ALGORITHMS AND EXPERIMENT ON SAR IMAGE ORTHORECTIFICATION BASED ON POLYNOMIAL RECTIFICATION AND HEIGHT DISPLACEMENT CORRECTION

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ABSTRACT:

This paper introduces the algorithm on SAR image orthorectification based on polynomial rectification and height displacement correction, and experiments according to the algorithm on ERS-2, RADARSAT, and airborne SAR image in mountain area. Many factors result in SAR image distortion, and most of them can be corrected by polynomial rectification. But the distortion of SAR image brought by elevation is very difficult to be corrected by polynomial rectification. In this paper, height displacement caused by elevation is corrected in advance according to the slant distance and elevation of each pixel, and the other distortion is corrected by polynomial rectification. Compared to other orthorectification algorithm on SAR image, it is very easy to implement. According to this method, programme has been designed. And then, experiment has been down on RADARSAT image in a mountain area in China (Dali, Yunnan), and polynomial rectification on the same image also has been down by the same ground control points. The accuracy of the former is about 2.8 pixels, and the latter 44.4 pixels. In this area, the most elevation difference of the ground control points is about 2972 meters. Some other experiments have been down on ERS-2 image (Chengdu, Sichuan), and 3 meters resolution airborne SAR image (Dabieshan, Anhui), and the results are similar to that of the first experiment. So, the new algorithm on SAR image orthorectification introduced in this paper is efficient and practicable for SAR image orthorectification in mountain area.

1. INTRODUCTION

The geometric correction process seems to be more important today than before (Thierry, 2003). Synthetic aperture radar (SAR) adopts side-looking imaging mode, and the side-looking angle of SAR image is much larger than that of optical image. This mode leads to a great influence to geometric distortion of SAR image. Consequently, it is very important for SAR application to rectify geometric distortion and create ortho-image.

Many SAR image rectification methods are put forward such as orthorectification of Radarsat fine using orbital parameters and DEM (Keong, 1995; Mohd, 2000), practical SAR orthorectification (Leland, 1996) and geometry processing of remote sensing images (Thierry, 2003). Now, the primary methods of SAR image rectification include polynomial rectification, collinearity equation method and the Range-Doppler method.

Polynomial rectification
Since 1970s, polynomial functions are well known (Wong, 1975; Billingsley, 1983). Based on polynomial function, polynomial rectification is a comparatively traditional method for rectification, which is often applied to optical image orthographic rectification. For SAR image of plant areas, it also can be used to rectify geometric distortion.

Collinearity equation method
This method includes two types. The first one is mathematical model, which presenters are F.Leberl etc. Change of linear elements in sensor's exterior azimuthal elements are considered, nor do angle elements. Therefore, after establishing SAR stereo model, there are biggish fluctuate parallax, and it is only the same with airborne SAR because this model is building in terms with the range equation of image points and zero Doppler condition. The other one is mathematical model of flat range projective radar images performed by G.Konecny etc. In this model, the changes of exterior azimuthal elements of sensors and terrain are considered, and the form of equation is similar to photogrammetric collinearity equation. Although the model is easy to be applied, it interpret something only referring to the characteristic of traditional optical imaging without taking into account SAR image side-looking projective characteristic. Forasmuch, this type model is only a simulant processing method to optical image.

The Range-Doppler method
The Range-Doppler method primarily discusses the relationship of image points and target points from the view of SAR imaging geometry. The following is its basic theory: In the range direction, the distribution of equidistance points from target to radar is homocentric circular cluster, which center of a circle is point bellow satellite. In the other hand, equal Doppler frequency shift points created by relative moving between satellite and target distribute as hyperbolic cluster in the azimuth direction. Therefore, ground target can be confirmed by the intersection of the clusters of homocentric rotundity and hyperbola. The Range-Doppler algorithm mostly lies on the accuracy of fundamental catalogue data.

