The x-component P_x is termed the horizontal parallax, and y-component P_y is termed the vertical parallax. The horizontal parallaxs P_x depend upon the elevation differences of the photographed object.

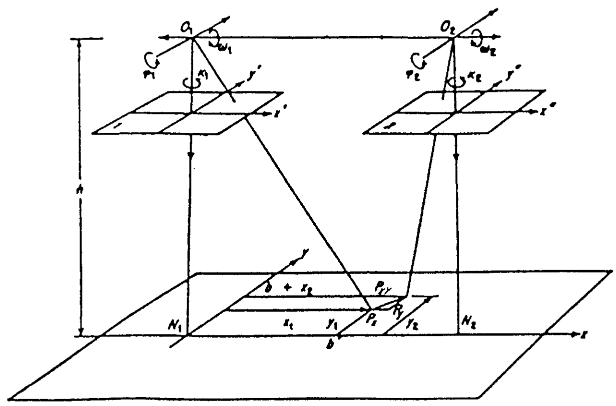


Fig.3 THE RELATION BETWEEN A PAIR OF IMAGES AND PERSPECTIVE PLANE

But, the vertical parallaxes P_y must simultaneously be corrected to zero in all points in the common perspective plane. The vertical parallax P_y may be actually eliminated by changing orientation elements, and the research constrains only five rotation elements, such as ϕ_1, ϕ_2, $(\omega_2-\omega_1)$, κ_1, and κ_2.

Now, when the perspective center rotates around the axis Y (primary), X (secondary) and Z (tertiary) through the angle ϕ, ω, and κ respectivery, the numerical relations between the pixel p(x,y) and the point P(X,Y) on the perspective plane can be represented as below.

$$X = h\frac{a_{11}x + a_{21}y + a_{31}c}{a_{13}x + a_{23}y + a_{33}c}, \quad Y = h\frac{a_{12}x + a_{22}y + a_{32}c}{a_{13}x + a_{23}y + a_{33}c}$$

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\omega & -\sin\omega \\ 0 & \sin\omega & \cos\omega \end{bmatrix} \begin{bmatrix} \cos\phi & 0 & \sin\phi \\ 0 & 1 & 0 \\ -\sin\phi & 0 & \cos\phi \end{bmatrix} \begin{bmatrix} \cos\kappa & -\sin\kappa & 0 \\ \sin\kappa & \cos\kappa & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad (15)$$

Accordingly, to perform relative orientation between both images, $Y_2 - Y_1 = 0$ in Eq.15 must be satisfied. However, since $Y_2 - Y_1 = 0$ is non-linear form, an approximate equations are used as mentioned below. Assuming that (Y_1), (Y_2) represents approximate Y_1, Y_2, respectively, and that each correction value is dY_1, dY_2,

$$(Y_1) + dY_1 = Y_1, \quad (Y_2) + dY_2 = Y_2 \qquad (16)$$

$$dY_2 - dY_1 = -\{(Y_2) - (Y_1)\} = p_y \qquad (17)$$

Moreover, since dY can be represented by

$$dY = \frac{XY}{h}\,d\phi + h\left(1+\frac{X^2}{h^2}\right)d\omega + Xd\kappa \qquad (18)$$

substituting Eq.18 for Eq.17, approximate Eq.19 can be utilized to acquire the five orientation elements.

$$p_y = \frac{(X-b)}{h}d\phi_2 - \frac{XY}{h}d\phi_1 + h\left(1+\frac{X^2}{h^2}\right)(d\omega_2 - d\omega_1) - (X-b)d\kappa_2 + Xd\kappa_1 \qquad (19)$$

The research uses ten pairs of the corresponding pixels, and the equations can be solved by the least square methods.

[4] Construction of the numerical rectification images

Using both relative orientaion elements and affine coefficients of the coordinate transformation, the numerical rectification image can be constructed. It has no vertical parallaxes in the image, and corresponds to its nadir photograph.

