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Constructing DEM Based on InSAR and the Relationship between InSAR DEM’s Precision and Terrain Factors

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Abstract

In this paper, taking the ENVISAT satellite SAR images in Bam city as an example, the authors construct Digital Elevation Model (DEM) with InSAR technology, and by comparing the InSAR DEM with SRTM-3 DEM they also research the relationship between InSAR DEM’s precision and terrain factors represented by slope and aspect. The results show that the elevation difference mean error between InSAR DEM and SRTM-3 DEM of the experiment area is 12.50 meters, and the precision is reduced with the increase of slope but basically has nothing to do with aspect. In this paper, taking the ENVISAT satellite SAR images in Bam city as an example, the authors construct Digital Elevation Model (DEM) with InSAR technology, and by comparing the InSAR DEM with SRTM-3 DEM they also research the relationship between InSAR DEM’s precision and terrain factors represented by slope and aspect. The results show that the elevation difference mean error between InSAR DEM and SRTM-3 DEM of the experiment area is 12.50 meters, and the precision is reduced with the increase of slope but basically has nothing to do with aspect.

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Key Words: InSAR; Digital Elevation Model (DEM); precision; slope; aspect

1. Introduction

High-quality, high-precision topographic information is crucial for geological & hydrological model building, geomorphologic analysis and natural disaster analysis. There have been continuous efforts throughout the world to obtain high-quality, high-resolution, high-precision 3D digital product—digital

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elevation model (DEM). InSAR technique is able to utilize phase information carried by radar echo signal to compile 3D topographic information. Thus, it has become one of the major approaches to quickly and accurately obtain DEM, representing a new direction of radar remote sensing study [1].

InSAR DEM precision is mainly affected by topographic factors, spatial baseline, temporal baseline, atmospheric delay and other factors. Both domestically and internationally, many achievements have been made on InSAR-based DEM construction and its relationship with topographic factors. Liu Guoxiang and Cai Guolin et al [2,3] studied InSAR DEM construction and analyzed its precision. Thierry Toutin [4] studied the relationship of DEM precision to slope gradient and aspect. In our study, SAR image data from EMS satellite ENVISAT of European Space Agency is used to construct DEM, and the relationship of DEM to topographic factors is further investigated.

2. Basic principle of InSAR

In InSAR technique, phase difference between two echo signals of the same region is used for elevation information acquisition to build DEM of the target area and obtain its 3D coordinates. According to the method of SAR image acquisition, InSAR can be divided into single-antenna repetitive-orbit SAR system and double-antenna double-orbit SAR system, which share the same basic principles. The next section takes single-antenna repetitive-orbit SAR system as an example to illustrate the basic principle of DEM construction based on InSAR.

Figure 1 is the schematic diagram illustrating the basic principle of InSAR. Figure S1 and S2 show the position of two antennas spaced by the distance B. The angle between baseline and the horizontal direction is \( \alpha \); H is the platform height. The slant range from point P on the ground to antenna S1 is \( \rho_1 \), and that to antenna S2 is \( \rho_2 \). \( \theta \) is the reference angle of sight of the first antenna; elevation at point P is h. The difference between \( \rho_1 \) and \( \rho_2 \) can be calculated by the absolute phase difference \( \phi_a \) of the corresponding pixel (where \( P=1 \) for double-antenna SAR system, and \( P=2 \) for satellite-born single-antenna repetitive-orbit SAR system):

\[
\rho_1 - \rho_2 = \delta_\rho = \frac{\lambda}{P.2\pi} \phi_a
\]  

(1)

From the geometric model in Figure 1, we can obtain the following formula:

\[
\cos(\theta - \alpha) = \sin(\theta + \alpha) = \frac{\rho_1^2 + B^2 - \rho_2^2}{2\rho_1B}
\]  

(2)
Since \( \rho \gg B \) that

\[
\delta_\rho \approx B \sin(\theta - \alpha)
\]  

(3)

Using \( \theta \) determined by Formula (2) and (3), the elevation at point P can be calculated by Formula (4) as follows:

\[
h = H - \rho \cos \theta
\]

(4)

To sum up, InSAR technique can be used to obtain the elevation information in the target area.

3. DEM construction procedure based on InSAR in the experimental zone

3.1. Experimental data

Bam in Iran, known as the “jade of the desert”, has arid climate, scarce ground surface vegetation and small spatial coherence, which makes it a typical target area of InSAR. In this study, two SAR images captured by ENVISAT satellite on June 11\(^{th}\) and December 3\(^{rd}\) 2003 are used as experimental data to construct DEM based on InSAR. Table 1 shows the basic parameters of experimental data.

Table 1. Basic parameters of experimental data

<table>
<thead>
<tr>
<th>Product name</th>
<th>Acquisition time</th>
<th>Orbit number</th>
<th>Orbit direction</th>
<th>Temporal baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>orbit66_11jun03.n1</td>
<td>2003. 6. 11</td>
<td>6687</td>
<td>Descending orbit</td>
<td></td>
</tr>
<tr>
<td>orbit91_03dec03.n1</td>
<td>2003.12.03</td>
<td>9192</td>
<td>Descending orbit</td>
<td>172 days</td>
</tr>
</tbody>
</table>

3.2. DEM construction procedure

In DORIS interferometric SAR software, images at No.6687 and No.9192 orbits are respectively primary and secondary images. DEM in the experimental area is constructed in accordance with data processing procedure shown in Figure 2. The following steps are followed to construct DEM based on InSAR technique:

3.2.1. Registration of primary and secondary images

Image registration is one key to DEM construction based on InSAR technique. After reading header files of primary and secondary images as well as orbital information, precise image registration is necessary to obtain accurate interferometric phase. Currently, image registration algorithms in InSAR data processing include coherence coefficient method, maximum interferometric spectral imaging method and average phase difference image fluctuation function method. In our experiment, maximum interferometric spectral imaging method is adopted to process the image data in the experimental area for accurate image registration.

