In-orbit Calibration Method Based on Empirical Model for Non-collinear TDI CCD Camera

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Abstract

An empirical model is proposed to solve the problem that exists in in-orbit calibration method for TDICCD camera in this paper. The method brings in the line frequency normalization and virtual image stitching from TDICCD images to the pre-processing procedure, which makes the virtual mosaic images has the same characteristics as the regular Linear push-broom CCD images, therefore the interior and external calibration is possible to realize. The experimental results show that the empirical model of TDICCD camera used in in-orbit calibration can improve precision and reduce the geometric distortion of images. Moreover, the geometric quality of images is enhanced. The method presented in this paper can be used to generate high-precision geometric rectification production.

Keywords: *TDICCD ; Internal Calibration ; External Calibration ; Empirical Model ; Geometric Accuracy*
.

1. Introduction

With the development of technique in high-resolution satellites, geometric positioning accuracy is much more concerned than ever. and is being one of the important assessment factor for satellites. According to the experiments, the main factors influencing the positioning accuracy of satellite images are showed as follow:（1） The precision of interior orientation ; （2） The precision of measured angle of camera， and (3)The precision of auxiliary data. Among which, the interior element affects geometric accuracy of the images, which leads to the position error presents in different sizes and orientations. And the overall geometric orientation precision are impacted by the remaining two factors. generally, camera's interior elements describes internal calibration, and the Camera mounting angle describes exterior elements. The interior and exterior calibration can be accomplished in both laboratory or in-orbit with control fields. As the strong momentum coursed by Satellite launching and disturbances during satellite operation, the elements will change. So, it's significant to use in-orbit calibration to guarantee satellite images with a stable geometric precision.

There are three types of internal calibration models for conventional push-broom linear array CCD cameras. Firstly, the physical parameters of the model has the trait that each coefficient has a clear physical meaning, while correlation between parameters lead to the normal equation morbid. Secondly, the self-calibration bundle adjustment with additional parameters. However, it's difficult to establish an adaptive mathematical model for additional parameter entries and find out stable solutions. Thirdly, the linear array internal orientation models illustrated with high-order polynomial. All these models have a common process for inversing the control point coordinates to images based on collinear equation model. As the TDICCD(Time Delay Integration Charge Couple Devices) camera's Line frequency changed over time, it's complex to convert the coordinates based on the collinear equation model. What's worse, iterations may not converge. Therefore, the current methods cann't directly used for In-orbit calibration of TDICCD camera.

Aiming at the problems exist in in-orbit calibration of TDICCD camera, we propose a new empirical model based approach .This paper can be divided into five parts. Part 1 is the introduction , Part 2 reviews the strict imaging model of TDICCD cameras. The third part is the in-orbit TDICCD camera calibration method , Part 4 will show the results of experiments, and finally the conclusion and future work.

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2.Strict Imaging Model of TDICCD Camera

Satellite CBERS1-02C was launched on December 22, 2011. It contains a high-resolution panchromatic camera with the resolution of 2.36m. Fig.1 shows the relative positions of three TDICCD in camera.

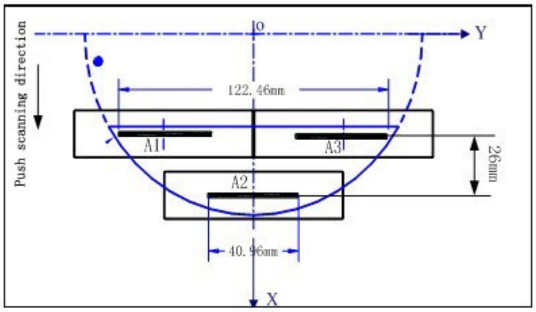

Fig.1 The three noncollinear TDICCD position on the focal plane of the camera

Compared with traditional CCD, the characteristics of TDICCD show as below:

1) It can adjust the integral series and line integration time (line frequency) in real-time, according to imaging areas and solar elevation angle at imaging time, to ensure the radiation quality of images.

