GEOMETRIC ANALYSIS OF 3D OBJECT POSITIONING USING SAR AND OPTICAL IMAGES

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Abstract: Synthetic Aperture Radar (SAR) and optical images are two major sources in environment remote sensing. The integration of these two datasets can help us to obtain more useful information. From geometric point of view, there two types of data may be combined for 3D positioning. Orientation modeling for satellite images is an important task for 3D positioning. To link an image point with its counterpart on the ground, Rational Function Model (RFM) has advantages of standardization for satellite image processing 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) building RFM for images, (2) virtual point generation with simulated errors, (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, using RPCs to build up the RFM may integrate two sensor imagers. We simulate error-free virtual points in the overlap area and add errors with normal distribution on the simulated observations to evaluate positioning errors. For a pair of conjugate points in SAR and optical images, we may formulate four equations to determine the 3D object coordinates.

In the study, we have the test data including one COSMO-SkyMed image and SPOT images with different tilt angles. Experiment results indicate that the highest accuracy may be achieved when the convergent angle is smallest. On the other hand, when the convergent angle is closing to 90°, the positioning error is getting large or even diverges. These error characteristics fit with geometric rules.

INTRODUCTION

In the geoinformatics field, it is an importance mission to obtain 3D coordinates of the objects. There are many ways to perform the 3D positioning, such as surveying, aerial photos, SAR images, LIDAR (Light Detection And Ranging), GPS and etc. Using remote sensing data in the large area can reduce cost and processing time, so we use the satellite data to positioning the 3D coordinates. 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. From geometric view, the optical imagery can provide direction of a ray, and the SAR imagery can provide range information. Thus, in this study, the proposed combine these two different sensor images to determine the 3D coordinates.

Before using remotely sensed images to positioning 3D coordinates, geometrics correction is an indispensable step. The geometric modeling for 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 using range and Doppler equations. The difficulty of adjusting orbit polynomials is the selection of polynomial orders. Toutin (2003) used the generic physical model to rectified the radar image. As the RSM involves much mathematics in dynamic sampling, a part of high-resolution optical satellite companies provide coefficients of RFM instead of ephemeris data. However most of 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. From geometric point of view, the converged angle of SAR and optical images would effect to the quality of 3D positioning. Thus, in this study, we try to analyze the relationship between the converged angle and the accuracy of 3D positioning.

The SPOT satellites collect wide swath and high-resolution optical images since 1986. COSMO-SkyMed satellites can supply very high-resolution X-bnad SAR images. COSMO-SkyMed has 4 satellites in the same orbital plane, so they can collect 4-7 images in the same area per day. In this study, we combine SPOT-5 images and one COSMO-SkyMed Single look image to geometric analyze the 3D positioning.

METHODOLOGY

This study proposes a procedure of geometric analysis of 3D object positioning using SAR and optical images. The workflow of the proposed scheme illustrated in Figure 1.

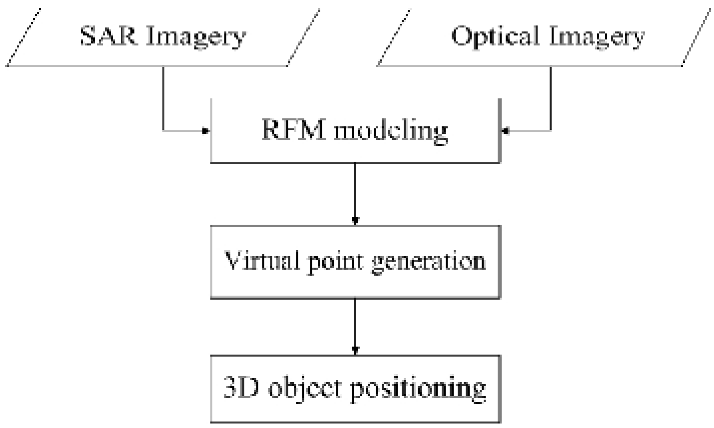

Figure 1: Workflow of the proposed method

RFM MODELING

RFM has the advantage of standardize processing for every satellite, and it can help us to integrate SAR and optical imagers. Following the equation 1, we can build up the RFM for SAR imagery and optical imagery. Then, using affine transformation refines the system error of RFM.

$$S = \frac{p_a(X,Y,Z)}{p_b(X,Y,Z)} = \frac{\sum_{i=0}^{i=3}\sum_{j=0}^{j=3}\sum_{k=0}^{k=3} a_{ijk} X^i Y^j Z^k}{\sum_{i=0}^{i=3}\sum_{j=0}^{j=3}\sum_{k=0}^{k=3} b_{ijk} X^i Y^j Z^k}$$

$$L = \frac{p_c(X,Y,Z)}{p_d(X,Y,Z)} = \frac{\sum_{i=0}^{i=3}\sum_{j=0}^{j=3}\sum_{k=0}^{k=3} c_{ijk} X^i Y^j Z^k}{\sum_{i=0}^{i=3}\sum_{j=0}^{j=3}\sum_{k=0}^{k=3} d_{ijk} X^i Y^j Z^k} \quad (1)$$

VIRTUAL POINT GENERATION

After RFM modeling for images, we generate the virtual point in the object space without any errors. Then, we determine the image coordinates of the virtual point by following the equation 1. We simulate the random errors with normal distribution and add the random errors on image coordinates of the virtual point.

