ORIENTATION THEORY FOR SATELLITE CCD LINE-SCANNER IMAGERIES OF MOUNTAINOUS TERRAINS

ATSUSHI OKAMOTO
SIN-ICHI AKAMATU
KYOTO UNIVERSITY KYOTO JAPAN

HIROYUKI HASEGAWA
PASCO CORPORATION TOKYO JAPAN

COMMISSION II

ABSTRACT

Satellite CCD line-scanner imageries of mountainous terrains are usually analyzed based on projective transformation. However, the attained accuracy may not be so high due to high correlations among the orientation unknowns. In order to overcome this difficulty, this paper presents a new approach of using ground point coordinates as the initial values in the iterative solutions, which are calculated by means of the method based on affine transformation (Okamoto, et al(1989,1991, 1992)). Tests with simulated examples clarified the effectiveness of the proposed orientation technique.

INTRODUCTION

Our first paper(Okamoto,et al(1992)) presents a general orientation theory of satellite CCD line-scanner imageries based on affine transformation, which can be very effectively applied for the case where the photographed terrain has rather small height differences. However, when the terrain is mountainous, this orientation theory is no more effective due to great image transformation errors caused by the height differences. In this paper a general orientation theory is first derived based on projective transformation. Then, in order to overcome the difficulty of this theory that very high correlations arise among the orientation parameters due to the facts that the satellite CCD line-scanner has a very narrow field angle and that height differences in the photographed terrain are rather small for the flying height of the platform, a new method is proposed that ground point coordinates calculated by means of the method using affine transformation are employed as the initial values in the iterative solutions of the orientation technique based on projective transformation.

BASIC CONSIDERATIONS

ORIENTATION THEORY OF LINE-IMAGES IN A PLANE

Let a line image be central-perspectively photographed in a plane as is demonstrated in Figure-1. The collinearity condition relating an object point P(Y,Z) and its measured image point $p_c(y_c)$ can be expressed in a following algebraic form (See Okamoto(1988))

$$y_c = \frac{A_1Y + A_2Z + A_3}{A_4Y + A_5Z + 1} \qquad (1)$$

in which A_i (i=1,···,5) are independent coefficients. Geometrically, these five orientation elements are considered to be a rotation parameter ω in the

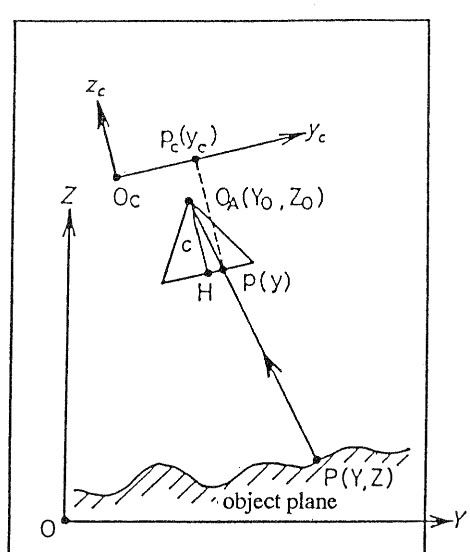


Figure-1 : central-perspective transformation of an object space into a line in a plane

plane, two translation parameters Y_0 and Z_0 which represent the projection center of the line-camera, and the two interior orientation parameters (the principal point coordinate y_H and the principal distance c). Thus, with five control points in the object plane (Y,Z), these five elements can be uniquely determined.

In considering the model construction and the one-to-one correspondence between the model and object planes, we must employ three overlapped line images as is shown in Figure-2. The general collinearity equations are

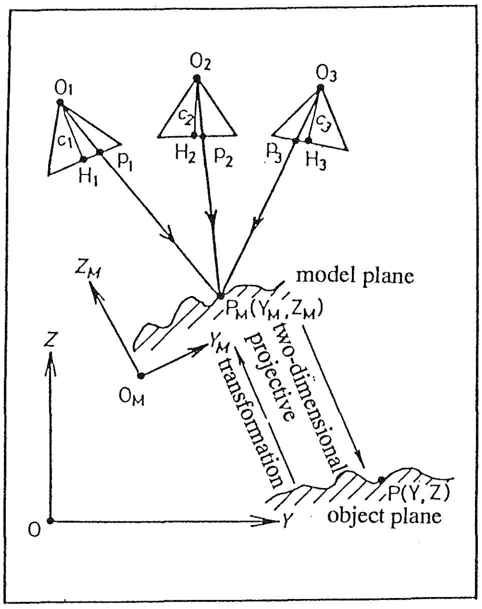


Figure-2 : relative and absolute orientation of three overlapped central-perspective line images