The relation between the pixel p(x,y) on the rectification image and the pixel p'(x',y') on the original image can be represented by common Eq.20 , where the coefficients matrix is given by Eq.21 in the case of left photograph, or Eq.22 in the case of right one [G.Konecny(1979)].

$$x' = c\,\frac{d_{11}x + d_{21}y + d_{31}c}{d_{13}x + d_{23}y + d_{33}c}\ , \quad y' = c\,\frac{d_{12}x + d_{22}y + d_{32}c}{d_{13}x + d_{23}y + d_{33}c} \tag{20}$$

$$\begin{bmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{bmatrix} = \begin{bmatrix} \cos\phi_1 & 0 & \sin\phi_1 \\ 0 & 1 & 0 \\ -\sin\phi_1 & 0 & \cos\phi_1 \end{bmatrix} \begin{bmatrix} \cos\kappa_1 & -\sin\kappa_1 & 0 \\ \sin\kappa_1 & \cos\kappa_1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{21}$$

$$\begin{bmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{bmatrix} = \begin{bmatrix} \cos\phi_2 & 0 & \sin\phi_2 \\ 0 & 1 & 0 \\ -\sin\phi_2 & 0 & \cos\phi_2 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\omega_2 & -\sin\omega_2 \\ 0 & \sin\omega_2 & \cos\omega_2 \end{bmatrix} \begin{bmatrix} \cos\kappa_2 & -\sin\kappa_2 & 0 \\ \sin\kappa_2 & \cos\kappa_2 & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{22}$$

To construct the numerical rectification image from the digital photographic image, it is necessary to adopt the pixel filling algorithm which transfers the gray levels from the input image to the output image pixel by pixel. In this case, the output pixels are mapped into the input image one at a time to establish their gray level. If an output pixel falls between four input pixels, its gray level is determined by bilinear interpolation [K.R.Castleman(1979)].

4-2 Implementation of matching and/or searching methods

This paper described the theory of matching and/or searching method in section 3. In practice, these methods are applied on the numerical rectification image. The steps of procedure are mentioned as below in detail.

[1] Correlation method and SSDA

These methods have something in common with the basic steps of procedure, but are different from the point of criterion which indicates the similarity between two pixels. These steps are as follows [Y.Ikebe,T.Hoshi and T.Matsushita(1981)].

(1) The calculating pixel p_1 is setted on the left image which is a base image, and a pixel corresponding to the pixel p_1 is searched within the right image.

(2) The pixel p_2' is given on the right image approximately corresponding to the pixel p_1. And the rectangular search-area S is setted so that the pixel p_2' becomes the center of search-area S. Its size has SX pixels in x-direction and SY pixels in y-direction . Then the correponding pixel is searched within S (See Fig.4).

(3) To compare the pixel p_1 with a pixel p_2 in the search-area, the similarity between two pixels is calculated. Two rectangular matching windows Wl and Wr are setted, where each center pixel of them is p_1 and p_2, respectively. These matching windows have WX pixels in x-direction, and WY pixels in y-direction in common. Then the similarity of two dimensional density patterns

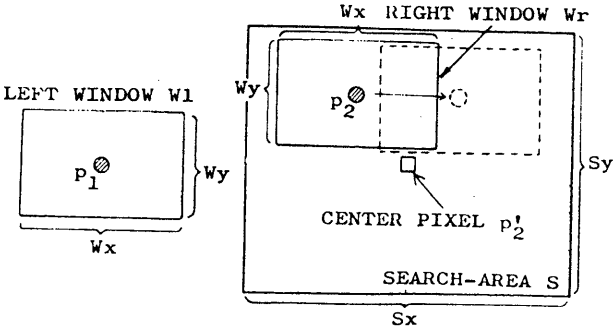


Fig.4 RELATION BETWEEN TWO WINDOWS AND SEARCH-AREA

between Wl and Wr is calculated, and this is replaced as similarity between two pixels.

As for this similarity criterion, Correlation method utilizes the two dimensional crosscorrelation coefficient, and SSDA utilizes the summation of absolute differences between both Wl and Wr.

(4) The pixel p_2 is moved all over within S and the similarity between the pixel p_1 and each pixel p_2 are calculated. Finally ,the pixel which indicates maximum similarity criterion within the search-area S is selected as the corresponding pixel to p_1 .

