Research on Terrain Radiation Correction Based on PALSAR Dual Polarization Radar Image

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Abstract. In the rugged mountains, the undulations of the terrain will affect the geometric and radiation characteristics of SAR imaging, resulting in SAR image distortion, which hinders its comprehensive application in the field of land subsidence monitoring, landslide disaster monitoring and so on. This article takes ALOS PALSAR as an example, combined with satellite orbit fitting technology to optimize parameters, based on the R-D positioning model, using DEM to simulate SAR images and extract parameters such as local incident angle, projection angle, and backscatter coefficient. The simulated SAR image is used to achieve the ortho-rectification of the original SAR image. The calculation method of the local incidence and projection angles and the backscattering coefficient is used to construct the terrain radiation correction model of the SAR image. The experimental results show that the research method is significantly effective, the mean square error of the radiant intensity of the image after correction is significantly reduced, and the texture characteristics of the image are significantly enhanced. This has certain practical significance for the application research on SAR image in information extraction, interpretation, quantitative analysis and parameter inversion.

1. Introduction

Synthetic Aperture Radar (SAR) is an active ground observation system with all-weather, high-resolution, and multi-polarity characteristics. It is widely used in agricultural, water conservancy, mountainous disaster monitoring and other fields. However, due to its unique imaging mechanism, the topographic fluctuations will make the echo received by the ground of each pixel during imaging very different, which will cause SAR images to have geometric and radiative distortions such as perspective shrinkage, shadows and overlay are produced. Therefore, before using SAR for classification and quantitative parameter inversion research, terrain effect removal is needed, that is, terrain radiation correction. In this paper, combined with relevant research experience, using ALOS PALSAR dual-polarization images, based on optimized imaging parameters, the method of local incidence angle and projection angle is used to study the correction of terrain radiation. The two methods are compared and analyzed experimentally.
2. Range - Doppler (R-D) model

The Range-Doppler (R-D) model was first proposed by Brown, W.E, etc. in 1981[1], and then in 1982 Curlander et al. [2] experts and scholars based on this model to establish three basic equations based on radar image composition.

Figure 1 shows a schematic diagram of the SAR imaging geometry. S represents the position of the satellite. Its position vector and velocity vector are $\vec{R}_s$ and $\vec{V}_s$ respectively, T is a feature point on the surface of the earth, and the projection point of the feature T on the surface of the ellipsoid is T', TT' is the elevation h of the ground point. Let the coordinate vector of the feature point T be $\vec{R}_t$. For the WGS-84 ellipsoid, the Earth's equatorial radius is $R_a = 6378137m$, and the spherical pole radius is $R_p = 6356752.3 m$. R is the distance from the satellite to the target T; $f_D$ is the Doppler center frequency corresponding to the T point; $\lambda$ is the radar wavelength. The R-D positioning model is to establish the relationship between the image point (i, j) and the feature $(X_t, Y_t, Z_t)$ from the geometric perspective of SAR imaging. From this, three equations of the R-D localization model are obtained, where: Equation (1) is the T coordinate vector of the feature $(X_t, Y_t, Z_t)$ the ellipsoid equation to be satisfied; Equation (2) is the distance equation satisfied by the satellite position vector and the target vector; Equation (3) is the Doppler frequency shift equation [3].

\[
\begin{align*}
\left( X_t^2 + Y_t^2 \right) / (R_a + h)^2 + Z_t^2 / R_t^2 &= 1 \\
R^2 &= (X_t - X_s)^2 + (Y_t - Y_s)^2 + (Z_t - Z_s)^2 \\
f_D &= -\frac{2}{\lambda} \frac{(R_w - R_s)(V_w - V_s)}{R}
\end{align*}
\]

The simultaneous equations (1) to (3) can be solved to obtain the corresponding geographic location of each pixel. The parameters of the R-D positioning model can be extracted from the PALSAR header file.

3. SAR Image Simulation and Ortho-rectification

3.1 Overview of the study area

The research area of this paper is located in the joint area of Maoxian and Anxian in the northwest of Sichuan Province, spanning the Minjiang River and the high mountain valley of the upper Minjiang River. This area is lined with mountains, deep rivers, high terrain, and complex geological structure. It is located in the Longmenshan seismic zone and is one of the seismically active areas in the country. The SAR image used is PALSAR dual polarization radar image. The longitude range of the study area
is 103° 35′47″ E-104° 22′40″ E, and the latitude range is 31° 23′48″ N-32° 00′ 13″ N, as shown in Table 1, are the main parameters of ALOS PALSAR data.

