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Stitching images of dual-cameras onboard satellite

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ABSTRACT

The way of installing dual-cameras on one satellite is adopted to further enlarge the imaging swath, thereby improving the efficiency of data capturing. In this case, stitching images of dual-cameras with high precision is a key step in the practical application. Due to the inadequate overlapping area of dual-cameras, stitching their images by classic methods may cause internal accuracy loss of the mosaic image. The reason is that classic methods estimate the geometric transformation of dual-cameras merely by a few unevenly distributed precise tie points in overlapping area of dual-cameras, which is similar to the case of using unevenly distributed ground control points (GCPs) in block adjustment. This paper proposed a new method to precisely stitch images of dual cameras without losing internal accuracy. First, a model was built to recover the relative geometric relation of dual-cameras and eliminate Charge-Coupled Device (CCD) distortions of each camera, then a virtual camera model depending on the calibrated geometric relation was adopted to achieve a seamless mosaic image. The panchromatic images of camera A and camera B onboard Yaogan-24 were collected as the experimental data. Experiment results show that the calibration accuracies of dual-cameras are better than 0.3 pixels, and the stitching accuracies can reach the sub-pixel level, ranging from 0.3 to 0.5 pixels. On the other hand, the positioning accuracies with GCPs of the mosaic image and of individual camera are better than 0.6 pixels and 0.5 pixels respectively, so the internal accuracy loss of the mosaic image only reaches 0.1 pixels, which can be neglected. This demonstrates that the proposed method can achieve seamless mosaic images without losing internal accuracy.

1. Introduction

Optical Satellites play an important role in the acquisition of Geo-spatial information, as they can conduct continuous and periodic earth observation with low cost. To improve the efficiency of data capturing by enlarging swath, multi-chip CCDs are widely used for high-resolution optical satellites. Information of the CCD butting system of several high resolution optical satellites is listed in Table 1 (Aguilar et al., 2014; Baltsavias et al., 2005; Gene et al., 2003; Jacobsen, 2007; Kubik et al., 2012; Latry and Delvit, 2009; Li, 2012; Liedtke, 2002; Panem et al., 2012).

In addition to multi-chip CCDs, dual-cameras onboard one satellite can further enlarge the imaging swath, which is adopted by the Yaogan-24 remote sensing satellite. The Yaogan-24 satellite was launched on November 20, 2014, and it is in a 645-km sun-synchronous orbit (Wang et al., 2016) and mainly used to conduct scientific experiment, carry out surveys on land resources, estimate crops yield and help with natural disaster-reduction and prevention endeavor (China News Service, 2014). Two cameras named camera A and camera B both with ground sampling distance (GSD) of 1.0 m were symmetrically installed onboard Yaogan-24 satellite perpendicular to the flight direction and each camera contains four CCDs. Although this way doubles the field of view, stitching images of dual-cameras with high precision emerges as a difficulty in the application.

Traditional image stitching methods have been studied by many researchers and can be generally grouped into the image-space-oriented and the object-space-oriented methods (Tang

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Table 1
Information of the CCD butting system.

Satellite	Launch year	Number of PAN CCDs(piece)	Imaging Swath (km)
IKONOS	1999	9	11.3
Quickbird-2	2001	6	16.5
ALOS	2006	6	35
WorldView-1	2007	50	17.
WorldView-2	2009	60	14.5
Pleiades-1A/1B	2011/2012	5	20
ZY3-01	2012	3 (N&M)/4 (F&B)	52

*N, B and F denote the nadir-view camera, the backward-view camera and the forward-view camera respectively; M denotes the multispectral camera.

et al., 2014). The latter aims to establish the mapping relation between the mosaic image and the original images by rigorous geometric models, then resample the original images for stitching. Zhang et al. (2012), Pan et al. (2013) and Tang et al. (2013) stitched multi-CCD images based on the mapping relation between geometric models of the virtual CCD and real CCDs, and acquired seamless mosaic images of multi-chip CCDs for both ALOS and Ziyuan-3, finally. However, these methods only considered the characters of multi-chip CCDs within one camera and mainly addressed stitching multi-CCD images of individual camera, so they are not applicable for dual-cameras onboard one satellite. While, the image-space-oriented methods directly model the mapping relation between the mosaic image and original images with simple geometric transformation (such as the affine transformation) based on tie points extracted from overlaps. This kind of methods have been adopted for image stitching in many studies (Adel et al., 2015; Brown and Lowe, 2006; Li et al., 2009; Lu and He, 2012). However, the stitching accuracies acquired by these methods are limited to the extraction accuracies of tie points, and overlapping areas between dual-cameras with scanty image texture (such as waters) can result in poor stitching accuracies. In addition, as shown in Fig. 1, the overlapping area between images of dual-cameras onboard Yaogan-24 is too small, which may result in internal accuracy loss of the mosaic image when use the image-space-oriented methods for stitching, it's because the methods estimate the transformation merely by a few precise tie points distributed unevenly, which is similar to the case of using unevenly distributed ground control points (GCPs) in block adjustment. Concerning defects in traditional methods, the stitching method with higher precision for dual-cameras should be further studied.

