Geometric Correction of High Resolution Image Using Ground Control Points

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ABSTRACT: 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.

The high resolution requirement makes the geometric correction become critical for the mission. The knowledge of the satellite navigation and the information of the digital elevation model (DEM) are both insufficient for the geometric correction needs. In this paper we first estimate 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 estimation shows that all the errors will be about 450 m. To increase the geometric accuracy of the image, a set of 20 ground control points (GCP) with accuracy in 1 m is then selected to determine the better knowledge of position, attitude, and pixel alignment for a scene of 24 km x 24 km. The transformation from any pixel of the imager to the Earth surface of WGS-84 model is formulated. Since the transformation is nonlinear, the least sum of the square errors between the ground control points and the corresponding pixel projections subject to some constraints is required to determine the position, attitude, and pixel alignment utilizing the method of Lagrange's multipliers with Newton iteration scheme. Finally, the image is geometrically corrected according to the determined transformation. Three simulated results demonstrate that the image geometric errors can be reduced to an order of 2 m for ROCSAT-2 panchromatic images.

1. INTRODUCTION

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 satellite motion, the pixel alignment, the Earth rotation model, 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 this paper we first estimate 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 will be given to valid this numerical procedure.

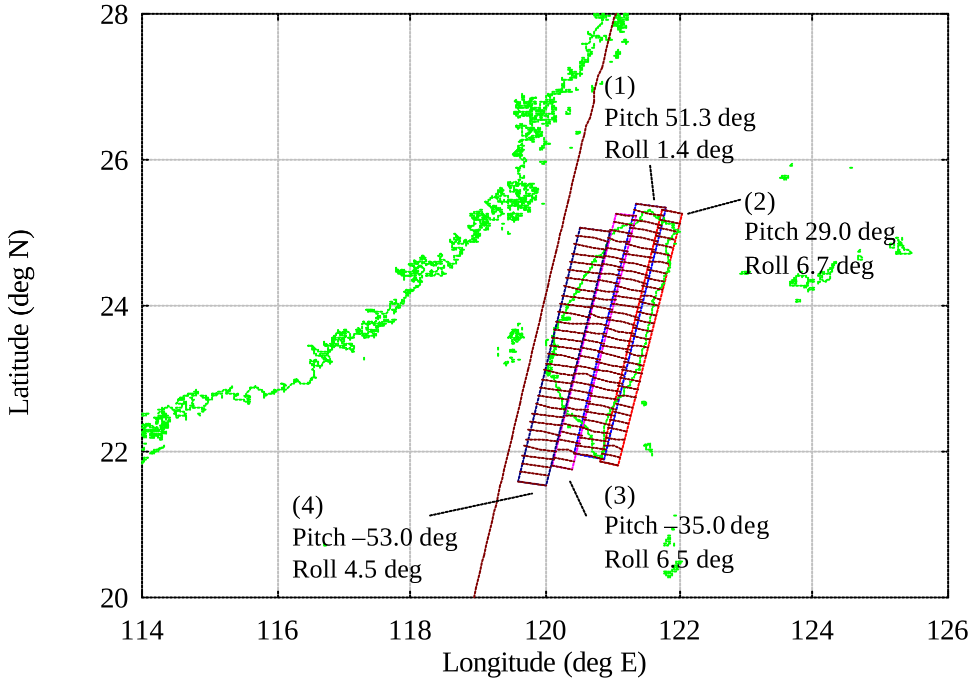

Figure 1. Coverage of 4-Strip Imaging

2. GEOMETRIC ERRORS IN SATELLITE IMAGES

Geometric errors in satellite images come from effects in instrument, spacecraft bus, and earth. The contribution from instrument includes instrument global distortion (e.g. CCD distortion, CCD position, and pixel size variation) and datation (variation in sampling rates). Spacecraft bus contributes further distortions via structure distortion, and variations in attitude, position, and velocity. Earth rotation, terrain and atmospheric effects also cause significant distortion in satellite images. The geometric errors can be corrected to a certain extent with detailed instrument and spacecraft information (ancillary data) that provides instrument calibration data, spacecraft attitude, position and velocity at sufficiently small time interval. Unfortunately these data are not accurate enough for a high-resolution satellite image like ROCSAT-2's. For ROCSAT-2, the uncertainty in position is about 10 meters, the pointing knowledge error (including instrument and structure distortions and attitude determination errors) is 450 meters. Consequently ground control points must be incorporated in the geometric correction process to reduce the error to within 2 meters. However, before applying GCP for geometric correction, it is desirable to pre-process the image data by using orbital geometry models [1] to remove as much as possible the errors based on instrument calibration data and spacecraft ancillary data.