2) During satellite operation, TDICCD can adjust the drift angle of the satellite platform in-time, to eliminate the motion blur of images. This makes the images have high clarity.

3) Shortcomings of TDICCD : the size of TDICCD is limited with the technology. In order to obtain larger image width, it can only be placed in non-collinear way. However, TDICCD placed in two rows cause the different image views of TDICCD and imaging time delay for the same surface features. These make geometric processing complicated. Fig.2 reflects this situation.

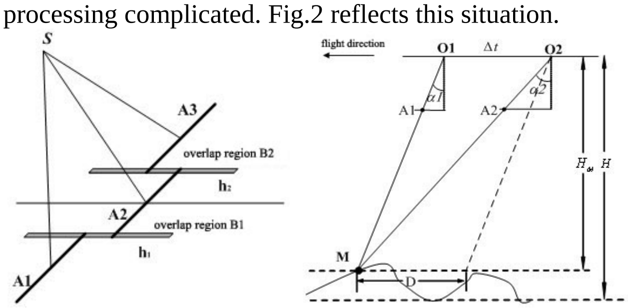

Fig.2 Imaging time delay with TDICCD placed in two rows of before and after

The stick imaging equation of each TDICCD has the following form.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{WGS84} = \begin{bmatrix} X_S \\ Y_S \\ Z_S \end{bmatrix}_{WGS84} + mR_T R_{GF} R_{FB} R_{BS} \begin{pmatrix} x_c \\ y_c \\ f \end{pmatrix} \tag{1}$$

Where, (x_C, y_C, f) are pixel coordinates in camera coordinate system, (X, Y, Z) are object coordinates of ground point in WGS84 geocentric cartesian coordinate system, (X_S, Y_S, Z_S) are object coordinates of satellite's center of mass in WGS84 geocentric cartesian coordinate system, m is the scale factor, R_{BS} is rotation matrix from camera coordinate system to satellite coordinate system with the origin at satellite center. R_{FB} is rotation matrix from satellite coordinate system to local orbital coordinate system. R_{GF} is rotation matrix from local orbital coordinate system to geocentric inertial cartesian coordinate system. R_T is rotation matrix from geocentric inertial cartesian coordinate system to WGS84 geocentric cartesian coordinate system.

And, R_{FB} and R_{GF} are determined by attitude and orbit measurement data. As attitude and orbit data is the temporal discrete points, it needs smoothing the data before processing. Then, fitting the data with polynomial or the Lagrange. Finally , calculating satellite's attitude and orbit at current imaging time with interpolating procession. The value of R_T is determined at imaging time and can be calculated by reference Standards of Fundamental Astronomy(SOFA).

3. In-orbit calibration method of TDICCD camera

3.1 Interior and external calibration

In the Eq.(1), the important factors which influence measurement precision of object coordinates obtained from images are auxiliary data error (such as like attitude error, the track error and time error), Camera installation angle error and the error of interior orientation. Within the camera's calibration is solving equations with using ground control points. In the process, the error from auxiliary data like R_{FB} , R_{GF} , R_T and (X_S, Y_S, Z_S) are processed as accidental error, at the same, the error from camera mounting angle and interior orientation that are contained in (x_C, y_C, f) and R_{BS} . External calibration is the process of calculating camera mounting angle or the rotate matrix R_{BS} , while interior calibration is to resolve

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elements of interior orientation. A strong correlation between elements of exterior and interior orientation of the various types of satellite imagery is found by studies. Thus, the problems like equation morbid may occur as the adjustment equations combined elements of interior and external orientation. Currently, a variety of solutions, like solving angle and line elements separately, merging strong-related items, ridge estimation method and using virtual observations to equations, are proposed for settling the problems of instable solution for normal equations as unknowns with strong dependencies.(Zhang Yongshen, etc., 2004) .In this paper, we adopt the method of solving parameters of exterior calibration and interior calibration stey by step.

