An Algorithm for Geometric Correction of High Resolution Image Based on Physical Modeling

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ABSTRACT: This paper describes the geometric correction algorithm developed for the ROCSAT-2 Image Processing System. The ROCSAT-2 satellite will be launched in 2003. Its mission is to daily image over Taiwan and the surrounding areas for disaster monitoring, land use, and ocean surveillance during the 5-year mission lifetime. The image taken by the Remote Sensing Instrument (RSI) on board is to have in the nadir direction a swath width of 24 km and a field of regard of ±45 deg for along-track and cross-track viewing. RSI will provide images for 2 m ground sampling distance (GSD) in panchromatic band and 8 m GSD in four Landsat-like multispectral bands. With its high accuracy, the physical modeling approach is a natural choice for the geometric correction of satellite imagery at such high resolution. In this paper we first describe the algorithm, then demonstrate its capability using satellite image data currently available (QuickBird-2 image data is one of the choices). This algorithm incorporates nonlinear transformations with least-square error and Lagrangian relaxation using satellite data (ephemeris, attitude, RSI), ground control point (GCP) data, and digital elevation model (DEM) data. The goal is to evaluate the geographical coordinate of each image pixel with an accuracy of two meters.

1. INTRODUCTION

The ROCSAT-2 mission is to daily image over Taiwan and the surrounding area for disaster monitoring, land use, and ocean surveillance during the 5-year mission lifetime. The satellite will be launched in 2003 into its mission orbit, which is selected as a 14 rev/day repetitive Sun-synchronous orbit descending over (120 deg E, 24 deg N) and 9:45 a.m. over the equator with the minimum eccentricity. The image taken by the Remote Sensing Instrument (RSI) on board is to have in the nadir direction a swath width of 24 km and a field of regard of ±45 deg for along-track and cross-track viewing, which is capable to completely image the whole Taiwan Island during one pass. RSI will provide images for 2 m ground sampling distance (GSD) in panchromatic band and 8 m GSD in four Landsat-like multispectral bands over 24 km swath width in the nadir direction.

During normal operations, RSI is operated for imaging over Taiwan and other areas through international cooperation. The satellite will orient the solar array to point the Sun for the rest portion of daytime orbit, and operate cyclically during every orbit period of 102.9 min. The imaging duty cycle is 8%, and the agility for the attitude maneuvers is 45 deg within one minute [1]. A scenario to take a mosaic image is shown in Figure 1 [2]. The four-strip imaging in this figure is significantly interesting, because it is able to completely cover the whole Taiwan Island during one pass.

The geometric correction of high-resolution satellite image needs to take into account the instrument characteristics, the satellite motion, earth rotation, terrain effects, and the ground control points (GCP) simultaneously. This is much different with the traditional geometric correction algorithms, which conducts the correction sequentially and uses the ground control points in higher level processing [3].

In our previous paper [4] we have estimated the orders of magnitude of the geometric errors for the image taken from the satellite, which are caused from the errors of the position, the attitude, and the pixel alignment of the imager. The pixel projection is then formulated according various models. To have the pixel projections match the ground control points, a correction procedure based on the methods of Lagrange's multipliers and Newton iteration are utilized to fit the system parameters. Some simulated examples have been given to valid this numerical procedure [4].

In this paper, we carry the work a step further by taking into account the terrain effects. Besides GCP, the digital elevation model (DEM) is a necessary input for this algorithm. The first step, georegerencing, is to calculate the pixel projection on the earth reference ellipsoid by applying satellite ancillary data and earth models. The second step is to refine the satellite orbit and attitude parameters by applying GCP, as elaborated in [4]. The third step is to apply Newtonian iteration method to gain further accuracy in pixel position.

The second section describes the georeferencing method. Section 3 describes the orbit/attitude refinement using GCPs [4]. Section 4 describes the algorithm for high-accuracy georeferencing using DEM. Conclusions are listed in Section 5.

