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Combined rigorous-generic direct orthorectification procedure for IRS-p6 sensors

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ABSTRACT

The accessibility of global data, such as the digital elevation model (DEM), and the development of global visualisations allow promising new methods for minimising the distortion in the online generation of rough orthorectified products to be developed. Direct georeferencing (DG) has attracted a considerable amount of attention in the applications of pushbroom raw images in orthorectification or mono-plotting using ancillary satellite data. This study builds on recent DG studies to achieve an "orthoimage" from raw data and to determine potential mapping errors due to the DG procedure. Thus, this paper focuses on establishing a simple method for mitigating the misalignments of space-borne imageries to be used in direct orthorectification. Towards this goal, instead of image resectioning, affine transformation in different coordinate systems is employed in the orthorectification algorithm to compensate for the systematic DG errors. For a given point, the elevation corresponding to the obtained planimetric coordinate is extracted using available topographic maps and global DEMs, such as SRTM's and ASTER's DEMs. As a result, parameters no longer need to be updated, as in the conventional orthophoto generation methods. To evaluate the proposed procedures, experiments were conducted over three different IRS-p6 sensors in five datasets with different swath widths and tilt angles. The obtained results also demonstrate that the geographic coordinate system and a simple 2D affine transformation can efficiently correct misalignments.

1. Introduction

In a typical imaging system, an actual 3D object is projected onto a 2D image plane after passing through a camera/sensor. The mathematical model linking the 3D object coordinates to the 2D image coordinates is known as the physical camera model. The reconstruction of the camera model or viewing geometry includes the exterior and interior orientations of the sensor. The exterior orientation (EO) describes the location of the projection centre and attitude of the bundle of rays, whereas the geometry of the bundle of rays is reconstructed by the measured image positions and interior orientation (IO). Linear array satellite images, referred to as "pushbroom images", have a set of the EO parameters for each image line, and the IO is restricted to this line. Thus, for a given satellite image sensor, the reconstruction of the imaging geometry involves a combination of the IO and EO (Radhadevi and Solanki, 2008; Tighe et al., 2009).

The DG methods utilise ancillary data to retrieve the physical geometry of the imagery. The sensor's EO parameters can be obtained from the physical parameters of the orbit through the Keplerian elements (Gugan and Dowman, 1988; Valadan Zoej and Foomani, 1999) or state vectors, where the position, velocity and attitude values for a particular time are contained in the ancillary data. This method was proposed by Toutin (2004), implemented in the PCI Geomatica software and has also been recently evaluated in the literature (Poli, 2001, 2005).

Theoretically, in this approach, which is referred to as the "rigorous camera model", the DG procedure does not require any ground control points (GCPs) or additional processes. Thus, the effectiveness and reliability of this method depends on the accuracy of the internal and external orientation data. In other words, the results may not be satisfactory if the interior orientation parameters, which are given by the pre-flight laboratory calibration and the exterior orientation measurements are inaccurate. If those data are available at a very high accuracy, the values of the misalignments and the shifts between the positioning and imaging instruments must be considered. Thus, multiple GCPs are needed for these bias and shift corrections (Poli, 2005).

In contrast to the camera model, a popular alternative is the rational polynomial coefficients (RPC) model, which is used by

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IKONOS and other high-resolution satellite systems (Grodecki and Dial, 2002; Tao and Hu, 2001). Both the rigorous camera and RPC models, which are solely produced from the data received by on-board GPS receivers, gyros and star trackers, inherit systematic biases in the attitude determination. Consequently, in-flight calibration and extended RPC bundle adjustment are used in the rigorous camera and RPC methods, respectively, to model these effects and to compensate for the existing biases (Grodecki and Dial, 2002). To enable the bias correction in both methods, GCPs provided in a conventional coordinate system, and the corresponding image coordinate measurements are required.

Connecting the image and the 3D ground model is one of the main tasks in photogrammetry, whereby concepts such as "orthorectification" and "monoplotting" are defined. Monoplotting is a technique for extracting 3D spatial information from a single image with an available DEM (Huang and Kwoh, 2008), and orthorectification is the process of correcting raw imagery for relief displacement and sensor collection parameters. The result of these processes is an accurate photo-map that can be used in GIS and other mapping applications (Tighe et al., 2009). Leprince proposed a procedure for accurately measuring the ground deformations from optical satellite images, in which DG was used as a part of an optimised model of the imaging system for the "precise orthorectification" of SPOT imagery (Leprince et al., 2007). In that study, looking directions were linearly corrected to compensate for attitude drifts and sensor orientation uncertainties using a few GCPs. The authors assert that their method is compatible with any pushbroom sensor. Another study (Jyothi et al., 2008) investigated the requirement of inclusion of a global DEM (GTOPO30 or SRTM) in the product generation system for Liss-4 data from IRS-p6. In that study, the authors determined the adequacy of GTOPO30 for improving the accuracy of the DG to achieve the orthorectified product. Similar to previous studies, the GCPs were used to update the initial trajectory obtained from the ancillary data. In recent studies (at the time of the preparation of this manuscript) the GCP selection has been the only manual part of the direct orthorectification that is not completely automated.

