Determination of GCP Location to Subpixel Values
in Landsat Imagery

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Abstract

A new algorithm was developed to determine the GCP location to
subpixel values in a Landsat imagery. The effects of the blur
of image, noises, the variation of radiation brightness around
a GCP and image rotation on the accuracy of GCP location were
studied by the simulation of Landsat TM image system. As a
result of the simulation, the above-mentioned parameters did
not affect so much on the accuracy of GCP location; but, the
influence of image rotation is very remarkable. This algorithm
was applied to a Landsat image of an agricultural area which
includes a farm pond as a ground control target.

1.Introduction

The accuracy of geometric correction of Landsat image data
depends on the accurate correspondence of image coordinates to
ground coordinates of sufficient number of GCP; in other words,
giving real numbers to image coordinates of GCP's instead of
integer numbers, which are usually given to image coordinates,
improves the accuracy of the geometric correction(Welch,1985).
However, to give real numbers to image coordinates is difficult
or requires a particular shape of GCP target in most of the
Landsat imagery.
The purposes of this study are to develop an algorithm to
determine the location of GCP in Landsat imagery to subpixel
values and to evaluate the performance of this algorithm by
computer simulation.

When the ground surface is regarded as a digital image, the
problem of determination of GCP can be considered as a problem
of image matching with Landsat image and land cover degital
image. In other words, one area, which is surveyed and
certified as having homogeneous land cover, high contrast to
the surrounding area and a remarkable shape, can be considered
as a ground control target.

The land cover map of this area should be treated as subpixel
digital image data of radiation brightness values. Then this
subpixel image is used as original image data in the
mathematical model of a Landsat image system. Then Landsat
images are simulated by the convolution of point spread
function with original subpixel image and by the sampling to a
pixel size of Landsat image.

The data of these simulated images depend on the way of
sampling and the other factors like noise, blur of image,
radiation brightness of original image data and image rotation.
If every parameter can be estimated well,the way of sampling in

which a simulated Landsat image data is most similar to an actual Landsat image data can be considered to have an fairly accurate matching position of both images.

2.Mathematical Model

The radiation brightness for one band of a pixel of actual Landsat TM data (F1) and that of a pixel of a simulated data (F2) are expressed as follows.

$$F1(x1,y1)=\int_{u=X_1-a/2}^{u=X_1+a/2}\int_{v=Y_1-a/2}^{v=Y_1+a/2}\int_{t=-\infty}^{t=\infty}\int_{s=-\infty}^{s=\infty}\{G_1(s,t)+n_1(s,t)\}\cdot h_1(u-s,v-t)\,ds\,dt\,dv\,du$$
$$+N_1(X_1,Y_1)$$

$$F2(x2,y2)=\int_{u=X_2-a/2}^{u=X_2+a/2}\int_{v=Y_2-a/2}^{v=Y_2+a/2}\int_{t=-\infty}^{t=\infty}\int_{s=-\infty}^{s=\infty}\{G_2(s,t)+n_2(s,t)\}\cdot h_2(u-s,v-t)\,ds\,dt\,dv\,du$$
$$+N_2(X_2,Y_2)$$

(EQ.1)

where

F1(x1,y1): radiation brightness of the pixel whose center coordinate is (x1,y1) in an actual Landsat TM data

F2(x2,y2): radiation brightness of the pixel whose center coordinate is (x2,y2) in a simulated data

G1(s,t): radiation brightness from the point(s,t) on the actual ground cover

G2(s,t): radiation brightness from the point(s,t) on the model of ground cover

h1(u,v): actual point spread function

h2(u,v): model of point spread function

a : Instantaneous field of view, IFOV = 30.0 m

N1(x1,y1): additive sensor noise on F1(x1,y1)

N2(x2,y2): additive noise on F2(x2,y2)

n1(s,t): additive noise on G1(s,t)

n2(s,t): additive noise on G2(s,t)

Suppose both grid structure of data of F1(x1,y1) and F2(x2,y2) are same as shown in Equation 2,

x1(i)-x2(i)=dx (constant)
y1(i)-y2(i)=dy (constant), i=1,2,,,,N   (EQ.2)

then the value of Z(dx,dy), the mean square error of the difference between F1(x1(i),y1(i)) and F2(x2(i),y2(i)), (i=1,2,,,N) has the minimum value.

$$Z(dx,dy)=\sqrt{\sum^{N}(F1(x1,y1)-F2(x2,y2))^2}\;/N$$ (EQ.3)

The minimum value point of Z(dx,dy) seems to be the point where the actual Landsat image is most similar to the simulated image. Therefore,the minimum value point of Z(dx,dy) can be regarded as the most matched point of actual Landsat image and ground cover map.