$$y_{c1} = \frac{A_{11}Y + A_{12}Z + A_{13}}{A_{14}Y + A_{15}Z + 1} \qquad (2)$$

for the first line image,

$$y_{c2} = \frac{A_{21}Y + A_{22}Z + A_{23}}{A_{24}Y + A_{25}Z + 1} \qquad (3)$$

for the second line image, and

$$y_{c3} = \frac{A_{31}Y + A_{32}Z + A_{33}}{A_{34}Y + A_{35}Z + 1} \qquad (4)$$

for the third one, respectively. Equations 2, 3, and 4 can also be expressed in the linear form with respect to the object space coordinates (Y,Z) as

$$\begin{aligned} (y_{c1}A_{14} - A_{11})Y + (y_{c1}A_{15} - A_{12})Z + y_{c1} - A_{13} = 0 \\ (y_{c2}A_{24} - A_{21})Y + (y_{c2}A_{25} - A_{22})Z + y_{c2} - A_{23} = 0 \\ (y_{c3}A_{34} - A_{31})Y + (y_{c3}A_{35} - A_{32})Z + y_{c3} - A_{33} = 0 \end{aligned} \qquad (5)$$

The condition that Equation 5 is satisfied for an arbitrary object point P(Y,Z) is derived the the following determinant form

$$\begin{vmatrix} y_{c1}A_{14}-A_{11} & y_{c1}A_{15}-A_{12} & y_{c1}-A_{13} \\ y_{c2}A_{24}-A_{21} & y_{c2}A_{25}-A_{22} & y_{c2}-A_{23} \\ y_{c3}A_{34}-A_{31} & y_{c3}A_{35}-A_{32} & y_{c3}-A_{33} \end{vmatrix} = 0 \qquad (6)$$

Under the condition of Equation 6 we can form a two-dimensional space (Y_M, Z_M) with the three overlapped line images, which can be transformed into the object plane by the projective transformation having eight independent coefficients, i.e.,

$$\begin{aligned} Y_M &= \frac{B_1Y + B_2Z + B_3}{B_7Y + B_8Z + 1} \\ Z_M &= \frac{B_4Y + B_5Z + B_6}{B_7Y + B_8Z + 1} \end{aligned} \qquad (7)$$

From the fact that the three line images have 15 independent orientation parameters, we can accordingly find the following characteristics of the orientation problem of overlapped line images in a plane:

1) Seven orientation parameters can be determined from the model construction condition (Equation 6), and
2) All the 15 orientation parameters of the three overlapped line images can be uniquely provided, if we set up the collinearity equations for seven object points including four control points.

THREE-DIMENSIONAL ANALYSIS OF CENTRAL-PERSPECTIVE LINE IMAGES

CCD line-scanner imageries are composed of many line images which are taken continuously from the traveling platform. Considering three overlapped imageries, the central projection for three line images is seldom generated on the same plane. In the usual case all points selected on one line image are recorded at the same instant, while the recording of the corresponding points on other overlapped line images are spread over a certain time period. Thus, the derived orientation theory seems to be of little practical use. However, through the following considerations we can find that the orientation theory presented is rigorously applicable for the analysis of practical line-scanner imageries. First, we will consider the relationship relating an object point P(X,Y,Z) and its measured image point $p_c(0,y_c)$ with respect to the three-dimensional reference coordinate system (See Figure-3.). This relationship can easily be found as a special case of the DLT (Abdel-Aziz and Karara (1971)) analysis of conventional photographs and has the form

$$\begin{aligned} 0 &= A_1X + A_2Y + A_3Z + A_4 \\ y_c &= \frac{A_5X + A_6Y + A_7Z + A_8}{A_9X + A_{10}Y + A_{11}Z + 1} \end{aligned} \qquad (8)$$

Substituting the first equation into the second one, we have

$$0 = X + D_1 Y + D_2 Z + D_3$$
$$y_c = \frac{D_4 Y + D_5 Z + D_6}{D_7 Y + D_8 Z + 1} \qquad (9)$$