3.2 Model of exterior calibration

Image geometric precision is consisted of the precision of interior orientation and exterior orientation. And, error of exterior orientation can be decomposed into the directions along the rail and vertical the rail. The positioning errors in the two directions corresponds to the error of camera mounting angle of φ_x,φ_y respectively. Though, the rotation matrix R_{BS} can be described with three angles, showed in Eq. (2), the error of exterior orientation will not be influenced by the rotation angle around the Z-axis. Therefore, External calibration only requires the solution of the error of φ_x,φ_y.

$$
\begin{aligned}
R_{BS} &= R_{\varphi_x} R_{\varphi_y} R_{\varphi_z} \\
&= \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\varphi_x) & -\sin(\varphi_x) \\ 0 & \sin(\varphi_x) & \cos(\varphi_x) \end{bmatrix} \begin{bmatrix} \cos(\varphi_y) & 0 & -\sin(\varphi_y) \\ 0 & 1 & 0 \\ \sin(\varphi_y) & 0 & \cos(\varphi_y) \end{bmatrix} \begin{bmatrix} \cos(\varphi_z) & -\sin(\varphi_z) & 0 \\ \sin(\varphi_z) & \cos(\varphi_z) & 0 \\ 0 & 0 & 1 \end{bmatrix}
\end{aligned} \quad (2)
$$

Assuming N control points have been known, the model can be written as,

$$
\begin{bmatrix} \bar{X} \\ \bar{Y} \\ \bar{Z} \end{bmatrix} = \frac{1}{m} R_{FB}{}^{-1} R_{GF}{}^{-1} R_T{}^{-1} \begin{bmatrix} X - Xs \\ Y - Ys \\ Z - Zs \end{bmatrix}
$$

The Eq. (1) can be converted into the following form,

$$
\begin{bmatrix} \bar{X} \\ \bar{Y} \\ \bar{Z} \end{bmatrix} = R_{BS} \begin{bmatrix} x_c \\ y_c \\ f \end{bmatrix} \quad (3)
$$

Taking the partial derivatives of φ_x,φ_y. The error equation for control points can be written as .

$$
\underset{3\times2}{A_i}\ \underset{2\times1}{Q} = \underset{3\times1}{L_i} \quad (4)
$$

Where,

$$
Q = \begin{bmatrix} d\varphi_x \\ d\varphi_y \end{bmatrix}, \quad A_i = \begin{bmatrix} \frac{\partial \bar{X}}{\partial \varphi_x} & \frac{\partial \bar{X}}{\partial \varphi_y} \\ \frac{\partial \bar{Y}}{\partial \varphi_x} & \frac{\partial \bar{Y}}{\partial \varphi_y} \\ \frac{\partial \bar{Z}}{\partial \varphi_x} & \frac{\partial \bar{Z}}{\partial \varphi_y} \end{bmatrix}
$$

$$
L_i = \begin{bmatrix} \bar{X} - \hat{\bar{X}} \\ \bar{Y} - \hat{\bar{Y}} \\ \bar{Z} - \hat{\bar{Z}} \end{bmatrix}, \quad \begin{bmatrix} \hat{\bar{X}} \\ \hat{\bar{Y}} \\ \hat{\bar{Z}} \end{bmatrix} = R_{BS} \begin{bmatrix} x_c \\ y_c \\ f \end{bmatrix}
$$

,

The coefficient matrix of normal equation can be obtained from Eq.(5).

$$
A^T A = \sum_{i=1}^{N} A_i{}^T A_i \qquad A^T L = \sum_{i=1}^{N} A_i{}^T L_i \quad (5)
$$

Solving the equations according to Eq. (6),

$$
Q = (A^T A)^{-1} (A^T L) \quad (6)
$$

$d\varphi_x, d\varphi_y$ are the corrections for φ_x,φ_y, and we get it from vector of Q.

Then, plusing $d\varphi_x, d\varphi_y$ to φ_x,φ_y. And, bringing the new value into list error equations, normalized and resolve equation, keeping on iterations until $d\varphi_x, d\varphi_y$ are less than given thresholds or iterative times reach a certain number .