Polynomial rectification regards general distortion of remote sensing image as combination of several of basic and high distortion. For relatively flat areas, it can reach sufficient rectification accuracy and is easy to use. Accordingly, it has been used in considerable fields. But considering some more hypsography areas, this method can not lead to satisfying results, especially in the condition of biggish slope. In this paper, we add this method to correction of height displacement caused by elevation, and it can improve corrective accuracy. At first, height displacement is corrected; and then the other distortion is corrected by common polynomial rectification. By contraries during resampling, we firstly extract the coordinates of image points which haven't been affected by elevation in terms of polynomial parameters. Secondly, we add height displacement and finally get true image coordinates.

2. METHODS

It is usual to adopt following expressions for quadratic polynomial rectification.

$$x=a_0+a_1X+a_2Y+a_3X^2+a_4XY+a_5Y^2$$
$$y=b_0+b_1X+b_2Y+b_3X^2+b_4XY+b_5Y^2 \quad (1)$$

Where □x,y□is image point coordinates, and correspondingly □X,Y□ is its ground point coordinates. a_i and b_i are unknowns.

In this paper, we introduce height displacement caused by elevation which is corrected in advance and make use of (2) for polynomial orthorectification.

$$x+dx=a_0+a_1X+a_2Y+a_3X^2+a_4XY+a_5Y^2$$
$$y=b_0+b_1X+b_2Y+b_3X^2+b_4XY+b_5Y^2 \quad (2)$$

Where dx is height displacement caused by elevation.

Displacement of radar image caused by terrain can be displayed in Fig 1.

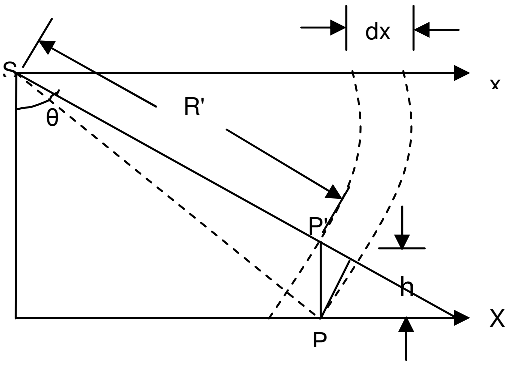


Figure 1. Terrain influence to radar image

We presume that h is elevation of ground point P', and its image coordinate is X'= λ R', where λ is imaging scale and P is projective point in ground datum plane. The slant range of P can be approximately describes as following equation:

$$R \approx R'+h\cos\theta$$

Where θ is the imaging angle of P'. Accordingly, displacement caused by elevation can be showed as:

$$dx=X'-X \approx -\lambda h\cos\theta$$

Suppose s is ground resolution, and we can realize following transform:

$$dx \approx -h\cos\theta/s$$

where□

$$\cos\theta \,□(H-h)/R$$

so□

$$dx \approx -h(H-h)/R/s \quad (3)$$

Equation□3□is approximate expression of height displacement. If it needs strict computation, the equation as follows can be used:

$$dx=\sqrt{(R^2-(H-h)^2)+H^2}-R$$
$$=\sqrt{R^2+(H*2-h)*h}-R \quad (4)$$

When there is a biggish θand ground point is far away from ground nadir point(for ERS-2 image, when θis 25 degree, the distance from ground point to ground nadir point is 323 kilometers), height displacement may be affected by ellipticity of the earth. We can reduce such affection by correcting datum plane which includes the correction of slant angle θ and flight height. In this way, according to normal of central tangential plane in each frame, We can calculate slant angle θ, and change flight height into distance from imaging center to tangential plane.

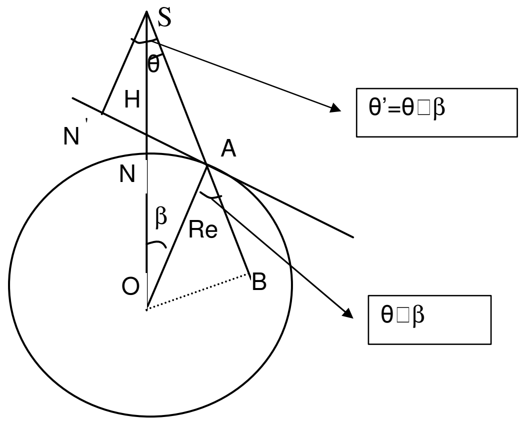


Figure 2. slope correction

Showing as Fig 2□where the earth level surface is regarded as a sphere O with a semi diameter Re□A is projection of ground point toward image point in the level surface, and N is ground nadir point.