For the pre-processing, typical orbital geometry model approach incorporates global transformations that take into account the aspect ratio, earth rotation, image orientation, …etc, and applies the transformation to the whole scene [2]. This approach is based on nominal satellite orbit and attitude when detailed ancillary data is not available, so the accuracy is usually poor. On the other hand, with detailed information extracted from ancillary, one can apply the correction processing to each pixel and hence get much higher accuracy. This pixel-wise approach takes into account the instrument distortion (measured pre-flight an/or in-flight), the spacecraft attitude, position and velocity at the instant the image is formed in each CCD pixel. The earth rotation effect is calculated by a high-precision earth rotation model which involves regular rotation, precession, and nutation. Therefore the geolocation (in terms of geodetic longitude and latitude) of each image pixel can be calculated. For the ROCSAT-2 image, the absolute geolocation error after pre-processing is expected to be within 450 meters. The relative errors between image pixels in the same scene are expected to be much less than 450 meters. The pre-processed data is then used as the initial condition for the correction processing using GCP.

3. FORMULATION OF PIXEL PROJECTION

Flowchart to show the formula.

Orbit position: ECI to ECF (Earth rotation matrix)

Attitude: LVLH to ECI to ECF
Pixel view direction: Body to LVLH (attitude) to ECI to ECF
Earth Surface: ellipsoid (WGS-84)

Pixel projection is the intersection of the Earth surface and the vector located at the orbit position with view direction.

4. CORRECTION USING GROUND CONTROL POINTS

System parameters having significant contributions to the geometric errors include the Euler angles of attitude, the argument of latitude of orbit, and the misalignment angle of the CCD array. The effects of attitude and orbit are commonly familiar. Here we take additionally into account the effects of CCD array misalignment, which is shown in Figure 2.

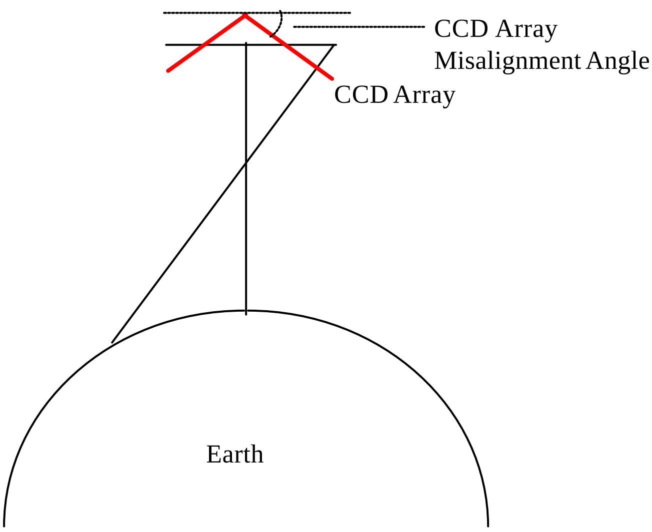

Figure 2. Schematic Diagram of CCD Array Misalignment Angle

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 5 parameters, which are 3 Euler angles, argument of latitude, and misalignment angle. 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 Newton iteration scheme is 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.