3.3 In-orbit calibration method based on an empirical model for non-collinear TDI CCD camera

As known before, TDICCD in this satellite has the particularities of the change in line integral time and arranged non-collinear, we discuss two step preprocess of line frequency normalization processing and virtual image

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stitching for imageries at this situation. Line frequency normalization processing is that resampling the images as along rail direction. After it , each row of images has the same line integral time. That is to say, the difference of imaging line number for the corresponding point presented on three TDICCD imageries in the along-track direction is a constant. Consequently, in region of larger relief, the error of line number for the corresponding points is no more than 1 pixel. It's the base for stitching the imageries from the three TDICCD to virtual imagery. For mosaic images, the first step is to re-project the image from the center TDICCD to the imaging plane of the other two TDICCD. Thus, a complete line image is forming. Fig.3 shows describe the procedure.

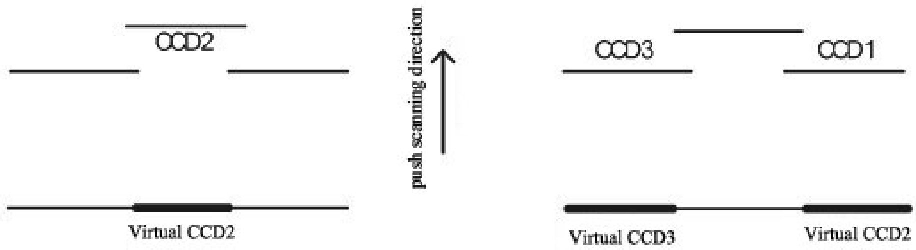

Fig.3 Virtual linear array image

The main point of this in-orbit calibration method is that it puts the two pretreatment methods into pre-processing process of the regular HR camera image. Thus, there exists no difference between the ordinary linear array push-broom CCD image and the virtual TDICCD image after image stitching. The virtual images can not only satisfy the imaging equation of Eq. (1) strictly, but also solving the exterior orientation elements with ground control points corresponding to the virtual image. What's more, rational polynomial model coefficients, which is equivalent to strict imaging model can be obtained with virtual linear array image , thus makes it possible to select ground control points using remote sensing image processing software (e.g. ERDAS) .
Assuming that there are N ground control points selected from the virtual linear array image by ERDAS software, and in accordance with part 3.2 of the external calibration, the formula (1) can be converted into the following forms:

$$\begin{bmatrix} x_c \\ y_c \\ f \end{bmatrix} = \frac{1}{m}(R_T R_{GF} R_{FB} R_{BS})^{-1} \begin{bmatrix} X - X_s \\ Y - Y_s \\ Z - Z_s \end{bmatrix} \qquad (7)$$

The internal calibration model for the normalized cubic polynomial is showed as following.

$$\frac{x_c}{f} = a_0 + a_1 \times s + a_2 \times s^2 + a_3 \times s^3$$
$$\frac{y_c}{f} = b_0 + b_1 \times s + b_2 \times s^2 + b_3 \times s^3 \qquad (8)$$

Where,

S is the number of unit on the virtual image; $\frac{x_c}{f}, \frac{y_c}{f}$ are the calculated from Eq.(7) according to control points. $a_0, a_1, a_2, a_3, b_0, b_1, b_2, b_3$ are coefficients for interior alibration, which are unknowns and composed with translation of sensor linear array relative to the camera main point, the size of CCD units, the tilt of CCD lines and lens' non-linear distortion. Then, the directions of each CCD unit in camera coordination can be computed in account of these coefficients. The initial value of the coefficients is given according to the design of the camera's factory or laboratory calibration results.

It's remarkable that, $\begin{bmatrix} x_c \\ y_c \\ f \end{bmatrix}$ presented the direction in a three dimension space in Eq. (1) is a vector, and the length of it is not a constant. $\begin{bmatrix} x_c \\ y_c \\ f \end{bmatrix}$ required by the ray of light intersecting on WGS84 reference ellipsoid. It needs to transform $\begin{bmatrix} x_c \\ y_c \\ f \end{bmatrix}$ to $\begin{bmatrix} \frac{x_c}{f} & \frac{y_c}{f} & 1 \end{bmatrix}^T$ when submitting $\frac{x_c}{f}, \frac{y_c}{f}$ obtained from interior calibration into Eq. (1).