We regard β as □AOS. Then, in the surface of AOS, AN' is tangent of the sphere O across point A, and SN' pass through point S which is vertical line according to AN'. So N' and θ' respectively express the new ground nadir point and slant angle.

Where OB□SA□B is intersection of OB and SA . because of SN'//AO□then:

θ'=θ□β

□BAO=θ'

θ'=arcsin[(Re+H)sinθ/Re]

H'=Resinβcos(θ□β)/sinθ

Corrected H' replaces H in formula(3)or (4). It is modified height displacement corrective formula and expresses as (3) or (4) in order to convenient for description.

If flight height is unknown, then dx is also unknown, and expression (2) must be modified.

Thinking of expression (3), the new expression (2)is the follow:

$$x+h^2/R=a_0+a_1X+a_2Y+a_3X^2+a_4XY+a_5Y^2+H\cdot h/R$$
$$y=b_0+b_1X+b_2Y+b_3X^2+b_4XY+b_5Y^2 \quad (5)$$

However, according to expression (4), dx should be linearized.

Suppose $Fx=a_0+a_1X+a_2Y+a_3X^2+a_4XY+a_5Y^2-(x+dx)$
Because $ddx=(h\sqrt{R^2+(H*2-h)*h/s})dH$

So $$dFx=da_0+Xda_1+Yda_2+X^2da_3+XYda_4+Y^2da_5+(h\sqrt{R^2+(H*2-h)*h/s})dH \quad (6)$$

Making use of (6)□the distortion in x direction can be corrected by polynomial orthorectification

3. DATA USED

According to the above-mentioned method, we have designed the processing software for the SAR image. And then, using ERS□RadarSat□airborne SAR image data, we go on some experiments with this method, and have received results of satisfaction.

4. RESULTS AND DISCUSSION

4.1 Experiment on ERS-2 image Orthorectification

Site: Chengdu region, Sichuan province
Flight height: 824000m
Resolution: 25m
Result Accuracy:
Error X: 1.7 pixels;
Error Y: 0.5 pixels;
Distance error: 1.8 pixels.

