Research on the Geo-Metrical and Radio-Metrical Topography Correction of the RADARSAT-2 Image

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Abstract. Terrain geometry and radiation characteristics of radar images have strong influence. The correction of these effects becomes indispensable when quantitative image analysis is performed with respect to the derivation of geo- and biophysical parameters. Based on RD geo-location model and digital elevation model, an ortho-rectification and TRC implementation flow was introduced. The correctness and effectiveness of the method were qualitatively and quantitatively evaluated through several experimentations. By comparing two kinds of effective TRC methods, we found the project-angle based method is more effective than the local incidence-angle based method. The rationality of computing effective TRC factor using initial SAR geo-location model was also demonstrated.

1. Introduction
Terrain geometry and radiation characteristics of radar images have strong influence. In terms of geometric features, terrain causes obvious geometric distortion such as foreshortening, layover, shadow and so on in SAR range image, due to the SAR principle of side-view imaging. And in terms of radiation characteristics, Beaudoin [1] found that the error range of the backscattering coefficient reaches plus-minus 5 dB which is caused by the terrain in the region of the great terrain fluctuation. Such great error cannot be ignored when various parameters are extracted and the radar image is analyzed quantitatively. So the precise geometric and radiation rectification are required for the radar image before the parameter extraction and quantitative analysis, building correct the relationship between the ground and the image and generating orthophoto map which have its special reference coordinate system. And the error of the backscattering coefficient is corrected or compensated to produce SAR data independent of the terrain change.

Early the topography radiometric correction factor was used to correct the topography radiation, using the SAR simplified geometrical model by surface slope angle [2] or local incidence angle [3, 4, 5], when geocoding product is obtained directly. In spite of this it is inevitable to bring certain error when the topography radiometric correction factor is calculated because of the lack of the knowledge of the geometric relationship in the process of geocoding [6]. In order to overcome these disadvantages, in this paper based on the strict Range-Doppler (RD) geo-location model and SAR imaging simulation, the method is proposed to do the orthographical rectification and calculate topography radiometric correction factor simultaneously. Firstly, the method builds the geometric relationship between the SAR image and the ground based on the rigorous RD geo-location model. Secondly, local incidence angle, the angle between the normal of the imaging plane and the normal of object plane (projection angle) are found to calculate the terrain radiation correction factor. Finally, the orthographical correction for the SAR image and terrain radiation correction will be fulfilled after simulate the SAR image.
2. The Principle and Method

2.1. The RD Geo-Location Model
Due to the SAR principle of side-view imaging, terrain causes obvious geometric distortion such as foreshortening, layover, and shadow and so on in SAR range image. This causes object point, having the same distance from the subastral point, imaging different columns. And along the flight direction the relative speed will change with the terrain elevation between satellite sensors and object point, giving rise to Doppler shift. This brings about image distortion in the azimuth direction. The accurate geometric correction is carried on for SAR image to rebuild the correct imaging geometry relationship, which describes the relationship the image point and its corresponding object point. Based on the SAR imaging principle, RD geo-location model describes the geometrical relationship between the object and SAR image, which have been the standard model of the all successfully launched SAR satellite. RD model can be described in the following three equations:

\[
\frac{X_i^2 + Y_i^2}{(R_e + H_i)^2} + \frac{Z_i^2}{R_p^2} = 1
\]

\[R = R(i, j)\]

\[f_d = -\frac{2dR}{\lambda dt}\]

Where the equation (1) is the ellipsoid equation; (2) is the slant-distance equation; (3) is Doppler equation. \((X_i, Y_i, Z_i)\) are the coordinates of the object point in the geocentric rectangular coordinate system; \(R_e\) is the earth ellipsoid equatorial radius; \(R_p\) is the earth ellipsoid polar radius; \(H_i\) is the ground point elevation; \(H_i = H(X_i, Y_i, Z_i)\) can be expressed as the terrain equation; \(R(i, j)\) is the slant distance of the corresponding point \((i, j)\) in the SAR image; and \(\lambda\) is radar wavelength [7]

The required parameters solve the above the equations can be obtained from the header files of SAR data. Satellite orbit parameters such as vector data can be obtained through simple calculation. The RADARSAT-2 is a high-resolution SAR satellite; iterative localization method is adopted based on Doppler frequency to solve the RD geo-location model, where the location precision is better.

