COMBINED ADJUSTMENT OF ALOS SAR AND OPTICAL IMAGES FOR 3D OBJECT POSITIONING

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ABSTRACT: Orientation modeling for satellite images is an important task for 3D positioning. Synthetic Aperture Radar (SAR) and optical images are two major sources in environment remote sensing. Optical imagery has good spatial resolution, and is easy for human beings to interpret. However, optical imagery has the limitation in weather conditions. SAR imagery takes the advantages of all-weather and day-and-night capabilities to detect object information in microwave bands. Thus, the integration of these two datasets can help us to obtain more useful information. Geometrically, Rational Function Model (RFM) has advantages of standardization for satellites and is easy to implement. Thus, we use RFM to integrate SAR and optical sensor orientation data for 3D positioning.
There are four steps in this study: (1) generation of Rational Polynomial Coefficients (RPCs) for SAR imagery (2) RPCs refinement for SAR and optical imagery (3) 3D object positioning, and (4) validation. Most high-resolution optical satellite companies provide the imagery with RPCs instead of the ephemeris data, but SAR satellite companies do by contraries. Thus, the generation of RPCs for RFM starts from radar back projection in the first step. Then we employ the ground control points to adjust the RPCs for two sensor images. For a pair of conjugate points in SAR and optical images, we have four equations to determine the 3D object coordinates.
This study tests ALOS images including PALSAR and PRISM. The experiment results show that using RFM can successfully integrate SAR and optical images to determine 3D coordinates for objects.

1. INTRODUTION

SAR and optical sensors are two types of major sensors in environment remote sensing. For optical imagery, it is easy to interpret by human beings because it can provide the better spatial resolution by passive optical sensors. However optical sensor has many limitations in weather conditions, such as night time or clouds. The SAR is using radio waves to detect the presence of object and to determine the distance (Lillesand, Kiefer and Chipman, 2007). Radar is the active remote sensor, which can work day-and-night.
Before using SAR or optical images, these data must need the geometric correction for high geometric accuracy. The geometric modeling if sensor orientation can be divided into two categories, namely, the rigorous sensor model (RSM) and the rational function model (RFM). For optical images, RSM is based on collinearity condition in which an image point corresponds to a ground point via the employment of the orientation parameters (Toutin, 2004). For SAR images, the general way for the rectification of SAR images is to adjust orbit polynomials. The difficulty of adjusting orbit polynomials is the selection of polynomial orders. Toutin (2003) used the 3-D Canada Centre for Remote Sensing (CCRS) physical model to rectified the radar image. As the RSM involves many mathematics in dynamic sampling, many high resolutions optical satellite companies provide the RPCs instead of ephemeris data, but SAR satellite companies do by contraries. The RFM uses a pair of ratios of two polynomials to approximate the RSM and has the advantage of standardization for satellites, so using RFM can help us combine SAR satellite imagery and optical satellite imagery. Many investigations have already confirmed about the capability of RFM in space-borne SAR imagery (Zhang et al., 2010), ERS TerraSAR-X, etc. Thus, this paper employs the RFM to combine the SAR imagery and the optical imagery for 3D positioning.
The advanced land observing satellite (ALOS) is a special earth resources satellite, and ALOS has three difference sensors in a satellite, namely, panchromatic remote-sensing instrument for stereo mapping (PRISM), advanced visible and near infrared radiometer type 2 (AVNIR-2), and phased array type L-band synthetic aperture radar (PALSAR). In this study, the target data set includes PRISM and PALSAR two difference sensor data. The central tasks include four steps: (1) generation RPCs for SAR imagery (2) RPCs refinement for optical and SAR imagery (3) 3D object positioning, and (4) validation.

2. THE PROPOSED METHOD

This study proposes a procedure of RFM-based 3D positioning for PRISM and PALSAR images. The workflow of the proposed scheme is illustrated in Figure 1.