4. Experiments

The experimental images of this article is from HR camera on CBERS1-02C Satellite, and reference data of field control points, high-precision aerial ortho photo and DEM are from the ground calibration field in Songshan, China.

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It shows the distribution of experimental imageries and control points in Fig.4.

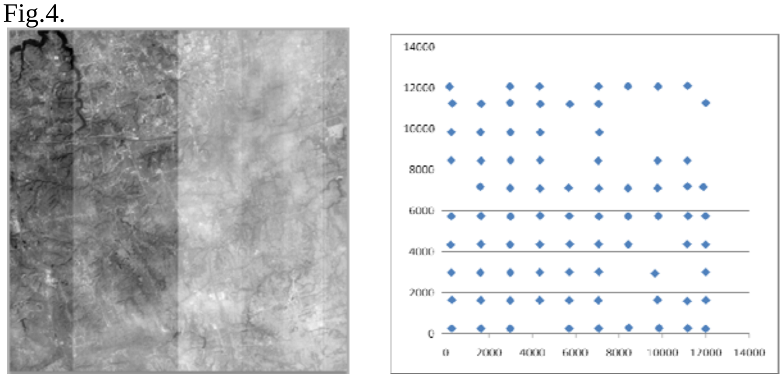


Fig. 4 The distribution of experimental imageries and control points.

Experimental steps are as follows.

1) Normalizing line frequency of images.

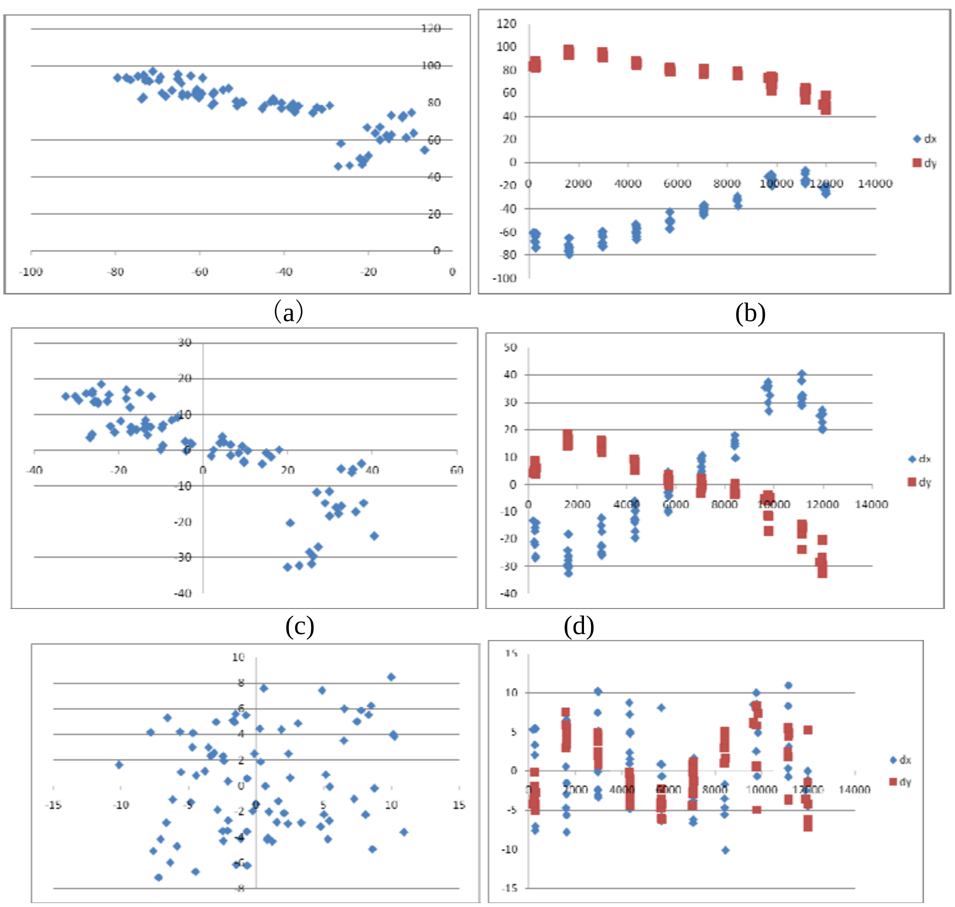
2) Stitching images to form a whole virtual image.