2.2. The Topography Radiometric Correction Model
The value of the backscatter coefficient is calculated by employing the calibration formula including the radiometric error from the terrain fluctuation when the terrain not flat, so topography radiometric correction factor is further computed to correct these errors based on RD geo-location model and DEM. Local incidence angle and projection angle is used as two kinds of topography radiometric correction factor. Where in the earth-fixed coordinate system (ECR) \(O\) as the earth’s core, \(S\) as the position of the satellite, \(S’\) as the position of substellar point, \(T\) as the object point (elevation is \(H\) ) on the earth surface, \(T’\) as its projection point on the earth ellipsoid surface, and \(R_e, (R_p)\) as the position vector in the ECR of \(S, (T)\). So \(R_s = R_p - R_e\) describes the vector pointing \(T\) to \(S\). Local incidence angle \(\eta\) is calculated by equation 4 and projection angle by equation (5).

\[
\cos \eta = \frac{\hat{n} \cdot \hat{R}_{ts}}{\| \hat{n} \| \| R_{ts} \|}
\]

\[
\cos \psi = \frac{\hat{n} \cdot \left| R_{ts} \times R_{ts} \times R_e \right|}{\| \hat{n} \| \| R_{ts} \times R_{ts} \times R_e \|}
\]
Where $\hat{n}$ is the normal vector of the earth surface cell located object point $T$. The topography radiometric correction equation is obtained by equation (4) and (5) using incidence angle and projection angle:

$$\sigma^0 = \frac{\sigma'^0}{\sin \theta} \sin \eta$$  (6)

$$\sigma^0 = \frac{\sigma'^0}{\sin \theta} \cos \psi$$  (7)

Where $\theta$ is as the radar incident angle assuming that the earth surface is the ellipsoid surface, and $\sigma'^0$ as the backward scattering coefficient. It is noteworthy that the result of the backward scattering coefficient $\sigma'^0 (m^2 m^{-2})$ with nonlinear transformation is different from $\sigma^0 (dB)$ with linear transformation because of the nonlinear progress of topography radiometric correction. Doing topography radiometric correction, we should enter the backward scattering coefficient $\sigma'^0 (m^2 m^{-2})$ into equation (6) and (7), then make its valve transform to dB valve.

3. Test Area and the Data

The study area of this paper is located in Zhayi Forest of Guizhou province, the size of study area is about 20 km*20 km. In study area the terrain ups and downs, the elevation range is 600~1700 m. This study area is conducive to verify the validity of the new method. The experimental data is Radarsat-2 Single Look Complex data, the resolution is 8m, and the specific parameters are shown in table 1. The DEM model data is standard 1:50 000 scale DEM data, which provided by National Administration of Surveying, Mapping and Geoinformation, the spatial resolution is 25 m.

According to the Radarsat-2 data technical documentation, the adjusted results of Radarsat-2 image with 8 m resolution should be sampled to 3.13 m, while the resolution of the DEM is 25 meters, and this will lead to the under sampling of simulated image, then it is necessary to carry out sampling process to DEM. The final DEM re-sampling rate is decided by formula (6) [4].

$$f \geq \left[ \frac{\delta_{rg}}{\delta_r} \sqrt{\frac{\Delta S_{out}}{2 \Delta S_{dem}}} \right]^{-1}$$  (8)

In formula, $\delta_{rg}$ is ground distance resolution of radar image, $\delta_r$ is oblique distance resolution of radar image, $\delta_{rg}/\delta_r = 1/\sin \theta$, $\theta$ is incidence angle of radar image; $\Delta S_{dem}$ is the original size of DEM, $\Delta S_{out}$ is the size of the output pixel of the simulated image. According to formula (8) the final DEM will be sampled to 5m, so we can ensure that each pixel of the simulated image will be at least assigned once in the simulation process. In order to obtain the better effect after re-sampling from original DEM, the cubic convolution interpolation method was carried out on the original DEM data sampling step by step, this can ensure that in each step after re-sampling the before sampling resolution when divided by the sampling resolution is less than 3.

| Table 1. System parameters of Radarsat-2 data |
|-----------------------------------------------|
| **Radar Satellite** | Radarsat-2 |
| Level | SLC |
| Acquire date | 2009/2/8 |
| Ascending and Descending | Descending |
| Incidence angle (unit: °) | 40.34 |
| Azimuth resolution (unit: meters) | 5.12 |
4. Results and Discussion

4.1. Orthographic Correction Effect Assessment

In order to quantitatively evaluate orthographic correction effect, this paper by using 1:1 0000 digital topographic map (DRG) for reference, analyzed the positioning accuracy of Radarsat-2 correction results, the results as shown in Table 2.

Through the analysis of the positioning accuracy, the positioning accuracy of Radarsat-2 orthographic correction result in east and west direction is about 15 meters and the north and south direction is about 45 meters, compared to the resolution of the Radarsat-2 itself, the positioning accuracy is high, and this proves that it is effective using the above methods for high resolution radar satellite Radarsat-2 data orthographic correction.