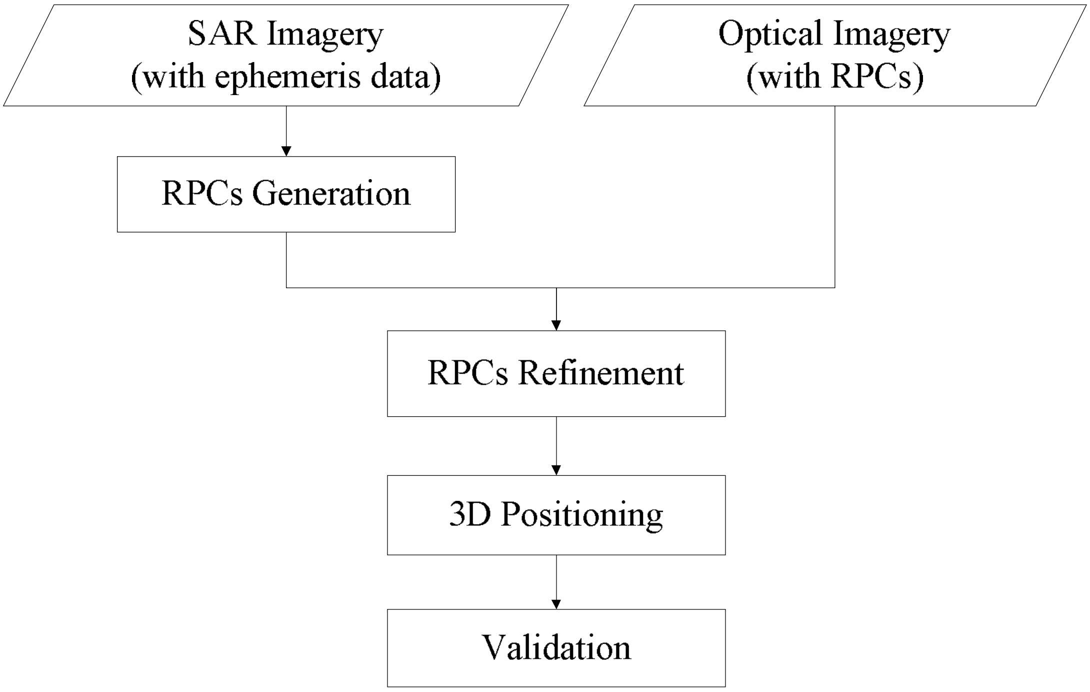


Figure 1. Workflow of the Proposed Method

2.1 Generation RPCs for SAR imagery

The SAR sensor model is also formulated as RFM. There are two methods to generate the RPCs: (1) derivation from ground control points (GCPs), and (2) generation from satellite ephemeris data. To avoid the first method that needs a large number of GCPs, we propose to use satellite ephemeris data to generate the RPCs. The major works of the proposed scheme are: (1) using the ephemeris data to generate a large number of virtual control points (VCPs), and (2) using the VCPs to generate the RPCs.

In the beginning, we establish the sensor model which describes the transformation of 3D object points and 2D image space for SAR imagery. It can be calculated from two equations. The first equation is the range equation as shown in Equation 1. It is used to describe the distance between an object point and the imaging center. The second equation, Equation 2, is a Doppler equation for Doppler frequency rate. Once we obtained the SAR sensor model, we generate a large number of 3D grid points are distributed in difference elevations. Then, the corresponding image coordinates are calculated from the sensor model, and these points are called virtual control points (VCPs). RPCs can be generated from a large number of VCPs. In order to minimize the approximate error, a least squares minimization process is applied to solve the RPCs (Gong and Zhang, 2003).

$$\vec{R} = \vec{P} - \vec{G} \tag{1}$$

$$f_D = -\frac{2}{\lambda}\frac{dR}{dt} \tag{2}$$

where R is the slant-range distance, f_D is the Doppler frequency changing with the time and λ is the wave length.

2.2 RPCs refinement

In order to compensate the systematic bias of RPCs, we use an affine transformation to correct for the systematic errors in the image space. The affine transformation coefficients can be calculated from ground control points. The equations of affine transformation are shown as Equation 3.

$$S_{GCP}=a_0+a_1\times S_{RFM}+a_2\times L_{RFM}$$
$$L_{GCP}=b_0+b_1\times S_{RFM}+b_2\times L_{RFM} \quad (3)$$

where, (S_{GCP}, L_{GCP}) are the image coordinates of GCP, (S_{RFM}, L_{RFM}) are the image coordinates determined by RFM, and a_0~b_2 are the coefficients of affine transformation.

2.3 3D positioning

Following the first two steps, we can use the RPCs to build up the RFM for SAR imagery as shown in Equation 4.