Table 1. Main parameters of ALOS PALSAR image

| Imaging time | Polarization mode | Central latitude and longitude(°) | Angle of incidence(°) | Wavelength (m) |
|--------------|-------------------|----------------------------------|-----------------------|----------------|
| 20100911     | HH/HV             | 103.9757E 31.6944N                | 38.7402               | 0.2361         |
| First slope distance (m) | Pulse repetition Frequency (HZ) | Chirp width (MHZ) | Distance Resolution (m) | Azimuth Resolution (m) |
| 846717       | 2141.3276        | 14                               | 9.36851               | 3.16603        |

3.2 SAR Image Simulation and Ortho-rectification

Because the spatial resolution of the simulated SAR image is usually much larger than the spatial resolution of the DEM image, in order to avoid the problem of undersampling of the original SAR image, the original DEM needs to be oversampled before the simulated SAR to ensure the image of the simulated SAR image. Spatial continuity of meta values [4]. In order to take into account the physical meaning of the model and facilitate the calculation, this paper uses the semi-empirical backscattering coefficient model [5] proposed by Muhelman, and substitutes the local incident angle η of Equation (4) into the backscattering model of Equation (5) to calculate the radar Scattering cross section σ.

\[
\eta = \cos \left( \frac{\hat{R}_n \hat{R}_m}{|\hat{R}_n||\hat{R}_m|} \right)^{-1} \quad (4)
\]

\[
\sigma = \frac{0.133\cos \eta}{(\sin \eta + 0.1\cos \eta)^{5}} \quad (5)
\]

Firstly, the row and column coordinates are read from the oversampled DEM, and the satellite orbits are fitted according to the imaging parameters provided by the PALSAR header file, so as to obtain optimized parameters with good accuracy. Using the optimized imaging parameters, the state vector of the satellite at any time can be obtained. Then, based on the R-D positioning model, iterative calculation is used to obtain the rectangular coordinates of the ground point space, which are converted into the geodetic coordinates, and the gray value of the image is determined using the nearest neighbor method [6]. Figure 2 shows the simulated SAR image. Obviously, the texture features of the simulated SAR are more prominent, which means that the richer the texture information, the more feature points can be monitored.

Establish a mapping relationship between the row and column coordinates of the points on the DEM obtained in the process of the simulated SAR image and the corresponding row and column coordinate information of the simulated SAR image, automatically extract feature points to match, and build a polynomial relationship between the simulated SAR image and the real SAR image, to achieve ortho-rectification of SAR images [7]. Figure 3 shows the ortho-rectified SAR image. It can be clearly seen from the figure that the texture characteristics of the SAR image after ortho-rectification are more pronounced, and the distortion such as perspective shrinkage and shadow overlay have been slightly improved. In particular, the location characteristics of SAR images have undergone significant changes after ortho-rectification, indicating the effectiveness of the correction method. However, the topographic effects of SAR images after ortho-rectification have not been completely eliminated.
4. Terrain radiation correction method

The backscatter coefficient $\sigma^0$, the local incidence angle image $\eta$, and the projection angle image $\psi$, can be extracted from the ortho-rectified SAR image, and these parameters can be substituted into the terrain radiation correction formula to complete the terrain radiation correction. According to the SAR geometrical constellation map, the terrain radiation correction formulas with local incident angle and projection angle as correction factors are respectively equations (6) and (7) [8].

$$\sigma^0 = \frac{\sigma^0}{\sin \theta} \sin \eta = \beta_i \sin \eta$$  

$$\sigma^0 = \frac{\sigma^0}{\sin \theta} \cos \psi = \beta_i \cos \psi$$  

The parameters of the local incident angle and projection angle are calculated during the SAR image simulation process, when the SAR image is ortho-rectified, the parameters of the local incident angle and projection angle are not recalculated, so the terrain radiation is based on this parameter. The correction will cause a certain error, so these two parameters need to be calculated in the optimized model. The technical process will be more rigorous, and the resulting terrain radiation correction image will be better.

The algorithm for radiating correction of SAR images based on local incident angle is a practical and easy-to-implement research method. This algorithm combines external DEM and radar reverse coding technology to obtain the local incident angle $\eta(i, j)$ at the image pixel $(i, j)$, so as to obtain the corrected normalized scattering coefficient, which is substituted into equation (8). available:

$$\eta = \cos \left( \frac{\hat{R} \cdot \hat{n}}{\| \hat{R} \|} \right)^{-1}$$  

Substituting equation (8) into equation (6) can complete the terrain radiation correction. Figure 4 shows the terrain radiation correction SAR image based on local incident angle method.