2. GEOREFERENCING

Georeferencing of a satellite image is a process for finding the position of each pixel in geographical or map coordinate.The direct georeferencing method gains its advantage with increasing satellite ancillary data accuracy. For example, the ROCSAT-2 can provide position data with accuracy up to 20 meters. The method is as follows:

The first step is: given satellite state vectors and attitude quaternion at a certain instant of time, the intersection of the sensor line-of-sight with the reference earth ellipsoid can be found by applying a simple algorithm involving several coordinate transformations and basic geometry. A schematic is shown below.

DEM is not used in this step.

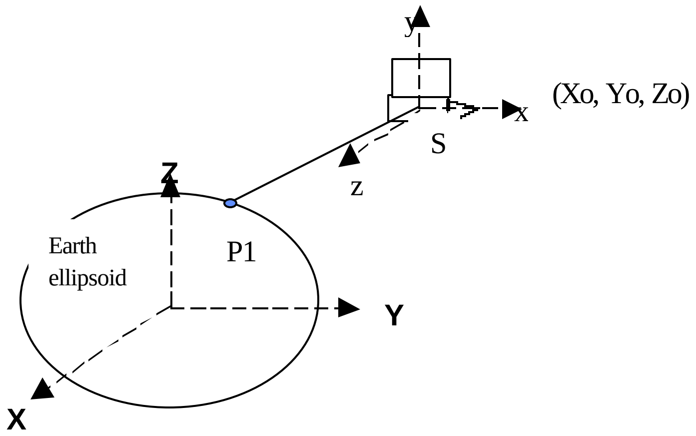

Figure 1. Schematic for georeferencing without DEM

The satellite ancillary data gives time of imaging in UTC, spacecraft orbital position and velocity in ECF, and the ECI to body quaternion. The procedure for pixel projection in ECF is as follows:

Step 1: compute Earth rotation matrix (J2000 to ECF) based on the Julian day number corresponding to the UTC
time.
Step 2: transform the attitude (in terms of Euler angles in the sequence of 1-2-3) from body to LVLH, to ECI, and to ECF and compute the corresponding "body to ECF" transformation matrix.
Step 3: transform sensor line-of-sight vector to ECF.
Step 4: find the coordinate (latitude, longitude, height) of the intersection of sensor line-of-sight vector and the
earth ellipsoid surface (WGS84).

The pixel position in ECF coordinate (X,Y,Z) can be found by solving the following equations:

$$\frac{X^2}{a^2}+\frac{Y^2}{a^2}+\frac{Z^2}{b^2}=1$$

$$\frac{X-X_0}{p}=\frac{Y-Y_0}{q}=\frac{Z-Z_0}{r}$$

Where a is the earth ellipsoid's semi-major axis, b is the semi-minor axis, (*p,q,r*) is the elements of the CCD line-of-sight vector in ECF coordinate. (*Xo,Yo,Zo*) is the spacecraft position in ECF coordinate.

3. ANCILLARY DATA REFINEMENT USING GROUND CONTROL POINTS

System parameters having significant contributions to the geometric errors include the satellite attitude, orbit, and the misalignment angle of the CCD array.

All the pixel projections are considered as the functions of the system parameters. The ground control points which correspond to the pixel projections are satisfied exactly or with the least square error. This allows us to determine the system parameters.

For the demonstration purpose, we want to fit 7 parameters, which are satellite position in ECF and attitude quaternion. The problem is to minimize the sum of square errors between the ground control points and the corresponding pixel projections subject to a constraint that the fit is exactly at the image center. The method of Lagrange's multipliers is utilized, and hence a system of nonlinear equations is obtained. The Gauss-Seidel iteration scheme is then applied to this nonlinear system to fit the system parameters. For demonstration purpose, we select 20 ground control points for a scene of 24 km x 24 km. The schematic allocation is shown in Figure 2.

