SAR Image Localization Research Based on the Azimuth Circle Adjustment
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Abstract: - According to the work mechanism of space synthetic aperture radar (SAR), this text introduced the localization algorithms of SAR image and the method of system error adjustment. On the basis of the concept of the azimuth circle and the combination of the north direction coordinate system of geography, carries on the adjustment to the localization data, so increased the SAR image localization accuracy at large scale, combines the simulated data and the image of Radarsat satellite, validate the localization algorithm and the adjustment method. The results had indicated that this algorithm might enable the localization accuracy of Radarsat image to achieve 400-600m, if the establishment of earth model might more accurate, the ground station could provide the more precise orbital data, the localization accuracy may further enhance.

Key-Words: - Synthetic aperture side-looking radar (SAR); Localization accuracy; System error; Adjustment

1 Introduction
Synthetic aperture radar technology is playing the influential role day by day, which by its entire day, all-weather and certain penetrability operating performance, in the domains of topographical survey; forest early warning, ocean monitoring as well as military remote sensing. In the application of SAR satellite imagery, the ground object has the precise pixel position on the image, in the following application of image; we must carry on the precise localization to the image in order to guarantee the geometry adjustment precision and the military precise attack effect. At the same time, any localization algorithm has the system error; which will affect the scope of the localization algorithm in the practical application. For the enhancement of localization accuracy, guarantees the application quality, it is necessary to carry on the adjustment to the localization result, reduces the error [1].

At present, for the SAR image goal's localization, we may use of the known geography information in the image formation region, such as some known ground control point's position, the relief map data, as well as some artificial or the natural features reference point, carries on the localization through interpolation extraction algorithms; we may also determines the goal's location using relative position relations of the pixel and the reference point. But, in most situations, it is difficult to find the appropriate reference point, especially in the applications of ocean monitoring and military attack. In 1982, Curlander et al, who advanced the localization theory to the image by using the earth model equation, the SAR Doppler equation, the SAR slant range equation, and has completed the automatic correction geography code post-processing system of the SAR image in 1989[2],[3].

This paper has researched the localization method to the SAR image at the basic of massive literature search's, which has advanced the SAR image localization method by using simulated data of the ideal point targets, and carry on the adjustment to the localization result combining the Earth model. We has confirmed the localization algorithm and the adjustment plan, which may cause the localization accuracy enhancement at large scale by researching and analyzing the simulated data's, it is possible to control the error to 400-600 meters.
The target point position's accurate degree is weighed through the localization accuracy in the SAR image, the localization of SAR image is also the post-processing foundation of the space borne SAR. This paper advanced one kind of target precision localization and the adjustment plan which may cause the large scale enhancement of the localization accuracy.

The intersection that the Doppler center frequency equation and the earth model equation in the ground, which confirmed the point of intersection between the Doppler lines and the slant range equation, which is the ground position of the target point, as shown in Figure 1.

Fig 1 the position relational graph of the satellite and target point under inertial coordinate system

The target localization of SAR image must choose the fixed coordinate system first, and the coordinate system is the inertia coordinate system, which may use the geocentric coordinate’s model to replace. Under this coordinate system, any target point RT in the ground satisfies the earth model equation:

\[
x_i^2 + y_i^2 + z_i^2 = (R_e + h)^2
\]

And

\[
h = h(x_i, y_i, z_i)
\]

Where, \(R_p = (1 - f) \cdot (R_e + h)\)

For the point, is the ground elevation value, is the Earth radius, and   is the smoothness factor. At the same time, the target point rotates along with Earth's rotation, its speed is:

\[
V_r = W_e \times R_r
\]

The height \(H\) of SAR platform maintains certain height, according to shown in Figure 2, know using the three-cornered relation:

\[
R_{i,j} = \frac{H}{\cos \theta}
\]

And \(\theta\) is the pronate angle from the platform to the target point.