Then, the pixel which gives maximum value criterion in the case of Correlation method or minimum one in the other case of SSDA is selected. And the vertical parallax and the elevation of ground surface is calculated from the coordinates of corresponding pixels in both images.

[2] Correlation and Phase-delay method using FFT

These methods utilize the Fourier transform and calculate the displacements between both images. In the case of Correlation method, the cross-spectrum is calculated in frequency domain and the crosscorrelation function values are acquired. According to the location which indicates maximum value in similarity, these displacements are determined.

On the other hand, Phase-delay method depends upon the fact that phase-delays between both spectrums of images finally represent the distance-delays, that is, the displacements between both image densities. Then these steps of procedure are as follows [Y.Ikebe,T.Hoshi and T.Matsushita(1982)].

(1) The calculating pixel p_1 is setted on the left image, and the corresponding pixel to p_1 is searched within the right image.

(2) The point p_2' which is approximately corresponding to the pixel p_1 is given on the right image. Two rectangular patches P_l and P_r are setted from both images. These patches have PX pixels in x-direction and PY pixels in y-direction and include the pixels p_1 and p_2' in the center position, respectively. Then, the displacements is calculated in x-direction and y-direction between P_l and P_r.

(3) Both frequency spectrums F(u,v) and G(u,v) are calculated by performing two dimensional discrete Fourier transform, respectively. Correlation method calculates the cross-spectrum and performs two dimensional discrete inverse Fourier transform of this spectrum. Then the values of crosscorrelation function are aquired. And according to the location which indicates maximum value of this function, the relative displacements Tx and Ty in both directions are determined, respectively..

Next, Phase-delay method can get the phase from the resultant F(u,v) and G(u,v), and consequently, phase-delays of each frequency component can be calculated. And the distance-delays between P_l and P_r in both directions are acquired at each frequency component. But in acutual applications, the calculations is not need all (u,v)-frequency components, because high frequency components are apt to accept the influences of noise. Therefore the calculations in high frequency components are excepted, and the average of distance-delays is taken in low components. This process is performed by

$$T_x = \frac{1}{5}\sum_{k=2}^{6} PX\cdot\theta_{fg}(k,1)/2\pi(k-1)\,, \quad T_y = \frac{1}{5}\sum_{k=2}^{6} PY\cdot\theta_{fg}(1,k)/2\pi(k-1) \quad (23)$$

and finally, the displacements in both directions can be produced.

(4) If the calculating results indicate no displacements, then the pixel p_2' is corresponding pixel to p_1 and this algorithm is terminated. When the displacements exist, the pixel p_2' is moved to

the location which is added the pixel p_2' to the displacements. Now, the algorithm returns to the step (2) and sets new patch on the right image. These processes continue until the displacements disappear completely. But, since these processes often do not converge, they do not continue more than 5 loops.

4-3 Improvement of searching process

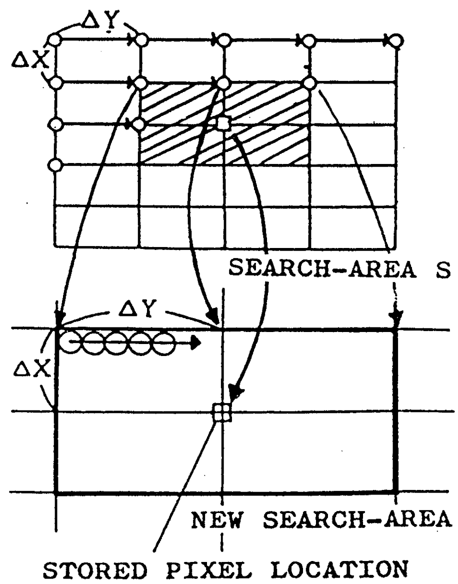
In both cases of Correlation method and SSDA, the size of matching window and search-area causes very significant influence to processing time. Many kinds of methods which reduce this processing time with maintaining the same accuracy have been developed. This section mentions about two methods on behalf of these methods [C.Mori and S.Hattori(1982), T.Kobori(1981)].