3) Choosing field control points and calculating the error of them.

4) Recomputing the error of field control points after external calibration.

5) Recomputing the error of field control points after interior calibration.

Fig.5 shows the results.



(a) (b)

(c) (d)

(e) (f)

Fig.5 (a), (c), (e) present the error distribution of control points. with horizontal axis representing the error perpendicular to the rail direction and vertical axis for error along the rail direction. Figure (b), (d),(f) shows trends of the error of control points in the two directions as the change of the virtual image row number. The error presented in figure (a) and (b) is calculated without calibration process. The error displayed in figure (c), (d) is obtained after external calibration. And the error shown in (e) ,(f) is required after both external and interior calibration.

Table1: The change of control point error before and after the scaling process (unit:pixel)

		Vertical the rail direction	Along the rail direction
Initial error	Mean	-47	+79
	Standard deviation	22	13
Error after external calibration	Mean	0	0
	Standard deviation	22	13
Error after external and interior calibration	Mean	0	0
	Standard deviation	5	4

5. Conclusion

In consideration of image feature of satellite CBERS1-02C, this article proposed a new calibration method based on non-linear TDICCD with an empirical model. The distinguishing feature of this method is to combine the line frequency normalization to virtual images stitching from three TDICCD images in pre-processing step. Thus, the mosaic image has the same characteristics with the common imageries from linear push-broom CCD It’s the key of this article to realize interior and external calibration.
According to the experiment, this in-orbit calibration method based on an empirical model for non-collinear TDI CCD camera can not only improve the precision of exterior orientation, but also lower the geometric distortion of images. It’s possible to generate high-resolution geometric rectification production directly with this method.
However, as the reasons that the precision of satellite attitude measurement is not high and the intensity of attitude measurement point is not dense enough, resulting in the drift angle error of the satellite platform and leads to the number of overlapping pixels from two adjacent TDICCD images changes. and the elements of interior orientation of the virtual image are unstable.
How to obtain the drift angle by the number of overlapping pixels of two adjacent TDICCD images accurately, is the problem we need to solve in further study.

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References

[1]J. Grodecki, G Dial, J Lutes. Mathematical model for 3D f eature extraction from multiple satellite images described by RPCs. ASPRS Annual Conference Proceedings,2004
[2]J.Grodecki.IKONOS stereo feature extraction-RPC appro ach.Proc. ASPRS Annual Conference, St. Louis, 2001
[3]C.Yu,M.L.J Apuzzo,C.S Zee,Z Petrovich.Instrumentation Assessments-A Phantom Study Of The Geometric Accuracy of Computed Tomographic and Magnetic Resonance Imagin g Stereotactic. Neurosurgery,2001
[4]C .V. Tao, Y. Hu. 3D reconstruction methods based on the rational function model. Photogrammetric Engineering and Remote Sensing, 2002
[5]C. V. Tao, Y Hu .The rational function model-A tool for p rocessing high-resolution imagery. Earth Observation Magaz ine, 2001
[6]J． Höhle. Photogrammetric measurements in oblique aer ial images. Photogrammetrie, Fernerkundung, Geoinformatio n, 2008
[7]G. Dial, J. Grodecki .IKONOS accuracy without ground c ontrol. Proceedings of ASPRS Comission1 mid-term,2002
[8]Y. Oh, K. Sarabandi, F.T Ulaby .An empirical model and an inversion technique for radar scattering from bare soil surf aces. Geoscience and Remote,1992

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