IN-FLIGHT GEOMETRICAL CALIBRATION FOR FORMOSAT-5 PANCHROMATIC AND MULTISPECTRAL SATELLITE IMAGES

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ABSTRACT: The remote sensing instrument (RSI) of Formosat-5 provides a panchromatic band with 2m ground sampling resolution (GSD and four multispectral bands with 4m GSD at nadir-view. As the linear arrays for panchromatic and multispectral bands are located at different locations in the focal plane, the aim of geometrical calibration for panchromatic and multispectral bands is to determine the relative transformation between different bands based on interior orientation parameters (IOP). The IOP includes a set of polynomial coefficients to determine the pointing direction for each pixel in the camera frame. These IOPs should be determined in laboratory status before satellite launching and in-flight status after launch. This study proposed an in-flight geometrical calibration procedure for Formosat-5 satellite images. The proposed methods include two major steps. The first step applies phase correlation matching to calculate the x-parallax and y-parallax for each pixel between panchromatic and multispectral bands. The parallaxes larger than 3-sigma are removed to preserve the robustness of coefficient determination. The second step utilizes a series of transformations to calculate the actual per pixel displacements in the focal plane. All the selected displacements in the focal plane are applied to calculate the polynomial coefficients of IOPs via lease squares adjustment. The experiment uses 122 pairs of Formosat-5 panchromatic and multispectral images which were acquired from Jan. 22 to Jan. 30, 2019. These images were used to analyze the band shift behaviors and determine the IOPs. The experimental results indicated that the mean parallaxes from pre-launch IOPs were larger than 2 pixels. Moreover, the calibrated IOPs achieved pixel-level accuracy (i.e. mean parallaxes) while the view-angle is less than 30 degrees. In summary, the proposed scheme demonstrated a procedure for in-flight geometrical calibration and showed improvement when compared to pre-launch parameters.

1. INTRODUCTION

Formosat-5 is an Earth Resources Satellite developed by National Space Organization of Taiwan. The CMOS-type Remote Sensing Instrument (RSI) of Formosat-5 provides both panchromatic (PAN) and multispectral (MS) images in 2m and 4m ground sampling distance (GSD), respectively. Table 1 shows the parameters of Formosat-5 RSI Instrument. As the linear arrays for PAN and MS are located at different locations in the focal plane, a band-to-band geometrical calibration process is needed to improve the geometrical consistency between PAN and MS images. It is an essential pre-processing for image fusion (e.g., pansharpening) (Teo and Fu, 2018).

The geometrical calibration is to determine the systematical interior orientation parameters (IOPs) while the geometrical correction is to determine the exterior orientation parameters (EOPs). All the satellite images in a certain period shared the same IOPs. These IOPs have to be determined using laboratory method before launching and calibrated during the in-flight stage within a specified period (Chang et al., 2018). This study aims to perform in-flight geometric calibration and the geometric calibration focuses on the band-to-band registration between panchromatic and multispectral images for Formosat-5 satellite.

Table 1. Specification of Formosat-5 RSI Instrument (NSPO, 2019; Spaceflight101, 2019)

Items	Specification
Spatial resolution	2m (Pan); 4m (MS)
Spectral resolution	Panchromatic (450-700nm) MS: Blue (455-515nm); Green (525-595nm); Red (630-690nm); Near-infrared (762-898nm)
Radiometric resolution	12 bits
Detector type	CMOS array, Pan: 12,000 pixels, MS: 6000 pixels

2. METHODOLOGY

The proposed scheme includes two steps. The first step performs image matching between panchromatic and multispectral images. The tie points are used to calculate the displacement in image space and then transform to parallax in the focal plane. The second step refines the IOPs for multispectral images using least-squares adjustment. Figure 1 shows the procedures of in-flight geometrical calibration.

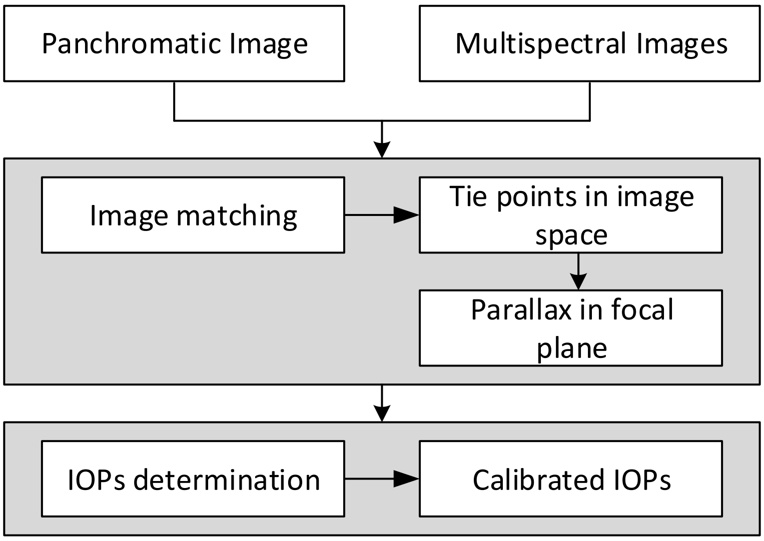

Figure 1. Workflow of in-flight geometrical calibration

2.1 Image Matching and Image Transformation

Image matching is to determine the tie point between PAN and MS images. In this study, the master image is PAN image and the slave image are MS images. Therefore, the geometric calibration is to transform the MS images into PAN image using IOPs. As the PAN and MS images were taken in the same mission with high radiometric consistency, this study adopts the phase-correlation matching (Stone et al., 2001) to determine the shifting between PAN and MS images. In the master image, every 256 x 256 pixels perform a phase-correlation matching together with slave image. Finally, a large number of tie points (i.e., $Sample_{PAN}$, $Line_{PAN}$, $Sample_{MS}$, $Line_{MS}$) can be obtained after image matching.