[1] The two stages processing

For calculating the similarities, it is not very efficient to transfer pixel by pixel for all pixels within the search-area. Then as shown in Fig.5, the two stages processing is the method in which the calculations are devided in two stages (stage 1, stage 2), and the corresponding pixels are searched.

Stage 1: Roughly transferring the pixel within the search-area at the intervals of ΔX pixels in x-direction and ΔY pixels in y-direction, respectively, the similarity of the pixel is calculated at each location. As the result, the locations of N pixels are stored in the order of high similarity.

Stage 2: For the N pixels which are stored in stage 1, the new search-area is setted at each pixel. It has $2*\Delta X$ pixels and $2*\Delta Y$ pixels in both directions, respectively, and each pixel is the center of new search-area. Then the similarity is calculated within the new search-area transferring the pixel by pixel. This process is performed for all N pixels, as the result , the pixel which indicates maximum value becomes the corresponding pixel.



[2] The method using previous searching information

This method reduces the size of search-area for next searching by making use of the relative displacement informations of previous searching . This method is illustrated in Fig.6.

At first, it is assumed that the pixel p_1 is corresponding to the pixel p_2 in previous searching. Then, on the next searching for the pixel q_1 which is neighbour pixel of p_1, the new search-area can be reduced. Because, the center pixel of new one can be moved to the location which is expected to be the corresponding pixel to q_2, by making use of both the location of

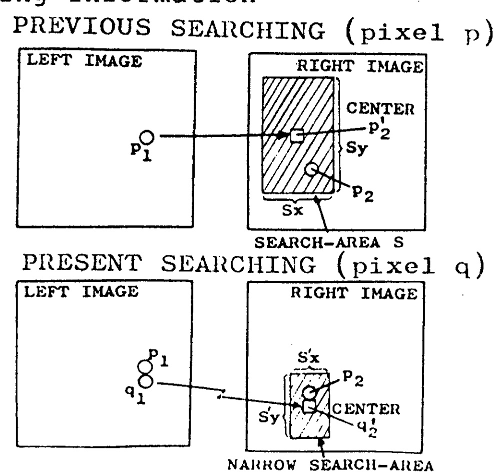


Fig.6 THE METHOD USING PREVIOUS SEARCHING INFORMATION

p_2 and the relative displacement between p_1 and q_1 . Therefore, it is expected that processing time is considerably condensed.

5. APPLICATION AND RESULT

In this section, each searching method is actually applied to aerial photographs, and its results are described. In the application, some sub-areas which have characteristic patterns are extracted from the photograph, and then these methods search the corresponding pixels in these sub-areas.

5-1 Correlation method and SSDA

The matching window size is considered to cause significant influences to both the searching accuracy and the processing time. Then, through many trials and errors we determine the window size by which these methods can search in high accuracy and at minimum processing time. Then three sub-areas which are selected from the photograph are considered to be 'Farm','Residential Land' and 'Mountains and Forest', respectively (See the Appendix). The searching tests of both Correlation method and SSDA are examined in three sub-areas by changeing the matching window size. In this examinations, the matching window shape is fixed in regular square, and the search-area size and shape are also constant .