This paper determines potential sources of error resulting from the DG procedure and investigates their mapping effects to overcome misalignment and registration issues. These remaining errors and their mapping effects motivate us to focus on establishing a simple method for mitigating the misalignments caused by the DG and thus utilising an available DEM for direct orthorectification. Having DG of the data using the conventional method in three coordinate systems (the Geodetic, Geocentric and orthographic tangential coordinate systems), depending on the coordinate systems used, 2D and 3D affine transformations are performed using a minimum number of GCPs to mitigate the DG's misalignments. For a given point, the elevation corresponding to the obtained planimetric coordinate is then extracted from the available global DEMs, such as SRTM's and ASTER's DEMs. As a result, parameters no longer need to be updated, as in the conventional orthophoto generation methods. To evaluate the proposed procedures, the developed method was compared with the parameter-updating method by implementing both methods over the satellite images under different geometric conditions. Furthermore, the use of Google Earth as a global data source is experimentally investigated. The results of this study should encourage the owners and vendors of imaging satellite systems with average technology to promote their products towards "online orthorectification".

The organisation of this paper is as follows. The conventional direct orthorectification procedure is elaborated in Section 2, and then an overall discussion regarding potential DG errors and the proposed orthorectification method are presented in Section 3. An examination of the proposed algorithm over five IRS-p6 images is provided in Section 4, and the conclusions and recommendations are presented in Section 5.

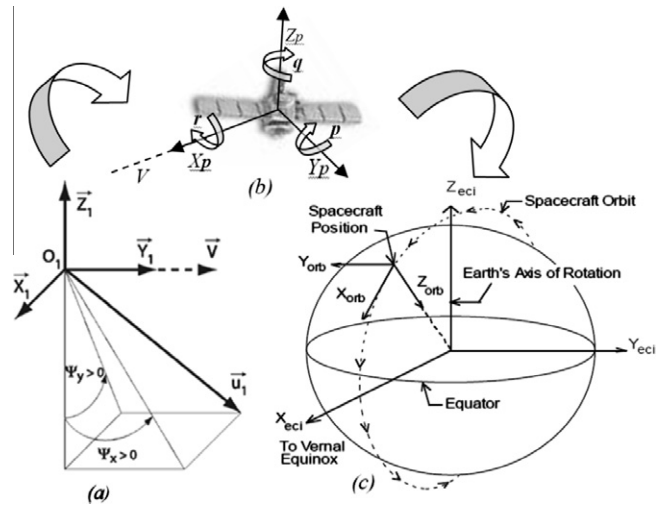

Fig. 1. Coordinate systems: (a) camera (SPOT-image, 2002), (b) platform and (c) orbit (Nishihama et al., 1997).

2. Conventional direct orthorectification procedure

The DG procedure of linear array images has been discussed by Poli (Poli, 2001, 2005) and Radhadevi (Radhadevi and Solanki, 2008). The position $[X, Y, Z]^T$ and velocity $[V_X, V_Y, V_Z]^T$ vectors of the satellite that are included in the ancillary data are used to calculate the orientation of the orbital system with respect to the Earth-Centred Inertial (ECI) and Earth-Centred Reference (ECR) systems. Because the ECI system is an inertial system, it does not rotate and is fixed with respect to the celestial frame. In contrast, the ECR or CT[1] system is fixed with respect to the Earth frame and is synchronised with the Earth's rotation. The transformation between the ECI (or CT) and ECR frames is the following rotation around the Z-axis, $R_Z(\theta)$, where θ is referred to as the sidereal angle:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{CT} = R_Z(\theta) \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{ECI} \quad \text{and} \quad \begin{bmatrix} V_X \\ V_Y \\ V_Z \end{bmatrix}_{CT} = R_Z(\theta) \begin{bmatrix} V_X \\ V_Y \\ V_Z \end{bmatrix}_{ECI} \tag{1}$$

According to Fig. 1c, the navigation of the satellite can be defined by the orbital coordinate system (Orb), in which its origin is at the platform centre of mass with the Z-axis pointing from the spacecraft's centre of mass to the Earth's centre of mass. The X-axis is oriented towards the instantaneous velocity vector, and the Y-axis is the cross product of the Z- and X-axes. The rotation matrix from the Orb system to the CT system, R_{Orb}^{CT}, is calculated as

$$R_{Orb}^{CT} = [r_\omega | r_\varphi | r_\kappa] \tag{2}$$

The position and velocity vectors of the satellite in the CT system are P_{CT} and V_{CT}, respectively, and the rotation vectors around the three axes, r_ω, r_φ, r_κ are calculated with the cross products of the vectors X_{CT} and V_{CT} as follows:

$$r_\kappa = -\frac{P_{CT}}{\|P_{CT}\|} \quad r_\varphi = \frac{r_\kappa \times V_{CT}}{\|r_\kappa \times V_{CT}\|} \quad r_\omega = r_\varphi \times r_\kappa \tag{3}$$

Inside of the spacecraft, the following two coordinate systems are also defined: (i) the Platform (P) coordinate system (Fig. 1b), which is concentric with the Orb system (Fig. 1c) and the transformation parameters of which are measured by the attitude sensors;

[1] Conventional Terrestrial.