The tie points indicate the displacement between PAN and MS images in image space. However, the geometrical calibration has to be performed in the focal plane. This study simply converts the displacement (i.e. $Delta_{Sample}$, $Delta_{Line}$) in image space to displacement in the focal plane (i.e. $Delta_x$, $Delta_y$) using the focal length, pixel size and original IOPs.

2.2 IOPs (Interior Orientation Parameters) Determination

Due to the narrow field-of-view of Formosat-5, a 3-order polynomial function (Equation 1) (Wang et al., 2014) is adopted to describe the location of detector in the focal plane. The previous step obtains displacements in the focal plane. The calibration is to determine a set of IOPs (i.e. $\Psi_{x0} \sim \Psi_{y3}$) which may improve the geometric consistency between PAN and MS images. The displacement in the focal plane (i.e. $Delta_x$, $Delta_y$) is converted to detectors' directional angles (i.e. Ψx(p) and Ψy(p)) using arctangent (see Figure 2). A least-squares adjustment is applied to obtain the IOPs as the number of observation is usually larger than the number of unknown coefficients.

$$\begin{aligned} \Psi_x(p) &= \Psi_{x0} + \Psi_{x1} * p \quad + \Psi_{x2} * p^2 + \Psi_{x3} * p^3 \\ \Psi_y(p) &= \Psi_{y0} + \Psi_{y1} * p \quad + \Psi_{y2} * p^2 + \Psi_{y3} * p^3 \end{aligned} \tag{1}$$

Where, $\Psi_x(p)$ and $\Psi_y(p)$ are the detectors' directional angles between line-of-sight and z-axis; $\Psi_{x0} \sim \Psi_{y3}$ are the IOPs; p is the number of sample in linear array.

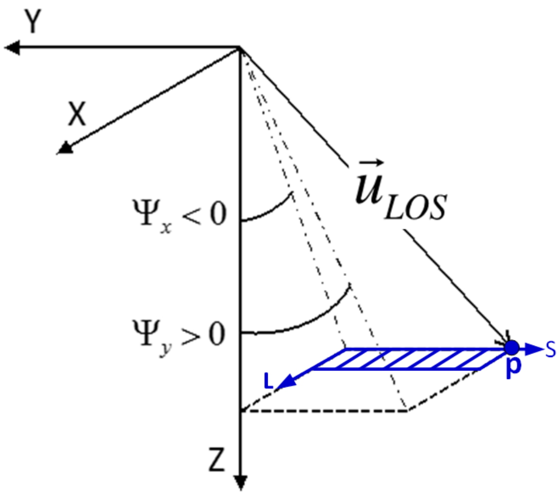

Figure 2. Look direction in focal plane

3. EXPERIMENTAL RESULTS

The test data includes 122 pairs of Formosat-5 Level 1A PAN and MS standard images. These images were acquired from Jan 22 to Jan 30, 2019 at different locations and in different view angles. The view angles were ranged from 0.36 to 38.14 degrees. All these 122 pairs were used to analyze and refine the IOPs in equation 1. In order to demonstrate the performance of in-flight geometric calibration, this study compared the displacements between PAN and MS images before and after calibration (Table 2). The experimental results indicated that the displacement is proportional to the view angles as the larger view angle produced large displacements when compared to smaller view angle. The proposed in-flight geometric calibration significantly improve the mean displacements after applying the refined IOPs.

Table 2. Displacements in Different Bands (before and after corrections)

Unit: pixels		Before Calibration			After Calibration			Improvement		
Viewangles (deg)		31.58	0.36	35.48	31.58	0.36	35.48	31.58	0.36	35.48
Band1	DeltaSample	4.10	3.64	4.95	0.28	-0.08	1.10	**3.82**	**3.72**	**3.85**
Band1	DeltaLine	-2.47	-2.36	-3.21	0.38	-0.01	-0.22	**2.85**	**2.35**	**2.99**
Band2	DeltaSample	1.95	2.35	1.11	-0.39	0.03	-1.15	**2.34**	**2.32**	**2.26**
Band2	DeltaLine	1.25	0.45	-0.15	0.70	-0.02	-0.75	**0.55**	**0.47**	**0.60**
Band3	DeltaSample	-1.26	-0.4	-2.65	-0.74	0.06	-2.12	**0.52**	**0.46**	**0.53**
Band3	DeltaLine	2.11	0.98	0.69	0.91	0.05	-0.32	**1.20**	**0.93**	**1.01**
Band4	DeltaSample	7.98	7.03	9.57	0.80	-0.04	2.35	**7.18**	**7.07**	**7.22**
Band4	DeltaLine	-2.9	-2.62	-2.62	0.41	0.13	0.83	**3.31**	**2.75**	**3.45**

4. CONCLUSIONS

This study presented the preliminary results of band-to-band geometrical calibration for Formosat-5 PAN and MS images. The proposed scheme generated a large number of tie point via image matching and then convert to detectors' directional angles for the determination of interior parameters. The experiment analyzed 122 pairs of PAN and MS images and determined the most-probability of IOPs. The experiment also compared the displacements before and after in-flight geometrical calibration. The improvements ranged from 0.47 pixels to 7.22 pixels. In summary, in-flight geometrical calibration is an essential process to improve the geometrical consistency between PAN and MS images.

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