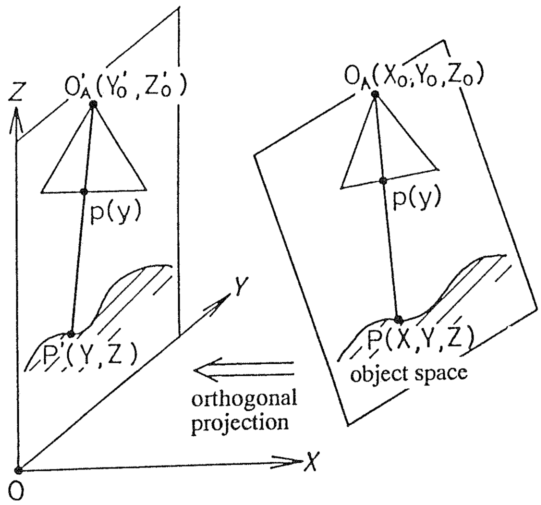


Figure-3 : three-dimensional analysis of central-perspective line images

The first equation in Equation 9 denotes the equation of the plane where the line-scanner image is central-perspectively taken of the object and the second equation indicates that a projective relationship is also satisfied between the line image and an image obtained by an orthogonal transformation of the object space into the Y-Z plane of the reference coordinate system (X,Y,Z). Further, the three-dimensional analysis of the line image can be carried out in two separate processes: the determination of the plane on which the line image was taken of the object and the orientation of the line image in the Y-Z plane, because we have no common coefficients in the first and second equations of Equation 9. Accordingly, the Y- and Z-coordinates of all object points can be determined by applying the orientation theory derived previously to overlapped satellite CCD line-scanner imageries, if changes of the orientation parameters along the flight paths are modeled adequately. The X-coordinate of the object points can be provided from the first equation of Equation 9 by utilizing the calculated Y- and Z-coordinates. In the practical analysis of satellite CCD line-scanner imageries these two equations are treated simultaneously.

TESTS WITH SIMULATION MODELS

In order to explore the characteristics of the proposed orientation method of satellite CCD line-scanner imageries, following two kinds of simulation models were constructed (See Figures-4 and 5.):

Simulation Model I
flying height of the satellite : H = 800 km
focal length of the scanner : c = 1000 mm
field angle of the scanner : α = 4deg.
pixel size : 13 × 13 micrometers
convergent angles : $\omega = \pm 30$ deg.
oblique angles : κ = 0deg.
maximum height difference
in the terrain : 3000 m

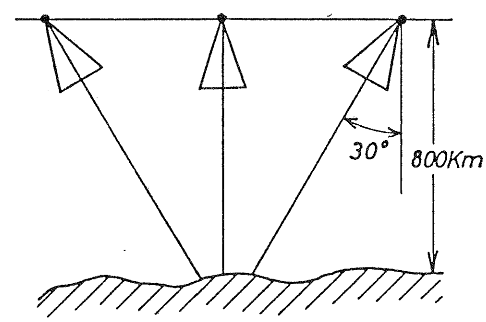


Figure-4 : three overlapped CCD line-scanner imageries taken from the three different flight paths of the satellite

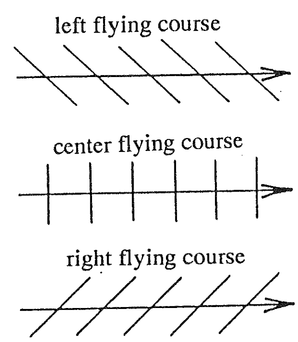


Figure-5 : three overlapped CCD line-scanner imageries taken oblique to the flight paths

number of object points : 65

Simulation Model II
flying height of the satellite : H = 800 km
focal length of the scanner : c = 1000 mm
field angle of the scanner : α = 4deg.
A pixel size : 13 × 13 micrometers
convergent angles : $\omega = \pm 30$ deg.
oblique angles : $\kappa = \pm 45$ deg.
maximum height differences
in the terrain : 2000 m, 4000 m
number of object points : 65

The image coordinates of the 65 object points were calculated by means of the collinearity equations. Then, the perturbed image coordinates were provided in which the perturbation consisted of random normal deviates having a standard deviation of 3.3 micrometers. In addition, maximum errors of the orientation parameters of the scanner along the flight path were assumed to be as follows : ±15 minutes regarding the rotation parameters (ω,φ,κ) and ±1.0 km regarding the translation parameters (X_0, Y_0, Z_0). The flying course (60 km) of the platform is divided into three sections and the exterior orientation parameters are assumed to vary linearly in each section (See Figure-6). Errors of the interior orientation elements are 1.0mm for the principal distance of the scanner and 0.5mm for the principal point coordinate.