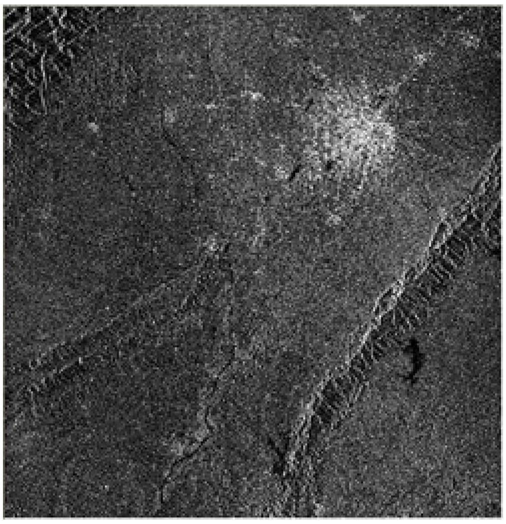


Figure 3. ERS-2 image in Chengdu

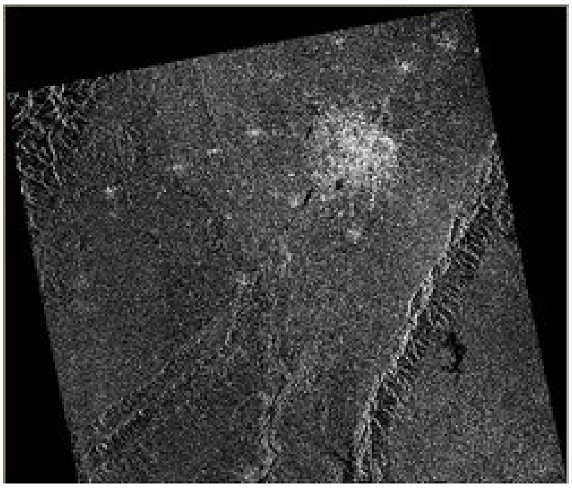


Figure 4. Chengdu ortho-image

No	X	Y	Z	Dx	Dy
0	364850	394750	585	0.5	0.1
1	372900	353900	460	0.8	1.0
2	379803	411945	605	-0.1	-0.6
3	406012	387608	492	-0.8	0.4
4	432327	347533	465	-1.2	1.1
5	430100	410300	466	0.5	0.6
6	375875	321750	415	-0.9	-0.8
7	375375	385375	513	-0.7	0.2
8	403650	356250	432	0.1	-1.5
9	436000	362000	459	0.4	-1.5
10	408500	332750	456	0.1	1.0

Table 1. Error of control points. The unit of X, Y, and Z are meter, and that of Dx and Dy are pixel.

Figure 5. Chengdu error distribution figure

4.2 Experiment on RadarSat image Orthorectification

Site: Dali region, Yunnan province
Flight height: 792594m
Original slant range: 1058128.9m
Resolution: 25m
Result accuracy:
Error X: 1.4 pixels
Error Y: 1.7 pixels
Distance error : 2.2 pixels

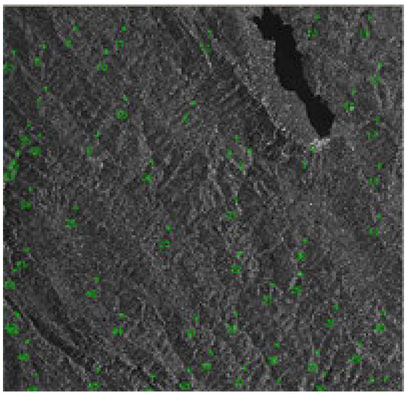


Figure 6. RadarSat image in Dali

In this area, experiment has been down by ortho and polynomial rectification on the same image by the same ground control points. The accuracy of the former is about 2.8 pixels, and the latter 44.4 pixels. The most elevation difference of the ground control points is about 2972 meters.

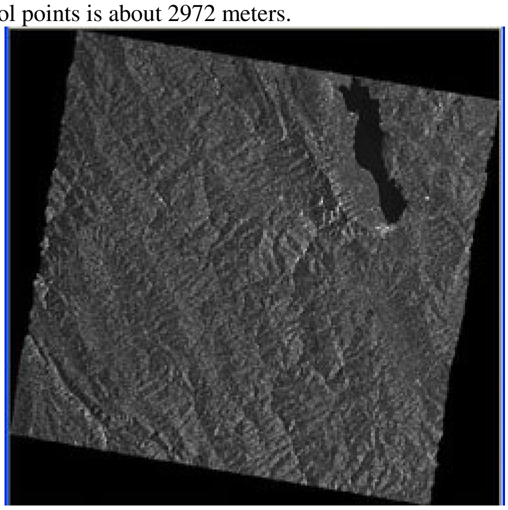


Figure 7. ortho-image of Dali

Comparing formula (3) with (4), we find that the accuracy of the latter is better than that of the former by 0.1 pixel. The result by formula (4) is:

Error X: 1.4 pixels
Error Y: 1.7 pixels
Distance error : 2.2 pixels

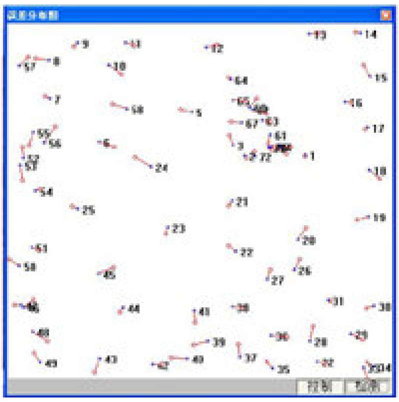


Figure 8. Dali Error distribution figure

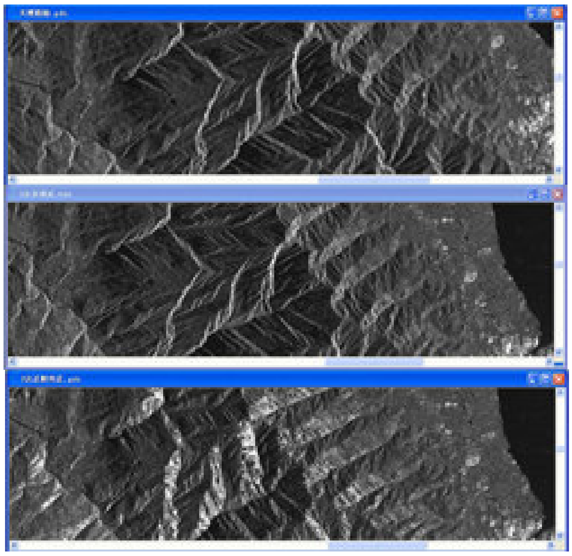
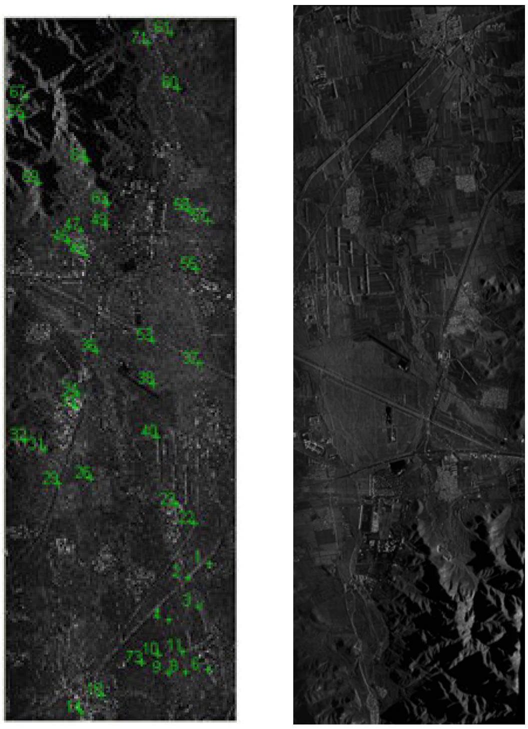


Figure 9. Comparing two corrected images with the original image(The first one is the original image; the second, result of polynomial rectification; the third, result of orthorectification).

4.3 Experiment on airborne SAR image Orthorectification

Site: Yanqing region, BeiJing
Flight height: 4300m
Original slant rang: 11252m
Resolution: 1.25m
Result accuracy:
Error X: 3.4 pixels
Error Y: 3.5 pixels
Distance error: 4.9 pixels



(a) The original image (b) ortho-image

Figure10. Images of Yanqing

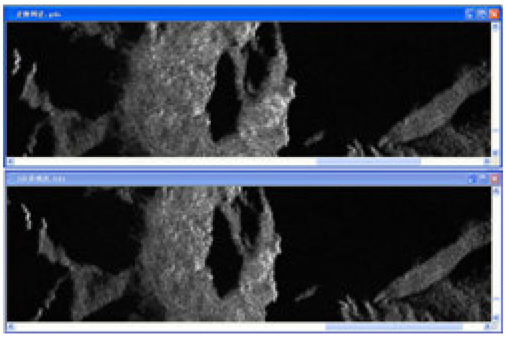


Figure 11. Comparing two kind of corrected images (The upper is ortho-rectified image, and the other is quadratic polynomial rectified image).

5. CONCLUSIONS

In this paper, a new algorithm on SAR image ortho-rectification has been proposed based on polynomial rectification and height displacement correction, which was provided with a systematic theory. It could be realized simply and rapidly, and it was very superior to other algorithms without precise catalogue data. From the analysis and the comparison to some experiments with space borne (ERS-2 and Radarsat) and high resolution airborne SAR images, it is shown that this new algorithm reached satisfying results in mountain area.

6. REFERENCES

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