A novel method is proposed for stitching images of dual-cameras onboard one satellite in this paper. First, a relative calibration model has been built for recovering the relative geometric relation of dual-cameras onboard one satellite and eliminating CCD distortions of each camera, then the seamless mosaic image can be acquired based on the mapping relation between geometric models of virtual camera and dual-cameras. Its superiority over traditional image stitching methods is that the stitching accuracy acquired by the proposed method is no longer constrained to the extraction accuracies of tie points, because tie point isn't needed for stitching images after relative calibration of dual-cameras. As a consequence, seamless mosaic image without loss of internal accuracy can be achieved even in the case that the overlapping area between dual-cameras is inadequate and the image texture of overlapped area is scanty. The experiment results also prove that the proposed method can achieve seamless mosaic images without losing internal accuracy.

2. Methodology

2.1. Relative calibration of dual-cameras

Conventional geometric calibration methods compensate for systematic errors of isolated individual camera without consideration of the relative geometric relation between multi cameras onboard one satellite (Breton et al., 2002; Furukawa et al., 2008; Osawa, 2004; Tadono et al., 2009). To recover the relative geometric relation of dual-cameras onboard one satellite, the common errors of dual-cameras and the specific errors of each camera should be distinguished, based on which a relative calibration model can be established (Jiang et al., 2014a; Poli and Toutin, 2012; Radhadevi et al., 2011;Tang et al., 2013; Zhang et al., 2014).

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{WGS84} = \begin{bmatrix} X_s \\ Y_s \\ Z_s \end{bmatrix}_{WGS84} + mR_{J2000}^{WGS84} R_{body}^{J2000} R_{cam}^{body} \begin{bmatrix} x - x_0 - \Delta x \\ y - y_0 - \Delta y \\ f \end{bmatrix} \quad (1)$$

Eq. (1) shows the rigorous geometric model of linear array push-broom sensors, where $(X \quad Y \quad Z)^T_{WGS84}$ is the object position vector in the geocentric earth-fixed coordinate system and $(X_s \quad Y_s \quad Z_s)^T_{WGS84}$ is the position of the satellite with respect to the geocentric earth-fixed coordinate system. Furthermore, m denotes the scaling factor, R_{cam}^{body} denotes the rotation matrix for converting the sensor coordinate system to the satellite body coordinate system, which were determined before launch. R_{body}^{J2000} is

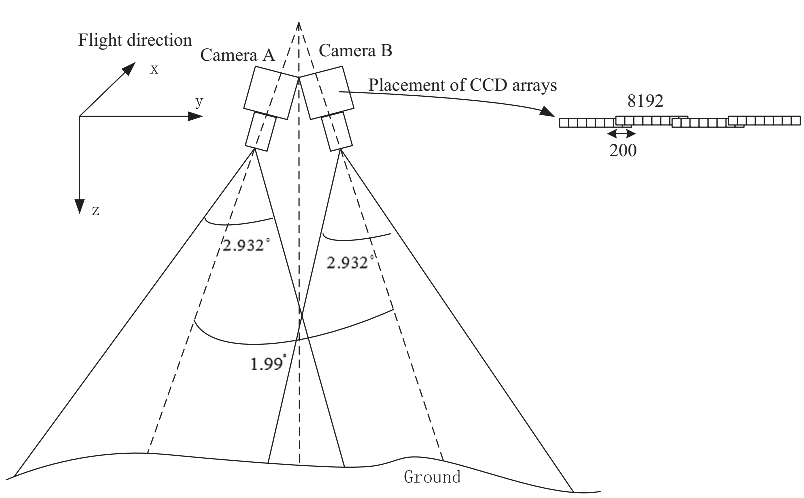

Fig. 1. Diagram of Dual-Cameras (A/B) onboard Yaogan-24.