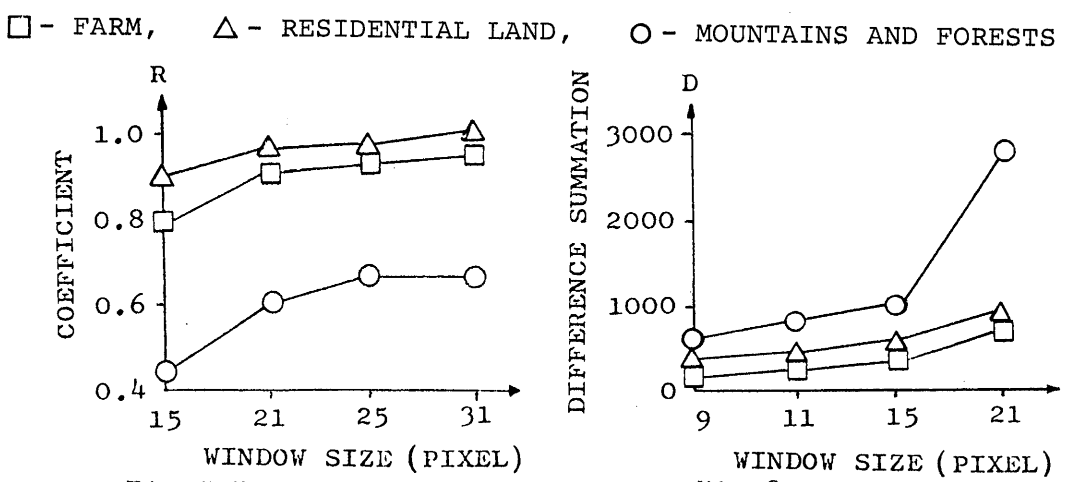


Fig.7 THE SEARCHING OF CORRELATION METHOD

Fig.8 THE SEARCHING OF SSDA

Fig.7 and Fig.8 show the results of Correlation method and SSDA, respectively. Fig.7 shows the correlation coefficients at corresponding pixel in vertical axis with each change of window size in horizontal axis. On the other hand, Fig.8 plots the changes of differences summation. When window size was more than 21 pixels, these searching results in Correlation method almost corresponded with each other. But, the searching result of 15 pixels window brought about many mistakes in 'Mountain and Forests' sub-area. They did not agreed with the searching results of more than 21 pixels window. On the other hand, SSDA showed the good searching results when the window size was setted for 11 or 13 pixels. These size are smaller than the size of Correlation method. But, the searching result of 9 pixels window did not correspond with these results of more than 11 pixels, and produced mis-searching results in many points.

Here, compared with two searching results of Correlation and SSDA, these almost corresponded with each other though there were some points which were produced about 1 pixel difference. In the 'Mountains and Forests' sub-area, however, there were considerable differences between these results. Judging from the object topography, it is proved that the Correlation method is more excellent than SSDA, but, from the point of processing time, SSDA is faster than Correlation method.

Next, both performances of the two stages method and the method using previous informations are examined in three sub-areas.

Table.1 THE PROCESSING TIME OF IMPROVED METHODS (SEC)

	PARAMETER	CORRELATION	SSDA
NORMAL	Wx,Wy =21 Sx,Sy =31	1.405	1.205
TWO STAGES PROCESSING	$\Delta X,\Delta Y$ = 3	0.603	0.518
	$\Delta X,\Delta Y$ = 2	0.415	0.361
USING PREVIOUS INFORMATION	Sx,Sy = 7	0.209	0.181
	Sx,Sy = 5	0.119	0.115
	Sx,Sy = 3	0.068	0.066

Table.1 summarized the processing time which is needed to search for one pixels pair, when the two stages method and the method using the previous information were adopted as for Correlation method and SSDA. The size of both matching window and search-area was fixed, and stored number N = 1 in the first stage of the two stages method. The searching results all corresponded with the originals. Consequently, it is proved that the two stages method could condense the processing time to about 30~40%, and the method using the previous information could condense it to only 4~5% against the normal searching.

5-2 Correlation and Phase-delay method using FFT

Since the patch size is very significant in these methods, we compared the searching results between these methods and with the results of both Correlation and SSDA while changing the patch size.

The Table.2 shows the differences of the results in both directions between Correlation method and these two methods, that is, Correlation method using FFT in upper row and Phase-delay method in lower row, respectively. In Table.2, we examined the searching result with changing the patch pixel size from 4 by 4 to 16 by 32, and checked the differences of searching results.

Table.2 THE DIFFERENCE PIXELS TO CORRELATION METHOD (PIXEL)

PY \ PX	4	8	16	32
4	(1, 1) (0, 0)	(1,-1) (-1, 1)	(2,-1) (0, 1)	
8		(-2, 3) (-2, 1)	(1,-1) (0, 6)	(1,-1) (-6,-3)
16			(2,-1) (0,-5)	(1,-1) (-2,-7)

As for Correlation method using FFT, though the patch size was relatively large, there were only few differnce pixels, and its algorithm could converge rapidly. On the other hand, in the case of Phase-delay method, however, it produced good searching only when the patch size was 4 by 4, or 4 by 8. And when the patch would become large size, the differences in y-direction increased.