3D OBJECT POSITIONING

Following the equation 1, we can build up the observation equations which show as equation 2. Then, we can input the observation with simulated random error and calculate 3D object coordinates by the least squares method.

$$\begin{bmatrix} \upsilon_1^S \\ \upsilon_1^L \\ \upsilon_2^S \\ \upsilon_2^L \end{bmatrix} = \begin{bmatrix} \frac{\partial S_1}{\partial X} & \frac{\partial S_1}{\partial Y} & \frac{\partial S_1}{\partial Z} \\ \frac{\partial L_1}{\partial X} & \frac{\partial L_1}{\partial Y} & \frac{\partial L_1}{\partial Z} \\ \frac{\partial S_2}{\partial X} & \frac{\partial S_2}{\partial Y} & \frac{\partial S_2}{\partial Z} \\ \frac{\partial L_2}{\partial X} & \frac{\partial L_2}{\partial Y} & \frac{\partial L_2}{\partial Z} \end{bmatrix} \begin{bmatrix} \partial X \\ \partial Y \\ \partial Z \end{bmatrix} + \begin{bmatrix} \hat{S}_1 - S_1 \\ \hat{L}_1 - L_1 \\ \hat{S}_2 - S_2 \\ \hat{L}_2 - L_2 \end{bmatrix} \quad (2)$$

RESULTS

Here, the test data include one COSMO-SkyMed single-look image and 14 SPOT-5 images with different viewing angle. The area is focus on Kaosiung City and Pingtung County in south Taiwan. The geometric analysis results are show as figure 2. From figure 2, when the converged angle is closing to 90 degree, the position error is larger.

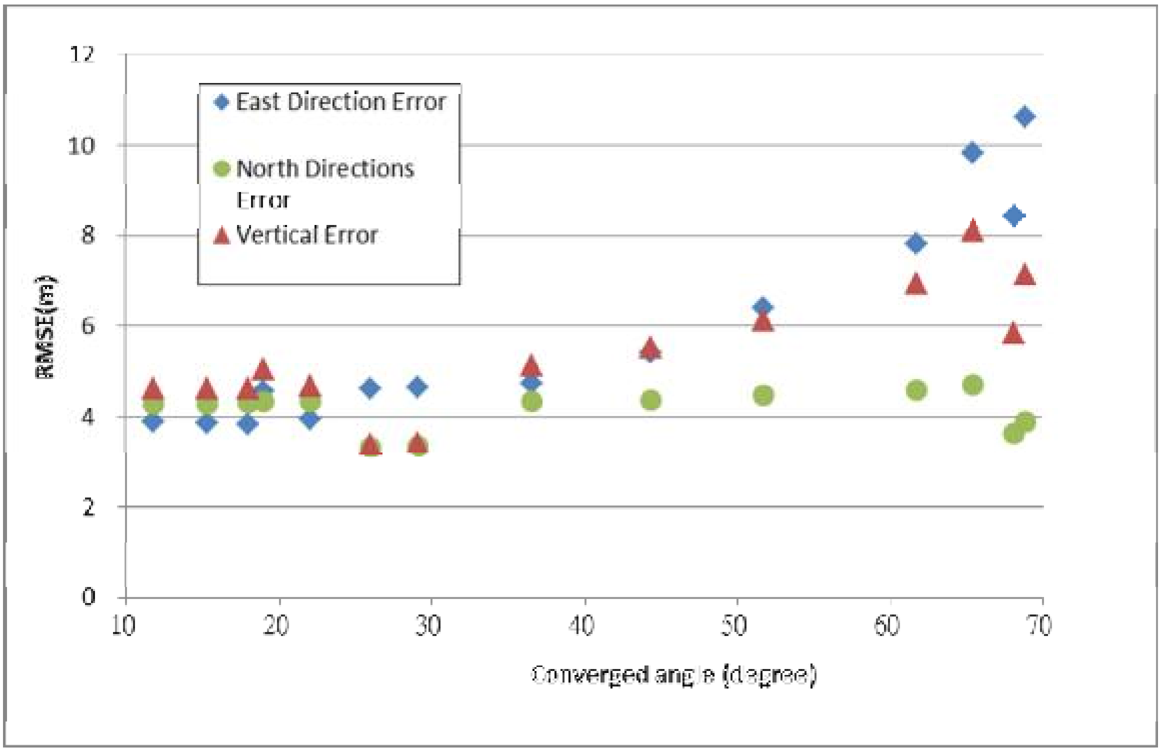

Figure 2: Geometric analysis results

CONCLUSIONS

This study uses the RFM to integrate SAR and optical images for 3D object positioning. The experiment results show that RFM has a capability to integrate SAR and optical data, and it has a potential of using SAR and optical images for 3D object positioning. From geometric viewing, the converged angle would affect the accuracy of 3D object positioning. The analyzed results show the positioning error is increasing when the converged angle is closing to 90 degree. In a good converged angle, we can achieve to about 5 meter position error by SAR and optical images.

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