The following six independent factors influence on the location of this minimum value point.
1) Arrangement of comparing pixels in actual image data and in

simulated image data (Mask shape)
2) The variation of radiation brightness of ground cover model
:G2(s,t)
3) The effect of noises in actual ground cover
4) The estimating accuracy of PSF for simulation ; the effect
of image blurring
5) The effect of the rotation of axis both in Landsat image and
in simulation image
6) The effect of radiometric noise on Landsat image data

No matter how much the above factors vary, if the location of
the minimum value point of Z is stable,the geometrical relation
between both images is expressed as follows, and the
coordinates of a pixel center in Landsat image data is
determined.

$$x1(i)=x2(i)+dx$$
$$y1(i)=y2(i)+dy$$
(EQ.4)

Then, in this study,the effects of above factors on the
accuracy of determination of the minimum value point location
of Z by computer simulation.

3.Computer simulation

A.Parameters
The Landsat image system was simulated by the model of Landsat
image system and the value of $Z(dx,dy)$, the square mean error
between simulated image data and reference data, which was
calculated by altering above mentioned parameters as follows.
In this simulation, four types of masks (Figure.1) were used
to save computation and the parameter of radiometric noise was
not considered since the radiometric noises are always removed
from actual Landsat images prior to any other analyses. The
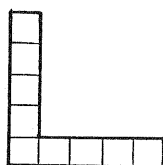size of a subpixel is one fifth of a normal pixel size.
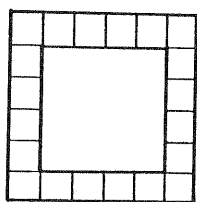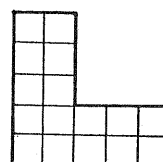
CLOSED TYPE   CLOSED TYPE
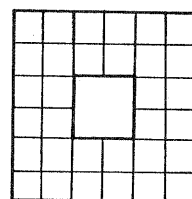
MASK TYPE A1   MASK TYPE A2

OPEN TYPE   OPEN TYPE

MASK TYPE B1   MASK TYPE B2

Fig.1   Mask Type in Simulation

1) Average radiation brightness of ground cover model was given supposing actual ground surface of bare soil and water surface. The average radiation brightness around ground target(bare soil) was 30.0 in CCT count and the average radiation brightness in ground target(water surface) was 10.0 in CCT count. And their radiation brightness were changed to 32.0 and 8.0 in CCT count, simulating the variation of radiation brightness of ground surface.
2) The noise on ground cover model was assumed to be normal gaussian noise N(0.0,1.0) on each subpixel.
3) PSF was produced from x-direction LSF and y-direction LSF as Carnahan(1986) mentioned. Every LSF was approximated as polynomials based on the LSF curve reported by Markham (1984) and the degree of blurring was evaluated by the coefficient k as follows.

$$PSF(k,X,Y)=LSFx(k,x) \times LSFy(k,y) \qquad (EQ.5)$$
$$\text{where} \quad LSFx(k,x)= \sum a_i(x/k)^{**i}, \quad i=0,1,2,,,,8$$
$$LSFy(k,y)= \sum b_i(y/k)^{**j}, \quad j=0,1,2,,,,5$$

The PSF(k,X,Y) in (EQ.6) was normalized before simulation. The values of the coefficient k for simulated image data was fixed at 1.0.
4) The angle of the rotation of both axes of Landsat image and those of ground cover map image in simulation was given as -3, 0 and +3 degree.

B.Reference data
The reference data was created under the condition as follows before simulation. The average radiation brightness of bare field and water surface are 30.0 and 1.0. The normal gaussian noise N(0.0,1.0) is added to the ground surface subpixel image. The coefficient k, the degree of image blur are 1.0 and 1.2 simulating a clear image and a blurred image. When k is 1.0,it shows the polynomials in the case of LSF curve reported by Markhan (1984). The rotation angle of images is 0 degree. A square water surface in bare field with a size of 5 x 5 pixels, is supposed to be a ground target. The reference data is given in integer number by quantization.

4.Results

The performance of the algorithm presented in this study was evaluated by comparing the actual location of GCP with the estimated location of GCP. And the distribution of Z(dx,dy) was plotted by contour line as shown in Figure 2, then the location of the minimum value point was searched. The results are shown in Table 1.