Table 2. Positioning accuracy analysis of orthographic correction results based on RD location model

| No. | X coordinate of DRG | Y coordinate of DRG | X coordinate of Radarsat-2 orthographic images | Y coordinate of Radarsat-2 orthographic images | dX(m) | dY(m) |
|-----|---------------------|---------------------|-----------------------------------------------|-----------------------------------------------|-------|-------|
| 1   | 672770.864          | 2970497.183         | 672790.696                                    | 2970465.772                                    | -19.832 | 31.411 |
| 2   | 677316.567          | 2971458.724         | 677330.486                                    | 2971418.680                                    | -13.919 | 40.044 |
| 3   | 658260.804          | 2979256.470         | 658267.458                                    | 2979203.456                                    | -6.654 | 53.014 |
| 4   | 665861.075          | 2982663.367         | 665867.127                                    | 2982633.390                                    | -6.052 | 29.977 |
| 5   | 672895.287          | 2983721.548         | 672907.456                                    | 2983689.059                                    | -12.169 | 32.489 |
| 6   | 656679.879          | 2970421.380         | 656700.245                                    | 2970381.004                                    | -20.366 | 40.376 |
| 7   | 669675.319          | 2975956.899         | 669696.531                                    | 2975924.586                                    | -21.212 | 32.313 |
| 8   | 664509.917          | 296713.910          | 664528.453                                    | 296684.393                                    | -18.536 | 29.517 |
| 9   | 679009.950          | 296292.2148         | 678994.501                                    | 296289.880                                    | 15.449 | 27.268 |
| 10  | 676583.453          | 2974709.069         | 676603.201                                    | 2974666.302                                    | -19.748 | 42.767 |

4.2. Topography Radiation Correction Effect Assessment

After the orthographic process of radar images, the range image is converted into back scattering coefficient, and when put in formula (6) and (7), the SAR image contrast before and after the topography radiation correction as shown in Figure 1.

From visual effect, the geometric image distortion after terrain correction has been effectively suppressed, the difference between light and shade of toward and backward radar has been cut effectively, but the very bright area on original orthographic image is still not eliminate, these areas are mainly overlapping area, because the overlapping area is more than one feature point imaging into an image point, which cannot be eliminated through the topography radiation correction method based on single SAR image, and need to use more apparent SAR image method to eliminate. The shaded area due to no radar wave radiation to the region also cannot use the same method for radiation calibration.

Figure 1. SAR image contrast before and after topography radiation correction (a) SAR image after orthographic correction; (b)SAR image after topography radiation correction based on local incidence; (c) SAR image after topography radiation correction based on project angle.
The important index that measures the effect of terrain on the backward scattering whether effectively be eliminated is image variance reduction percentage before and after correction, which is used by almost all researchers. The index \( \alpha \) is expressed as:

\[
\alpha = \left( \frac{s_1^2 - s_2^2}{s_1^2} \right) \times 100\%
\]  

Table 3. Statistics of variance of back scattering coefficients before and after topography radiation correction

|                | \( S_0 \)         | \( S_1 \)         | \( (S_0 - S_1)/S_0 \) |
|----------------|-------------------|-------------------|------------------------|
| Local incidence angle | 7.679721          | 7.094845          | 7.62%                  |
| Projection angle    | 7.679721          | 7.005542          | 8.78%                  |

From the above chart we can see that, after topography radiation correction, image variance has been effectively reduced, which suggested that the topography radiation correction based on the projection angle and local incidence angle is effective. The variance of method based on projection angle reduces less than the method based on local incidence angle, which suggested that topography radiation correction method based on projection angle is more effective, that is in consistent with the conclusion of literature 6, in the practical application the projection angle is the recommended method for topography radiation correction processing.

4.3. The Rationality Based on the Initial Positioning Model Calculating Local Incidence Angle and Projection Angle

Through statistics, we found that in this experiment for the initial positioning model the oblique distance error in distance direction is about 4.76 SLC pixel size, orientation error is about 16.6 SLC pixel size, equivalent to 22.99 m and 84.99m, respectively, but this is a small amount compared to the height of the satellite to the center of the earth (about 716 km) and the minimum slant distance from satellite to the features (about 1000 km), the local angle of incidence and angle of projection of the calculated value of change can be ignored. Therefore, even though the experiment SAR data has initial orbit error, but will not have a significant impact for local incidence angle and projection angle calculation, this shows that local incidence angle and projection angle were calculated based on initial positioning model are reasonable and effective.

5. Conclusion

In this paper, SAR orthographic correction and terrain radiant correction model based on strict SAR imaging geometric model and calibration formula are given, the experimental results show that the positioning accuracy is higher, orthographic correction can meet the requirements. The image variance significantly reduced after terrain radiant correction, and the terrain radiant correction image texture characteristics comparison before and after correction also shows that the influence of terrain has been effectively eliminated, and this demonstrates that the method of this paper is correct and effective; the quantitative evaluation of the two kinds of effective terrain radiant correction method showed that the method based on projection angle is more effective to remove the influence of terrain; this paper also analyse the terrain radiant correction factor calculation rationality based on initial positioning model, and found that the calculation results is not sensitive to initial positioning error model, the calculation of terrain radiant correction factor based on the initial positioning model is effective. This paper provides the SAR image processing a general and effective method.

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