3.2.2. Interferogram generation

The second step is to generate high-quality interferogram by complex conjugate multiplication of two registered images.
3.2.3. Interferogram filtering and unwrapping

As high-quality interferogram is essential for DEM generation, various noises must be filtered, i.e., feed forward filtering and feed backward filtering. Interferogram filtering includes spatial convolution filtering and Goldstein filtering, and the former is adopted in this study. After interferogram filtering, the obtained phase difference is only the principal value in the range \((-\pi, +\pi]\). To obtain the true phase difference, we have to add to or subtract from this value by integer multiples of \(2\pi\), which is called phase unwrapping. Phase unwrapping can be divided into phase unwrapping algorithm based on path integral and that based on minimum norm.

3.2.4. DEM generation

According to Formula (2), (3) and (4), the unwrapped phase can be converted to DEM.

4. Analysis of InSAR DEM precision and its relationship to topographic factors

4.1. DEM precision analysis based on InSAR

SRTM-3 DEM jointly generated by NASA and NIMA is chosen as the reference standard for precision assessment \(^\text{[5]}\). DEM precision values constructed in this paper are analyzed by subtraction for the same area. Table 2 shows the parameter information of SRTM-3.

Table 2. Parameter information of SRTM-3

<table>
<thead>
<tr>
<th>Data name</th>
<th>Product type</th>
<th>Elevation precision</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>srtm_48_07.zip</td>
<td>SRTM90mDEM</td>
<td>30m</td>
<td>25N-30N</td>
<td>55E-60E</td>
</tr>
</tbody>
</table>

Using matlab software \(^\text{[6]}\), SRTM-3 DEM is read. Then InSAR DEM generated in our study is matched with SRTM DEM by homonymous points. Surfer software is used to cut out the same region (north latitude \([28.9^\circ, 29.05^\circ]\), east longitude \([58.9^\circ, 59.05^\circ]\)) from InSAR DEM and SRTM DEM. Through subtraction, elevation difference map is obtained. Figure 3-(a) shows DEM generated in the experimental area in our study; Figure 3-(b) shows the reference DEM; Figure 3-(c) shows the difference map after the subtraction; Figure 3-(d) shows the distribution of elevation difference.

The standard deviation of elevation difference is 12.50m. Figure 3-(d) indicates that error basically follows normal distribution, with small discretization and steep distribution curve. As we can see from Figure 3-(c), elevation has high precision in flat areas but low precision in areas with fluctuating topography. That is, areas with complex topographic features have increased elevation differences; elevation difference shows similar variation with DEM. Therefore, elevation precision is closely associated with topographic factors.

4.2. Relationship of InSAR DEM to topographic factors

Topographic factor is a mathematical parameter quantitatively representing the topographic features. To analyze the relationship between topographic factors and DEM precision, we select two topographic factors, slope and aspect to analyze DEM based on InSAR. Slope gradient describes locally the inclination angle of slope; aspect refers to the direction in which the slope faces. At present, there are many mathematical models available for the calculation of slope gradient and aspect in DEM. The DEM calculation method based on grid is adopted in this study \(^\text{[7]}\). Slope (S) and aspect (A) at a specific point
on the ground are functions of the elevation variation of curved surface \( Z = f(x, y) \) in east-west direction and north-south direction.

\[
S = 180 / \pi \tan^{-1} \left( \sqrt{(\Delta x)^2 + (\Delta y)^2 / 2} \right) \quad (5)
\]

\[
A = \tan^{-1}(\Delta x / \Delta y) \quad (6)
\]

where \( \Delta x \) is the variation rate of elevation in east-west direction; \( \Delta y \) is the variation rate of elevation in north-south direction.

Using Formula (5) and (6) and Topographic Analysis in ERDAS IMAGINE 9.2 software, the slope gradient and aspect at each point of the experimental zone in DEM are calculated, in order to further discuss the impact of topographic factors on DEM precision.

Figure 4-(a) is the statistical graph of slope in the gradient range 0°-68° at the step length of 4°; Figure 4-(b) is the statistical graph of aspect in the range 0°-360° at the step length of 20°; Figure 4-(c) shows DEM precision for every 4°; Figure 4-(d) shows DEM precision for every 20°. From Figure 4-(c), we can easily see that DEM precision gradually decreases as the slope increases. When the slope is in the range [10°, 80°], DEM precision shows linear relation with slope gradient, and the standard deviation reaches the maximum value when the slope gradient is greater than 80°. Figure 4-(d) indicates that DEM precision has no significant relationship with aspect.

\( \text{(a) InSAR DEM} \)

\( \text{(b) SRTM-3 DEM} \)

\( \text{(c) Elevation difference} \)

\( \text{(d) Distribution of elevation difference} \)

Figure 3. DEM comparison in the experimental area and the distribution of elevation difference

5. Conclusion

In our study, SAR image data from ENVISAT satellite is used to construct DEM and analyze DEM precision. The study results are as follows: ① InSAR technique is an effective approach to construct DEM; ② Standard deviation of elevation difference between InSAR DEM and SRTM-3 DEM in our
experiment is 12.50m; ③ as the slope gradient increases, DEM precision gradually decreases, i.e. the greater the slope gradient is, the lower the precision is; ④ InSAR DEM has no significant relationship with aspect.

Figure 4 Statistical relationship of DEM precision to slope gradient and aspect in the experimental area

References