Moreover, in the 'Mountains and Forests' area, these algorithm could not converge rapidly, and there were many mis-searching pixels in the results.

But from the point of the processing time, as shown in the Table.3, it is proved that these method are more excellent than Correlation method and SSDA, moreover the two stages method and the search using the previous information.

Table.3 THE PROCESSING TIME OF TWO METHODS USING FFT (SEC)

PATCH SIZE	CORRELATION	PHASE-DELAY
M=8, N=8	0.0205	0.0190
M=8, N=4	0.0135	0.0125
M=4, N=4	0.0105	0.0095

6. DISCUSSION AND CONCLUSION

Each method produced good searching results in the sub-areas such as 'Farm' and 'Residential Land'. For example, in the case of Correlation method, crosscorrelation coefficients at the corresponding pixels indicated 0.8 through 0.9 in both sub-areas. The searching results of SSDA were quite similar with those of Correlation method. And two methods using FFT also gave good searching results when small patch size was adopted. Especially, in the 'Farm' sub-area, which could be considered to have a constant periodic textures, the results almost agreed with those of Correlation method.

On the other hand, in the 'Mountains and Forests' sub-area, mis-searching results increased and the accuracy decreased. Correlation coefficients became smaller than 0.6 and SSDA produced mis-searchings in higher frequency than Correlation method. Moreover, when applied to the 'Mountains and Forests' sub-area, Correlation and Phase-delay method using FFT did not converge at any patch size. This is one of most difficult problems met with these methods. For reasons why it is difficult to search in the 'Mountains and Forests' sub-area, three points can be considered. First, a delicate difference of photographed object between left image and right image exists due to the shadows of trees and the changes of the elevations. And the second is that these patterns are also susceptible to the influences from random textures of high frequency. The third point is that considerable distortion is produced in x-direction at steep slope points.

Fortunately four methods proposed in this paper appears promising in searching the pixels from a pair of images. We will elaborate the conclusions in the following.

(1) Correlation method is the most suitable one from the view point of searching accuracy. But searching speed is slower than other methods.

(2) SSDA is superior to Correlation method except when searching in the 'Mountains and Forests' sub-area , in searching accuracy and processing time.

(3) Correlation and Phase-delay method using FFT are inferior to both Correlation method and SSDA on searching accuracy. In the 'Farm' sub-area, these methods may be used for processing since searching speed is fast, provided that user could allow about 1 pixel error in the results.

(4) From experiments with various window and patch size, the optimum window size proved to be 21 by 21 in Correlation method, and 11 by 11 in SSDA, and the optimum patch size was 4 by 4 in two methods using FFT.

Consequently, our results show that no one method is superior to all other methods both in searching accuracy and processing time. The conclusion is then that we select the most suitable method depending on the object patterns of the processing area.