The calculation method based on the projection angle was proposed by Ulander[9] in 1996. This method uses the component $\hat{u}$ and the distance component $\hat{v}$ of $\hat{n}$ in the azimuth direction and relates the incident angle $\theta$ of the ground unit to achieve the projection angle calculation. The projection angle calculation formula proposed by Ulander is shown in equation (9):

$$\psi = \cos \left( \sin \theta \cdot \cos \hat{u} + \cos \theta \cdot \sin \hat{u} \cdot \sin \hat{v} \right)^{-1}$$  

Using the above formula, a calculation method based on the projection angle is used to correct the terrain radiation of the SAR image. Figure 5 shows the terrain radiation corrected SAR image based on the projection angle method.
Figure 4. Terrain radiation corrected SAR image based on local incidence angle method.

Figure 5. Terrain radiation corrected SAR image based on projection angle method.

Since the image mean square error can measure the degree of dispersion of $\sigma^0$ in the image, it is determined based on the difference in the brightness values of the image pixels. If the difference is smaller, the image mean square error will be smaller. On the contrary, the value of the mean square error bigger. Therefore, in order to evaluate the effect of this correction method, this article uses the percentage reduction of the mean square error of the image before and after the terrain radiation correction to measure, that is,

$$\frac{S_1 - S_2}{S_1} \times 100\%$$

(10)

Among them, $S_1$ is the mean square error of the image before correction, and $S_2$ is the mean square error of the image after correction, as shown in Table 2 is a statistical table of the mean square error of the image before and after topographic radiation correction.

| Calibration status | $S_1$   | $S_2$   | $S_1$-$S_2$ |
|--------------------|--------|--------|-------------|
| Local incident angle | 4.97594 | 4.52307 | 4.97594-4.52307 |
| Projection angle   | 4.97594 | 4.41496 | 4.97594-4.41496 |

It can be seen from Table 2 that the mean square error of the radiation intensity of the SAR image after terrain radiation correction is significantly reduced, indicating that the overall brightness difference of the image is reduced, and the texture characteristics of the image are significantly enhanced before and after the terrain radiation correction. The rationality and effectiveness of the method are verified.

In order to further analyze the results, a statistical analysis of the scatter plot of the distribution of pixel intensity values between the corrected $\sigma^0$ and the local incident angle $\eta$ is performed. The results are shown in Figures 6 (a), 6 (b), and 7 (a), 7 (b). Different colors in the figure represent different degrees of density, of which yellow means less density and red means greater density. The darker the color, the higher the density of the points.

Figure 6 (a) and Figure 6 (b) are scatter plot relationships between $\sigma^0$ of different dual polarization modes HH and HV and local incident angle $\eta$. The local incident angle $\eta$ can indicate the characteristics of terrain fluctuations. It can indicate the severity of the radiation distortion caused. It can be seen from the figure that where the scattered points are concentrated in the position of the backscattering coefficient $\sigma^0$ corresponding to the smaller and larger local incident angle $\eta$, this distribution also conforms to the Topography of the study area. Figures 7 (a) and 7 (b) are also scatter plot relationships between the backscatter coefficient $\sigma^0$ and the projection angle of the HH and HV polarization modes. As can be seen from the figure, with respect to the local relationship between the
incident angle and the backward scattering coefficient, the more uniform the projection angle between the scattergram scattering coefficient, the deepest color is also stabilized. If a straight line is fitted in the scatter plot, it can be shown that the slope of the straight line in Figs. 7 (a) and 7 (b) is obviously smaller than that of the straight line in Figs. 6 (a) and 6 (b). Because the slope of the fitted straight line will be more horizontal in Figures 7 (a) and 7 (b), this shows that the terrain effect has been basically eliminated. The method of image terrain radiation correction based on the projection angle is relative to the local incidence angle. Method is more effective.

5. Conclusion
This article takes ALOS PALSAR dual-polarization data as an example, extracts its imaging parameters and simulates satellite orbits to obtain optimized parameters. Based on the optimized parameters of the R-D positioning model, the original SAR images are simulated and matching techniques are used to obtain SAR ortho-rectified images. Based on this, combining the calculation method of local incident angle and projection angle and the backscatter coefficient to perform the terrain radiation correction of SAR image, the following conclusions are obtained.

Conclusion 1: Using the imaging parameters extracted from the PALSAR header file to perform SAR image simulation and SAR image ortho-rectification can obtain better correction accuracy.
Conclusion 2: The terrain radiation correction effect based on the projection angle calculation method is better, and this technique can effectively eliminate terrain distortion.

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