As a result of simulation, every parameter effects on the accuracy of the estimation of GCP location. Because of the size of subpixel in order to save computation; one fifth of one pixel, the detail effects of each parameter on the location accuracy can not be mentioned, but the errors in most of the cases are smaller than 0.2 pixel in length(Figure 3).
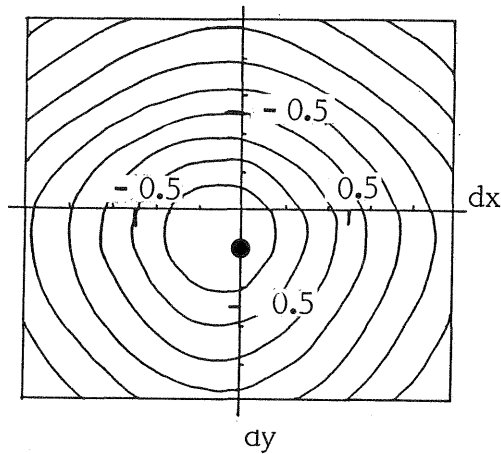
Minimum value of Z =2.2
Contour interval = 0.9
Unit : 1 pixel

*Mask Type : A2
*Radiation brightness(CCT)
Bare soil=32.0
Water= 8.0
*SNR=20
*k=1.0
*Image rotation angle=0 degree
● : Minimum value point

Fig.2 Distribution of value of Z(dx,dy)

Table 1. Simulation parameters and the location of minimum value point

Contrast	Rotation (degree)	Blur (k)	No.	Mask Type			
				A1	A2	B1	B2
RD1 (bare soil)= 30.0 RD2 (water)= 10.0	-3.0	1.0	1	(-0.2,0.0) 1.6	(-0.2,0.0) 1.8	(0.0,-0.2) 1.5	(-0.2,0.0) 2.0
		1.2	2	(-0.2,0.0) 1.6	(-0.2,0.0) 1.6	(0.0,-0.2) 1.3	(-0.2,-0.2) 1.7
	0.0	1.0	3	(0.0,0.0) 1.4	(0.0,0.0) 1.6	(0.0,0.0) 1.3	(0.0,0.2) 1.7
		1.2	4	(0.0,0.0) 1.3	(0.0,0.0) 1.5	(0.0,0.0) 1.1	(0.0,0.0) 1.4
	+3.0	1.0	5	(-0.2,0.0) 2.0	(-0.2,0.0) 1.9	(0.0,0.0) 1.4	(0.0,0.2) 1.8
		1.2	6	(-0.2,0.0) 1.9	(-0.2,0.0) 1.7	(0.0,0.0) 1.2	(0.0,0.0) 1.5
RD1 (bare soil)= 32.0 RD2 (water)= 8.0	-3.0	1.0	7	(-0.2,0.0) 1.7	(-0.2,0.0) 2.4	(0.0,0.0) 1.5	(-0.2,0.0) 2.6
		1.2	8	(-0.2,0.0) 1.8	(-0.2,0.0) 2.1	(0.0,-0.2) 1.5	(0.0,-0.2) 2.3
	0.0	1.0	9	(0.0,0.2) 1.4	(0.0,0.2) 2.2	(0.0,0.2) 1.1	(0.0,0.2) 2.3
		1.2	10	(0.0,0.0) 1.4	(0.0,0.0) 1.9	(0.0,0.0) 1.3	(0.0,0.2) 2.1
	+3.0	1.0	11	(-0.2,0.0) 2.0	(-0.2,0.0) 2.6	(0.0,0.2) 1.1	(0.0,0.2) 2.5
		1.2	12	(-0.2,0.0) 1.9	(-0.2,0.0) 2.2	(0.0,0.0) 1.3	(0.0,0.2) 2.2

upper :location of minimum value point (x,y) by pixel
lower :minimum value of Z (dx,dy)

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Mask Type A1　　　Mask Type A2

Mask Type B1　　　Mask Type B2
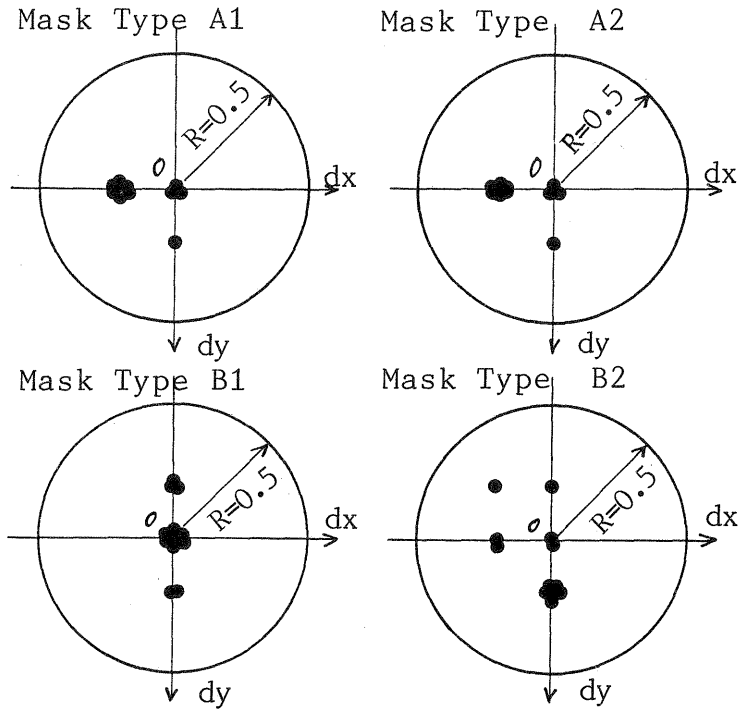
Unit: 1 pixel