Fig 2 the location relational graph between the satellite platform and target

The position of satellite and the speed are the functions of the satellite’s flight time, which may obtain by the orbital data which provided by satellite. The relations are between it and the target point slant range.

\[
R^2_{i,j} = (R_T - R_S) \cdot (R_T - R_S)
\]

The Doppler frequency shift of the antenna beam through the target point is . The relation between, the satellite position, and the target point position is:

\[
f_D = -\frac{2}{\lambda R} (R_T - R_S) \cdot (V_T - V_S)
\]

So long as assigns each pixel slant range \(R_{ij}\) and the Doppler center frequency \(f_D\) on the SAR image, settle equation (1),(5),(6),associated then obtains each goal correspondence position \(R_T\).

By \(R_T(x_t, y_t, z_t)\) and the earth’s core model may know:

\[
\begin{align*}
  x_t &= R_e \cos \alpha \cdot \cos \beta \\
  y_t &= R_e \cos \alpha \cdot \sin \beta \\
  z_t &= R_e \sin \alpha
\end{align*}
\]

And \(\alpha, \beta\) is the earth’s core latitude and longitude of the target point.

By counter-triangle formula may know:

\[
\begin{align*}
  \alpha &= \arcsin \frac{z_t}{R_e} \\
  \beta &= \arcsin \frac{y_t}{R_e \cos \alpha}
\end{align*}
\]

By the earth’s core model may know[6][7]:

\[
\begin{align*}
  x &= \frac{z_t}{R_e} \\
  y &= \frac{y_t}{R_e \cos \alpha}
\end{align*}
\]
\[
\begin{aligned}
\beta &= \gamma \\
\tan \alpha &= (1 - e^2) \tan \Phi 
\end{aligned}
\]  

(9)

According to the coordinate transformation, we can obtain the geographic coordinate of the target point:

\[
\begin{aligned}
\gamma &= \beta \\
\Phi &= \arctan \left( \frac{\tan \alpha}{1 - e^2} \right)
\end{aligned}
\]  

(10)

And \( \gamma \) is the geographic longitude of the target point, \( \Phi \) is the geographic latitude of the target point.

According to localization algorithm studies [4] of spaceborne synthetic aperture radar image parse in the paper, the projection of satellite platform's central point's on SAR image was confirmed to the center of circle in the azimuth circle. \( L \) which is the distance from the actual target point to the center of circle \( O \) in the azimuth circle, is obtained according to the photograph position of the reality target point \( T \), that is, the distance \( L \) between \( T \) and \( O \) should be equal to the distance \( L' \) from \( T' \) to \( O' \), therefore \( T \) with \( T' \) should be in the same circular arc which the centre of a circle is \( O \), and the radius is \( L \), as shown in Figure 4.

And \( L = h \times \tan \theta \)  

(11)

\( h \) is this spot the ground elevation value of the point; \( \theta \) is the pronate angle from the platform to the target point.

In the SAR image, the ground image mapped on the plane negative from the spherical surface position, according to the imaging characteristic of SAR image, we may measure the distance between two points directly in the picture, the distance is termed plan distance. We can demarcate the longitude and latitude of the conjectural target point \( T' \) and \( O \) to the transit instrument. Make sure the location of the center of circle \( O \) in the photograph utilizing the geometry theory, measure the distance \( L \) between \( O \) and \( T \) in the photograph, and make out the direction line of just north on the photograph or the transit instrument separately. Measure the nip angle between \( OT \) and the direction line of just north in the photograph, and measure the nip angle between \( OT' \) and the direction line of just north in the transit instrument. In case of the nip angle between \( OT \) and \( OT' \) in the earth’s core coordinate is \( \theta \).

Then \( \theta = \theta_1 - \theta_2 \)  

(12)

If \( \theta < 0 \), then conjectural point is deflexion near from the direction line of just north than the real point; If \( \theta > 0 \), then conjectural point is deflexion near from the direction line of just north than the real point.

