New method for airborne SAR image positioning

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Abstract: Synthetic aperture radar (SAR) geometric positioning obtains the geodetic coordinates of each pixel in a SAR image. However, due to the changes in geometry, position and attitude angle of the sensor and the influence factors such as topography, atmospheric refraction, plus the curvature and rotation of the earth, image deformation will occur. Therefore, there is a great practical significance to explore the precise geometric positioning method for SAR images. It proposed a new positioning method combining range-Doppler model and polynomial model, realising SAR image accurate positioning with the digital elevation model data. The method considers the effects of terrain-height-induced geometric distortions and establishes a practical positioning model based on the geometric relationship of imaging. The result shows that the positioning accuracy of the proposed method is higher than the accuracy of the traditional rang-Doppler model and polynomial model with a small number of ground control points.

1 Introduction

Synthetic aperture radar (SAR) [1] is a all-weather remote sensing ground observation technology that can obtain high-resolution radar images similar to optical images under extremely low visibility weather conditions. SAR has attracted widespread attention for its high-accuracy and high-resolution terrain information acquisition. Airborne SAR remote sensing imagery is a useful complement to optical remote sensing images and is widely used in terrain mapping, land and resources surveys, crop estimation, hydrological monitoring and disaster assessment. SAR images have geometric distortions caused by non-ideal motion state, terrain height and others. Therefore, it is significant to develop accurate geometric positioning methods for SAR images in practice.

The traditional geometric positioning models [2] are polynomial model [3] and range-Doppler model [4]. The polynomial model achieves plane positioning by fitting the polynomial transformation relationship between the SAR image coordinates and geodetic coordinates. However, this model lacks strict geometric relationships and relies on a large number of ground control points (GCPs). The range-Doppler model has a strict geometric relationship, but it cannot give a closed expression of the target location and it is not convenient for calibration processing. Moreover, the existing algorithms based on both models have many shortcomings in practical applications. For example, Zhang et al. proposed polynomial localisation algorithm [5] which has many unknown parameters and has strong dependence on GCPs, and it is unstable. Ma et al. proposed range-Doppler location algorithm [6] which is based on zero Doppler. The assumption does not apply to real data processing. Zhang and Sun proposed the airborne SAR direct location algorithm [7], which lacks the necessary parameter calibration and the accuracy is difficult to guarantee. Considering this, based on the imaging geometry of SAR images, taking the influence of terrain height into account, the paper establishes a practical geometric positioning model combining range-Doppler model and polynomial model, realising accurate positioning with the use of the digital elevation model (DEM). The SAR image is initially resampled to a uniform range image. The range-Doppler equations are used to locate, and then reposition to obtain a simulated geodetic space with the DEM. Finally, a polynomial model between the simulated location and the real location is established and the polynomial coefficient is corrected by the least-squares method.

2 Methodology

The use of several GCPs in flat areas can achieve accurate correction of SAR images. However, in the complex terrain areas, the distortion of the image produced by the terrain undulations is very large. It is difficult to achieve accurate correction of terrain relief areas with only a certain number of control points. Therefore, accurate correction of each pixel of the image must be performed based on the DEM. Under the circumstances that the DEM data grid interval has a low precision and that it is hard to directly establish the mapping relationship between SAR image and DEM, it is difficult for DEM to be directly applied to the accurate correction of SAR images. Therefore, an intermediate link must be established. This article is divided into three steps:

- Slant range to ground range projection.
- Range-Doppler positioning.
- Polynomial model.

According to the slant range to ground range projection and range-Doppler equations, the SAR image pixels initially are located to obtain the geodetic coordinates. Also then the DEM is used to reposition to generate a simulated SAR image. The link between the simulated image and the real image is established. Moreover there is a fixed mapping relationship between the simulated image and the SAR image. So the mapping relationship between the real image and the SAR image is established.

2.1 Slant range to ground range projection

Slant range to ground range projection converts the slant range image which is the time-uniformly sampled original SAR image, to the ground range which is the ground-to-space uniformly sampled image. In practical operation, starting from the ground range image, the slant range image should be converted to the uniformly sampled ground range image by finding the corresponding ground range sampling point in the SAR image

\[
x_g = \sqrt{r^2 - (H - h)^2} \\
y = r \times PRF
\]

(1)

where \((x_g, y)\) is the range-azimuth coordinate in the ground range image, \(r = r_0 + x \cdot d_r\) and \(r_0\) is the nearest slant range from sensor to
ground, \( d_s \) is the ground range sampling interval, \( x \) is the ground range coordinate of pixel point slant range image. \( H \) is the height of the aircraft and \( h \) is the average terrain height. PRF is the pulse repetition frequency and \( t \) is the slow time.

2.2 Range-Doppler location

The existing classic method of solving R-D model is Newton iteration method. However, due to the strictness of Newton’s iterative selection of initial values, considering positioning accuracy and practicality, this paper uses the least-squares method to perform the coding experiment

\[
F_1 = \sqrt{(X_s - X_s)^2 + (Y_s - Y_s)^2 + (Z_s - Z_s)^2} - R
\]

\[
F_2 = (V_{Xs}(X_s - X_s) + V_{Ys}(Y_s - Y_s) + V_{Zs}(Z_s - Z_s))/R + 2f_{DC}
\]

\[
F_3 = \frac{X_i^2 + Y_i^2 + Z_i^2}{(R_s + h)} - 1
\]

(2)

\[
x = \begin{bmatrix} dx \\ dy \\ dZ \end{bmatrix}, \quad B = \begin{bmatrix} \frac{\partial F_1}{\partial X_s} & \frac{\partial F_1}{\partial Y_s} & \frac{\partial F_1}{\partial Z_s} \\ \frac{\partial F_2}{\partial X_s} & \frac{\partial F_2}{\partial Y_s} & \frac{\partial F_2}{\partial Z_s} \\ \frac{\partial F_3}{\partial X_s} & \frac{\partial F_3}{\partial Y_s} & \frac{\partial F_3}{\partial Z_s} \end{bmatrix}
\]

(3)

\[
l = \begin{bmatrix} -F_1 \\ -F_2 \\ -F_3 \end{bmatrix}, \quad V = \begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix}
\]


















































































































































































































































































































































































































































































































































































































































































































































































































































































































































































The RMSE of monitoring points by different methods is listed in Table 3. By this comparison and analysis, it can be found that the positioning method proposed in this paper is of higher accuracy than the traditional polynomial positioning method and range-Doppler positioning method with a small number of GCPs.

### 4 Conclusion

This paper proposes an improved positioning method based on simulated pixel. Firstly, the slant range image is converted to the ground range image. The range-Doppler equation is used to locate and then the DEM is used to reposition to obtain the simulated geodetic coordinates. Also then establish the polynomial model between the real geodetic coordinates and the simulated geodetic coordinates, and the polynomial coefficients are corrected by the least-squares method. In this way, the mapping relationship of the image of the simulated geodetic coordinate space to the real geodetic coordinate space is established, and then the mapping relationship between the SAR image coordinates and the geodetic coordinate space is established. The geometric positioning of the SAR image is realised.

Compared with the traditional polynomial model lacking strict geometric relationship and the range-Doppler model not giving the closed-form expression of the target position and inconvenient to calibration processing, the method not only considers the spatial geometrical process of imaging, but also is easy to implement. With a small number of control points, accurate positioning can be performed effectively. However, this method is more complicated than the polynomial model in areas where the topography is less fluctuating, and the accuracy is not much more improved. It needs to be further optimised.

### 5 References

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