Fig.3 Errors of estimated location of GCP

Radiation brightness of
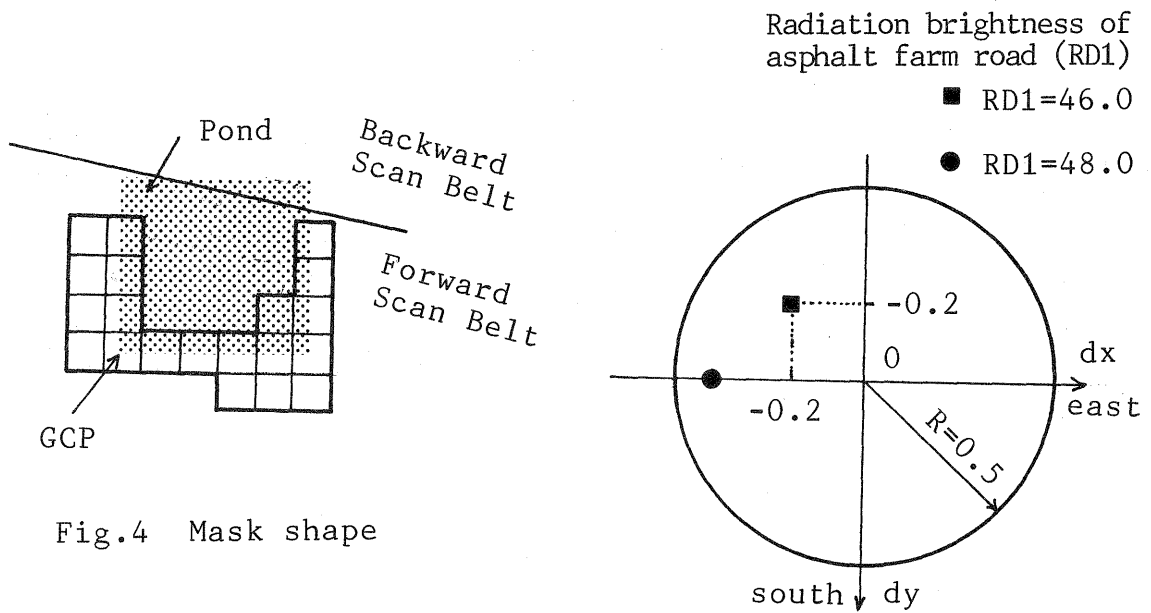asphalt farm road (RD1)

■ RD1=46.0

● RD1=48.0

Fig.4　Mask shape

Unit: 1 pixel

Fig.5　Estimation of GCP location

5.Application to an actual Landsat image in rural area

The algorithm presented in this study was applied to the actual Landsat image(Scene of Kanto plain of Japan on November,1986). The A-type data; just radiometrically calibrated, was used in this calculation. A farm pond (150 m x 150 m) was selected in rural area as a ground target.

The ground truth was undertaken on the same day of the Landsat flight and the condition of ground surface was studied and the homogeneity of ground surface was assured around that pond. And the subpixel image data of ground cover map was stored for the calculation. The size of a subpixel was 6m x 6m, which is one fifth of a pixel size. The average radiation brightness from two ground cover categories of ground target and around ground target were given 7.9 and 30.2 in CCT count of BAND 4, the standard deviations were respectly 1.2 and 4.6. And also, the CCT count of asphalt farm road surrounding the farm pond, another ground cover was estimated from 46 to 48 by the consideration of MTF, the width of the road(6m) and CCT count on the road. The PSF curve in (EQ.5) was used. The mask has an open type shape as shown in Figure 4, because of the difference between the scan direction on the upper part of the target and that on the lower part of the target.

The location of the lower left corner of the farm pond as a GCP was estimated as shown in Figure 5. So the position of the lower left corner can be considered to shift 0.2 pixel to the east and 0.2 pixel to the south to the location of the center of the GCP pixel as expected before, if the radiation brightness of asphalt farm road was 46.0 in CCT count and the effects of any other variation of factors were ignored, especially the effect of mask shape.

6.Conclusion

A new algorithm to determine the GCP location in a Landsat image to subpixel values was presented in this study. The effects of the image blur, noises, the variation of radiation brightness around a GCP and image rotation on the accuracy of the location were studied by simulation. As a result of the simulation, those factors did not affect so much on the accuracy of the GCP location. So this algorithm may improve the geometrical correction of Landsat image.

References
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