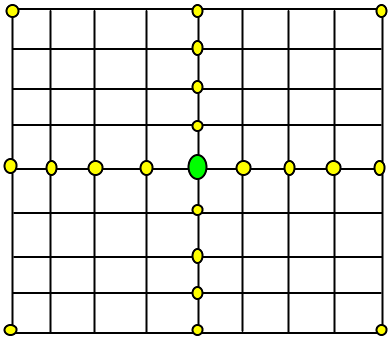

Figure 2. Schematic Allocation of 20 Ground Control Points

The mathematical formulation can be expressed by the following equations:

$$\text{Minimize} \quad f(\underline{x},\underline{q}) = \sum_{GCP} [(lon - LON)^2_{GCP} + [(lat - LAT)^2_{GCP}]$$

$$\text{subject to} \quad g_1(\underline{x},\underline{q}) \equiv (lon - LON)_c = 0$$

$$g_2(\underline{x},\underline{q}) \equiv (lat - LAT)_c = 0$$

$$\begin{cases} \nabla(f - \underline{l} \bullet \underline{g}) = 0 \\ \overset{\times}{\underline{g}} = 0 \end{cases}$$

where x̲ and q̲ denote the satellite position and attitude quaternion, respectively. The function f is the sum of square errors to be minimized. The function g's are the constraints. The numbers in $\underline{\lambda}$ are the Lagrangian multiplier.

4. REFINED GEOREFERENCING USING DEM

The above steps provides refined orbit/attitude data and an initial guess (coordinate of P1) for the next step, which utilizes DEM to find the correct position of the pixel of interest. Newton iteration method is applied, as shown in Figure 2.

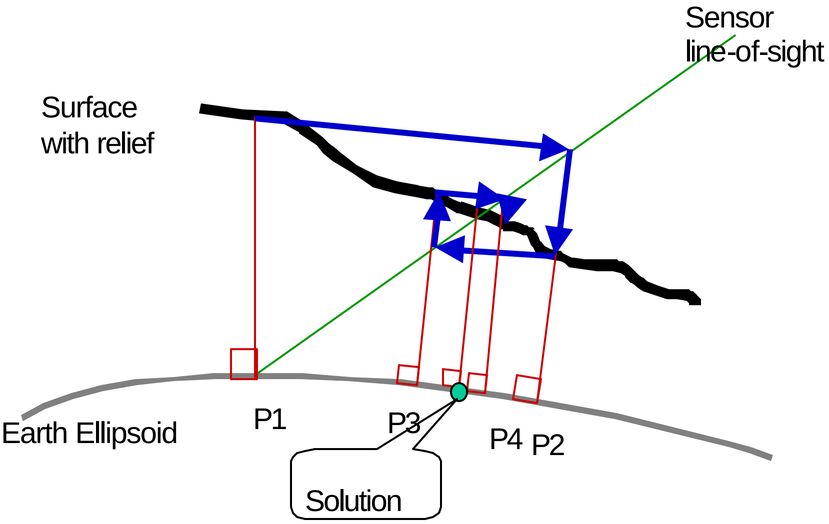

Figure 3. Schematic for georeferencing with DEM

Based on the sensor line-of-sight vector obtained by the refined orbit/attitude data described in Section 3, the initial guess (position of P1) can be found by the algorithm given in Section 2. Starting from P1, the Newtonian iteration methods gives successively P2, p3, …, etc, until the error is less than a prescribed value.

5. SUMMARY

The method for geometric correction fully utilizes satellite ancillary data, GCP, and DEM. The basic steps are:

Step 1. Direct georeferencing using original ancillary data only
Step 2. The ancillary data is refined by using GCP and Gauss-Sidel iteration method with Lagrangian multiplier
Step 3. The georeferencing is fine-tuned using refined ancillary data and Newtonian iteration with DEM.

This paper address the basic mathematical formulation. Application to real satellite images will be performed in the near future. In practice, several potential problems occur, including missing or erroneous ancillary data. Some measures like Kalman filtering may be incorporated to assure ancillary data quality. This work will keep in progress with the ROCSAT-2 mission.

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