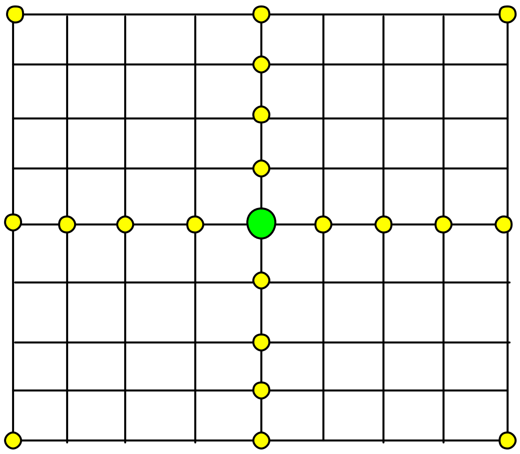

Figure 2. Schematic Allocation of 20 Ground Control Points

5. SIMULATION RESULTS

Three cases are simulated to valid the present procedure of geometric correction. All the cases have the same time of taking image. The parameters to be determined for each case are shown in Table 1. Convergence can be achieved within 10 iterations. The average geometric error for each pixel is less than 2 m, which is contributed fromthe errors not being corrected and including the jitter and other factors.

Table 1. System Parameters of Simulated Cases

Case	Roll	Pitch	Yaw	Delta Argument of of Latitude	CCD Array Misalignment Angle
1	5 deg	20 deg	0 deg	0 deg	0 deg
2	5 deg	20 deg	3 deg	0.2 deg	10 deg
3	5 deg	20 deg	10 deg	1 deg	10 deg

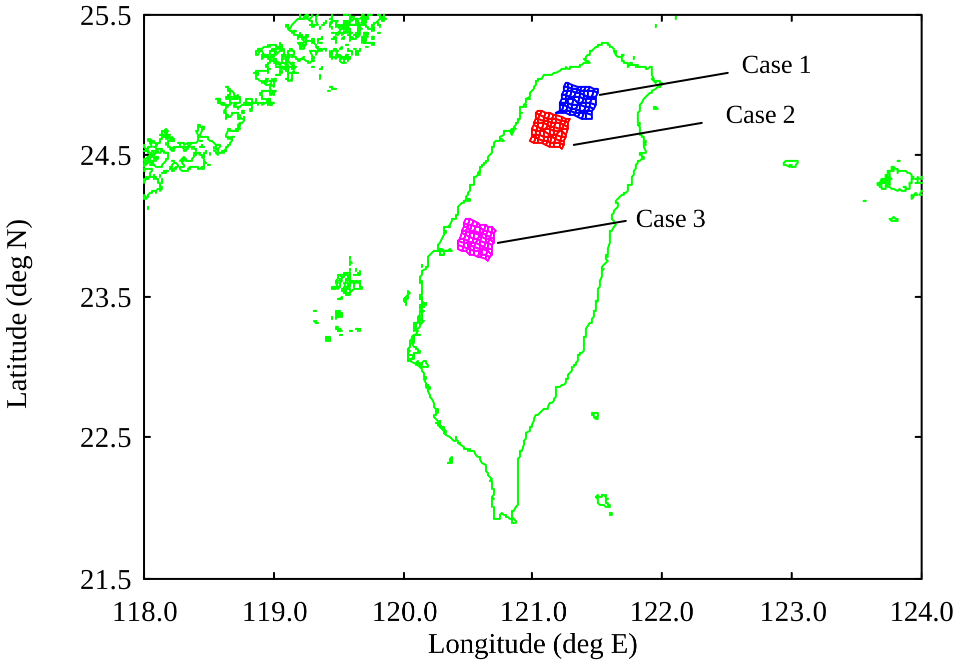

Figure 3. Simulated Cases

6. CONCLUSION

A numerical procedure is proposed for the geometric correction of high resolution image using ground control points. Although in this paper we present three simulated cases to fit 5 parameters using 20 ground control points, this procedure is also valid for numbers of parameters and ground control points. If DEM data are available, one can add it in this procedure to get more accurate results.

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