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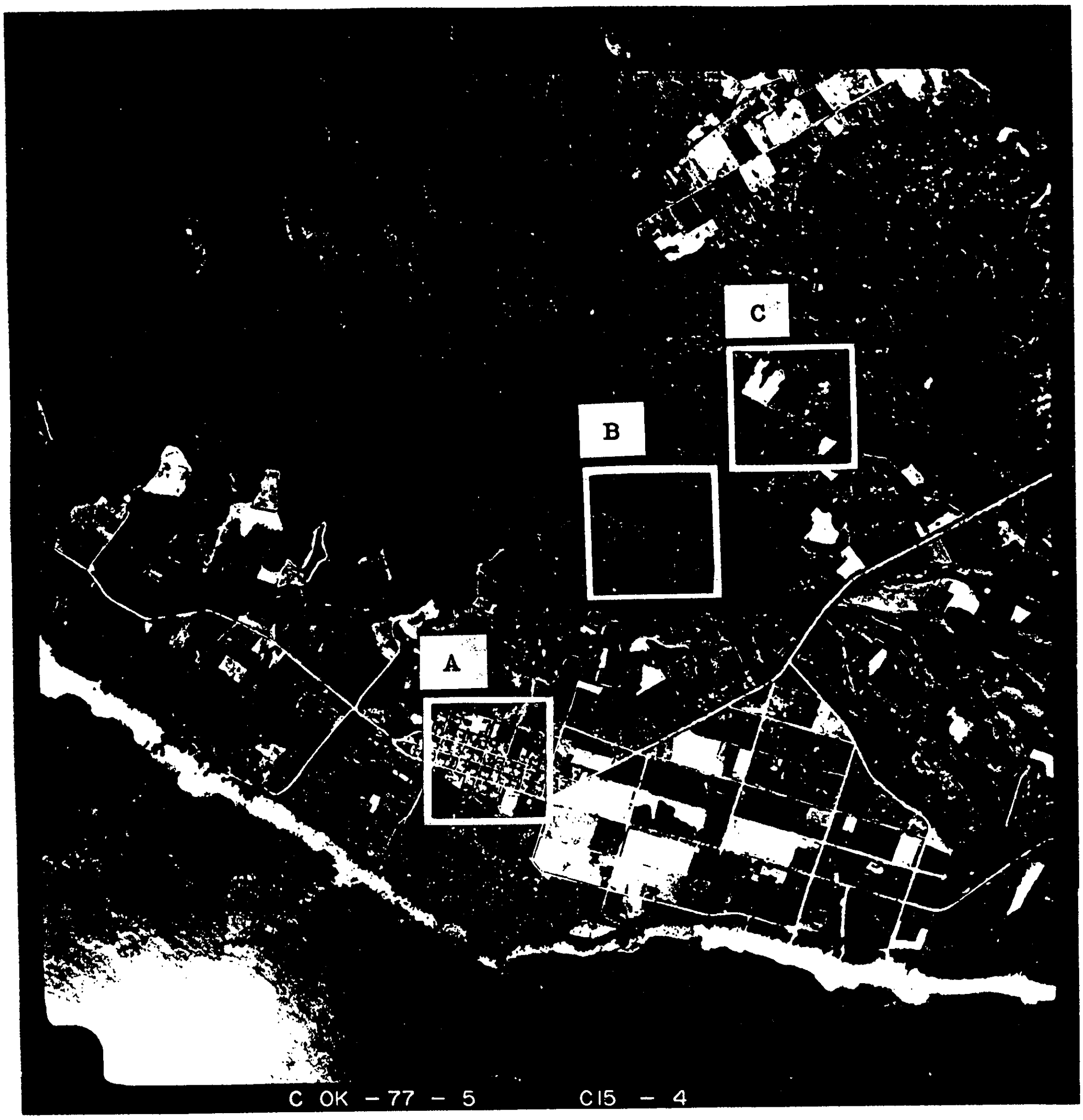
APPENDIX



THE SUB-AREAS OF AERIAL PHOTOGRAPH (in Left)

Symbol	SUB-AREA
A	RESIDENTIAL LAND
B	MOUNTAINS AND FORESTS
C	FARM

THE FLIGHT CONDITION

Test Area	Iriomote Island in JAPAN
Flying Day	September 29, 1977
Photo Scale	1/ 10,000
Flying Height	1,610 m
Camera Constant	153.62 mm

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TITLE

RESRERCH OF MATCHING AND/OR SEARCHING METHODS OF IDENTICAL POINT ON STEREO AERIAL IMAGES AND ITS APPLICATION

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ABSTRACT

In the field of topographic surveying and mapping from aerial photographs, researchs touching upon technical improvement which constructs digital terrain models easily and efficiently using a drum-scanner and a computer system instead of a stereoplotter are being advanced by many photogrammetry workers. This paper describes about four methods for matching and/or searching pixels corresponding to identical point on stereo aerial images, and reports the results of these applications to photographs.

In this research, stereo vertical photographs were decomposed into digital images using a drum-scanner. By performing relative orientation between digital images, we reconstructed a pair of numerical rectification images. On these images, we found the corresponding pixels to identical ground point, and its digital terrain model was finally made.

SUPPLEMENTARY NOTES