As shown in Figure 3, in the plane of \( \Delta OTT' \)

\[
TT' = (2L^2 - 2L' \cos \theta)
\]  

(13)

![Fig3](the position relational graph between the target point and measuring point In azimuth circle)

It’s known from Fig3, in \( \Delta O,TT' \),

\[
\cos(O,T'T') = \frac{R_x^2 + R_y^2 - TT'^2}{2R_z} 
\]  

(14)

After determining of \( \arccos(O,T'T') \), because of \( TT' \) is section of a circular arc in the spherical surface and the geocentric distance is \( R \), we can acquire by fan-shaped arc length formula:

\[
TT' = R \times \arccos(O,T'T') 
\]  

(15)

So long as has determined the azimuth nip angle \( \theta \) and the distance \( L \) of the target dot, and the adjustment process has nothing to do with the satellite platform and the radar parameter, we may discover that we can carry on the adjustment to the precision of goal from the above inferential process, therefore, the adjustment plan has the strong compatibility.

3 Analyze Application of the Localization Adjustment Plan

According to the actual GPS localization data, we will apply this algorithm to compare the localization result to the first-level SAR image in Beijing area. We selected six experimental spot randomly. There into, includes SiTong bridge, MuXi terra, the country trade bridge, the east exit of north road in east three link, the center island of the lake in south side of Summer Palace, the center island of the lake in east side of Summer Palace. The measurement result and adjustment data see Table 1 and Table 2.
### Table 1 The localization result of the point target

<table>
<thead>
<tr>
<th>Target point</th>
<th>Real longitude</th>
<th>Real latitude</th>
<th>Survey longitude</th>
<th>Survey latitude</th>
<th>Longitude deviation</th>
<th>Latitude deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiTong Bridge</td>
<td>116.314800</td>
<td>39.965305</td>
<td>116.314388</td>
<td>39.965185</td>
<td>-0.000412</td>
<td>-0.000120</td>
</tr>
<tr>
<td>MuXi Terra</td>
<td>116.328770</td>
<td>39.905677</td>
<td>116.328077</td>
<td>39.905405</td>
<td>-0.000693</td>
<td>-0.000272</td>
</tr>
<tr>
<td>Country trade bridge</td>
<td>116.454900</td>
<td>39.931828</td>
<td>116.455127</td>
<td>39.931983</td>
<td>0.000227</td>
<td>0.000155</td>
</tr>
<tr>
<td>East exit north road in east three link</td>
<td>116.455070</td>
<td>39.939508</td>
<td>116.455299</td>
<td>39.939784</td>
<td>0.000229</td>
<td>0.000276</td>
</tr>
<tr>
<td>Centre island of the lake in south side of Summer Palace</td>
<td>116.265460</td>
<td>39.984460</td>
<td>116.265140</td>
<td>39.984435</td>
<td>-0.000320</td>
<td>-0.000027</td>
</tr>
<tr>
<td>Centre island of the lake in east side of Summer Palace</td>
<td>116.269604</td>
<td>39.989802</td>
<td>116.269693</td>
<td>39.989823</td>
<td>0.000089</td>
<td>0.000021</td>
</tr>
</tbody>
</table>

### Table 2 The localization result adjustment data table of the point target

<table>
<thead>
<tr>
<th>Target point</th>
<th>Survey longitude</th>
<th>Survey latitude</th>
<th>Adjustment longitude</th>
<th>Adjustment latitude</th>
<th>Longitude deviation after adjustment</th>
<th>Latitude deviation after adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiTong Bridge</td>
<td>116.314388</td>
<td>39.965185</td>
<td>116.314623</td>
<td>39.965209</td>
<td>-0.000177</td>
<td>-0.000096</td>
</tr>
<tr>
<td>MuXi Terra</td>
<td>116.328077</td>
<td>39.905405</td>
<td>116.328689</td>
<td>39.905598</td>
<td>-0.000081</td>
<td>-0.000079</td>
</tr>
<tr>
<td>Country trade bridge</td>
<td>116.455127</td>
<td>39.931983</td>
<td>116.454963</td>
<td>39.932003</td>
<td>0.000063</td>
<td>0.000175</td>
</tr>
<tr>
<td>East exit north road in east three link</td>
<td>116.455299</td>
<td>39.939784</td>
<td>116.455158</td>
<td>39.939600</td>
<td>0.000088</td>
<td>0.000092</td>
</tr>
<tr>
<td>Centre island of the lake in south side of Summer Palace</td>
<td>116.265140</td>
<td>39.984435</td>
<td>116.265292</td>
<td>39.984387</td>
<td>-0.000168</td>
<td>-0.000073</td>
</tr>
<tr>
<td>Centre island of the lake in east side of Summer Palace</td>
<td>116.269693</td>
<td>39.989823</td>
<td>116.269657</td>
<td>39.989851</td>
<td>0.000053</td>
<td>0.000049</td>
</tr>
</tbody>
</table>
According to the localization result analysis we can know that, this algorithm localization accuracy achieves between 400m--600m. After the adjustment, longitude measured deviation average value: -0.000037°; Latitude measured deviation average value: 0.000011°.