The two simulation models were analyzed using the proposed orientation theory for different configurations of ground control points (See Figures 7a and 7b). The obtained results regarding the standard error of unit weight, the average external error of the approximations of the object point coordinates, which were calculated by means of the method using affine transformation, the average internal error at the check points, and the average external error were given in Tables-1 and 2. We can find in Tables-1 and 2 the following characteristics of the orientation problem of satellite CCD line-scanner imageries using projective transformation:

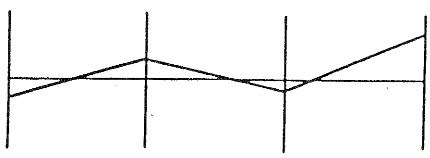
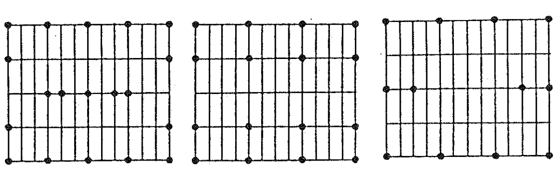
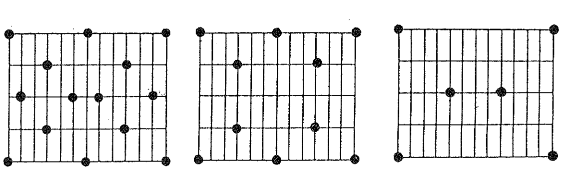


Figure-6 : changes of the orientation parameters along the flight path



A B C

Figure-7a : congigurations of control and check points in the analysis of satellite CCD line-scannerimageries taken normal to the flight paths



A B C

Figure-7b : congigurations of control and check points in the analysis of satellite CCD line-scanner imageries taken oblique to the flight paths

	A	B	C
$\hat{\sigma}_0$	3. 4 μm	3. 3 μm	3. 4 μm
$\hat{\sigma}_A$	1 3. 8 m	1 3. 8 m	2 2. 3 m
$\hat{\sigma}_I$	5. 1 m	5. 7 m	1 5. 3 m
$\hat{\sigma}_E$	3. 5 m	5. 0 m	1 2. 9 m

Table-1 : the obtained results for the analysis of satellite CCD line-scanner imageries taken normal to the flight paths of the satellite (the maximum height differnce in the terrain : 3,000 m)

$\hat{\sigma}_0$: the standard error of unit weight

$\hat{\sigma}_A$: the average external error at check points using affine transformation

$\hat{\sigma}_I$: the average internal error at check points using projective transformation

$\hat{\sigma}_E$: the average external error at check points using projective transformation

1) When the overlapped imageries are taken normal to the flight paths(Simulation Model I), the obtained accuracies are high only with many ground control points. If the number of ground control points is diminished, the internal and external errors increase rapidly.
2) In order to increase the connecting ability of adjacent models(Equation 6), the line-scanner imageries should be taken oblique to the flight path(Hofmann(1986)). In Simulation Model II the obtained external errors are small even with ten control points given.

CONCLUDING REMARKS

This paper has derived the general orientation theory using projective transformation for the

	A	B	C
$\hat{\sigma}_0$	3.3 μm	3.3 μm	3.4 μm
$\hat{\sigma}_A$	7.8 m	8.0 m	13.0 m
$\hat{\sigma}_I$	7.5 m	11.5 m	15.5 m
$\hat{\sigma}_E$	4.4 m	6.4 m	8.9 m

Table-2a : the obtained results for the analysis of satellite CCD line-scanner imageries taken oblique to the flight paths of the satellite (the maximum height differnce in the terrain : 2,000 m)

	A	B	C
$\hat{\sigma}_0$	3.4 μm	3.3 μm	3.4 μm
$\hat{\sigma}_A$	14.8 m	15.8 m	24.5 m
$\hat{\sigma}_I$	8.3 m	12.2 m	16.6 m
$\hat{\sigma}_E$.	4.8 m	8.6 m	16.3 m

Table-2a : the obtained results for the analysis of satellite CCD line-scanner imageries taken oblique to the flight paths of the satellite (the maximum height differnce in the terrain : 4,000 m)

three-dimensional analysis of satellite CCD line-scanner imageries and proposed an orientation technique of employing approximations of photographed ground point coordinates as the initial values in the iterative solutions, which were calculated by means of the orientation method based on affine transformation. Through the tests with simulated examples the proposed orientation method has proved to be very effective for the three-dimensional analysis of satellite CCD line-scanner imageries taken of mountainous terrains.

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