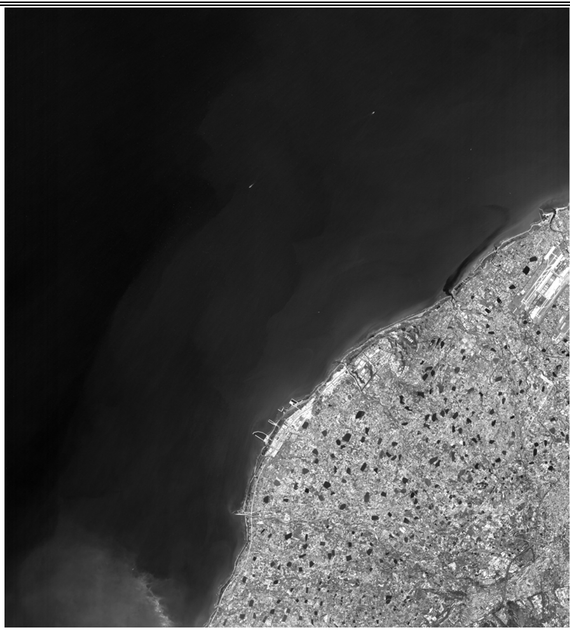
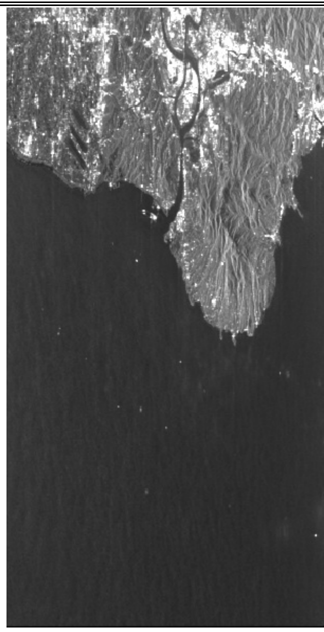
$$x=\frac{p_a(X,Y,Z)}{p_b(X,Y,Z)}=\frac{\sum_{i=0}^{m1}\sum_{j=0}^{m2}\sum_{k=0}^{m3}a_{ijk}X^iY^jZ^K}{\sum_{i=0}^{n1}\sum_{j=0}^{n2}\sum_{k=0}^{n3}b_{ijk}X^iY^jZ^K}$$
$$y=\frac{p_c(X,Y,Z)}{p_d(X,Y,Z)}=\frac{\sum_{i=0}^{m1}\sum_{j=0}^{m2}\sum_{k=0}^{m3}c_{ijk}X^iY^jZ^K}{\sum_{i=0}^{n1}\sum_{j=0}^{n2}\sum_{k=0}^{n3}d_{ijk}X^iY^jZ^K} \quad (4)$$

We can measure the conjugate points in SAR and optical images. RFM has four equations and three unknowns including 3D object coordinates, and we can calculate the 3D object coordinate by the least squares method.

3. EXPEROMENT RESULTS

The test data set includes the ALOS PRSIM and PALSAR images, and the area is focus on Taoyuan county in Taiwan. The information about the test data is shown on Table 1. GCPs and ICPs are measure from SPOT-5 ortho-images and 40 meters spacing DEM.

Table 1. Relation information of the Test data

Sensor type	ALOS/ PRISM	ALOS/PALSAR
Image	 ©JAXA, 2006	 ©JAXA, 2010
Date	2006/10/18	2010/03/07
Product Level	1B1	L 1.1
Pixel Spacing Sample/line (m)	2.5 / 2.5	4.67 / 3.19
No. of GCPs / ICPs	8 / 8	5 / 8

We select some conjugated points to be independent check point and compared with our 3D positioning in this preliminary test. The validation results are shown as Table 2. The results show that using SAR and optical images for positioning is work. The elevation error is larger than horizontal error, and it should be caused by unfavorable quality of the reference data.

Table 2. Validation results

	E	N	H
RMSE (m)	6.57	7.23	18.92

4. CONCLUSTION AND FUTURE WORK

This paper tried to combine two different remote sensing data for 3D positioning. The RFM has the advantage of standardization for satellites, and this advantage also helps us to combine these two sensor data. The preliminary results show that RFM has a capability to integration SAR and optical data, and it has a potential of using SAR and optical images for 3D object positioning. In the future, more satellites will be tested to ensure the applicability of the proposed method. In addition, test data with higher quality reference is needed in the further investigation. The accuracy analyses on the intersection angle between two types of image are suggested.

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