According to the computed result we may see that: In the situation of no any external influence, this algorithm has been controlled the accuracy after the decimal point fifth, its ground error is 400-600 meters, which will conform to the military position error request basically and has the high localization accuracy and has the practical application value.

### 4 Error Analysis of the Localization Adjustment plan

The spaceborne SAR imaging mechanism is complex somewhat compared to the aircraft-borne SAR imaging process. Because the satellite is in near circular orbit, the distance is different between the satellite and the ground at different position, moreover the SAR image is the side-looking radar image imaging, if considered again the wave complication of the ground, the erroneous source is various which affects the localization accuracy and the adjustment precision of the point target of SAR.

#### 4.1 Error Analysis of Target Localization Algorithm

According to the localization principle of SAR image, we may know that, it is different for each kind of error to the localization influence, satellite track measuring error including orbital direction error, radial direction orbital direction error and cross orbital error. The measuring error mainly causes the localization error of the location, the measuring error of the radial direction along orbital direction track measuring error along orbital direction, for the localization accuracy of the distance and location, the distance is primarily. There into, the first two errors constitute the main error source which the orbital surveys, but cross orbital position measuring error cross orthogonal the radial direction orbital measuring error, its influence very small [5].

For the localization of target in the earth's surface, usually uses the ellipsoid mathematics earth model of revolution to replace the genuine geoids. The different ellipsoid of revolution, the ellipsoid parameter is various, the actual target height is not dissimilar in observes belt. Because SAR image information reflects is that back direction dispersion intensity, therefore, the hypsography is one of the main error sources which affects SAR image quality and position precision [6].

Besides the above factors, the Doppler center frequency is also the main parameter which in the localization computational process. The Doppler center frequency has something to the satellite orbit, the radar angle of view, the antenna direction, earth rotation factors and so on. In the different slant range, the Doppler center frequency also differs. At present, the Doppler parameter may obtains through clutter locking and the self-focusing technology, this kind of technology may enormous enhance the estimate precision of Doppler parameter. Therefore, Doppler center frequency error influences the localization accuracy very small [7].

#### 4.2 The Goal Adjustment Error Analysis

The factors which influence the adjustment precision are large, except the error of using the approximate localization material, but also its own error, below carries on the analysis to the algorithm error.

First, the observed value are excessively many in the algorithm, the personal error is inevitable in the measuring process leads;

Second, the correspondence known ground control point of geographic coordinate, which is composed by many pixel spots in the image, therefore, in the actual use, it is unable to judge pixel position precisely.

Once more, the earth model is the emerging scientific research topic, its availability still in discussion. In fact, any earth model is an approximate description to Earth, even if it is the 25th degree earth model equation precise, a 50 meter radius error in the big ground also causes 150 meter pixel localization error. Its localization error is 2 to 3 times for the model error, and has not considered the elevation difference in the algorithm, these disturbance factor will affect to the result.

Finally, we will use the average radius of Earth Re when judgment the arc TT’, the value of Re has the change along with the earth surface condition, which has the big disturbance to the result.

### 5 Conclusions

From the above analysis, you can see that the slant range of SAR image - Doppler center of earth model localization algorithm suits the localization of SAR image in the spaceborne SAR ground datum processing system. Its localization accuracy is mainly
decided by each kind of parameter measuring accuracy of system and the hypsography influence. The azimuth circle system error adjustment algorithm to be able to combine the localization algorithm with this paper well, increased the localization accuracy large scale, if uses the more precise position material as well as the entire precision earth model, the adjustment precision will further enhance.

References:
[6] QJ 1028A-95, Astronautics product commonly used coordinate system[S].