SAR STEREO-MAPPING BASED ON DEM

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ABSTRACT:

In the western region of China, Synthetic Aperture Radar images have been used in extraction of topographic maps. Stero mapping with stereoscopic image pair is very useful for extraction of feature elements (roads, buildings and other surface features) from SAR image. The basis of stereo-mapping is stereoscopic image pair, of which the vertical parallax must be removed, and the horizontal parallax reserved. This paper presents a method of generating SAR stereoscopic image pair based on Digital Elevation Model, which is used in stereo-mapping. First of all, orientation of SAR image must be completed; then according to DEM, stereoscopic image can be generated through image re-sampling along the range direction from original image. The vertical parallax will be removed, when re-sampling, and the horizontal parallax will be reconstructed with central projection or slant-range projection. There are two ways to generate stereoscopic images from single original image or two different original images. The two images generated from single original image are called mono-source pair. The two images generated from the two different images are called dual-source pair. Experiment is done in this paper with high-resolution space-borne SAR images. Mono-source and dual-source stereoscopic image pairs are generated with central and slant-range projection, and feature elements of topographic map are extracted with the image pairs in the experiment. It proves that the method above is feasible.

1. INTRODUCTION

SAR is an active microwave imaging system with high resolution. Compared with optical sensors, it has series of advantages, such as all-day, all-weather and penetrating through cloud, mist and a certain depth of ground, and so has been used in many fields. As the development of SAR technology, its applications are expanding continuously. The technologies, generating ortho-image with SAR image, extracting three-dimensional topographic information with InSAR and deformation monitoring with D-InSAR (M.Gelautz, 2004), have been relatively mature, but research on SAR analytical stereo-mapping is still limited. The key technique of stereo-mapping is generation of ideal stereoscopic image pair, of which the vertical parallax must be eliminated, and the horizontal parallax reserved (Franz.W.Leberl, 1985). Because of existence of epipolar line, ideal stereoscopic image pair can be made with optical stereo image pair re-sampling along the epipolar line and eliminating the vertical parallax between the left and right images (Z.X. Zhang, 1997). The method of this paper is re-sampling along the same geographic direction with SAR images to eliminate the vertical parallax and reconstruct the horizontal parallax according to DEM. The mono-source stereoscopic image pair has well stereoscopic vision, and can be used to assistant image interpretation. The dual-source stereoscopic image pair has more detailed topographic information, and can be used to map and edit contours. The principle and method of mono-source and dual-source will be introduced, and the experiment with SAR image will be done.

2. GENERATION OF IMAGE PAIR

In the method of this paper, the two images of stereoscopic image pair can be re-sampled from single SAR image, and also can be from two different SAR images with overlapping regions. The specific approach is extracting the relatively independent stereoscopic image firstly, and then making up a stereoscopic image pair with two stereoscopic images.

The procedure of extracting stereoscopic image is actually a process of image simulation. Establish the map between the simulated image and the original SAR image with simulated imaging orbit and imaging parameters (resolution), and then resample to get stereoscopic image. The image re-sampling depends on DEM in the same direction, so two maps should be established. One is the map between original image coordinates and geographic coordinates, the other is between geographic coordinates and simulated image coordinates. In this way, the vertical parallax will be eliminated, and the map between the original image coordinates and simulated image coordinates is established indirectly.

2.1 SAR Image Geometry

Establishing the map original image coordinates and geographic coordinates is geo-location of SAR image, the key is the establishment of SAR Geo-location model. SAR Geo-location model is the basis of SAR image geometric process, several models have been raised at home and abroad at present. Among them, the Range and Duppler (R-D) model follows SAR imaging geometry strictly, so it can be used for the basic model of SAR image geometric process (E.X.Chen, 2004). With an SAR image, the formulation of R-D model is as follows:

$$\begin{cases} R = \left| R_{sc} - R_{tc} \right| \\ f_d = -\dfrac{2}{\lambda} \dfrac{(R_{sc} - R_{tc}) V_{sc}}{\left| R_{sc} - R_{tc} \right|} \end{cases} \qquad (1)$$

Where R = the slant range from objective to sensor

R_{sc} = the position of sensor

R_{tc} = the position of objective

V_{sc} = the velocity of sensor

f_d = the central duppler frequency

λ = the wavelength

The first equation is the range equation, the other is duppler equation. Model parameters can be extracted original image parameter file, in the solution process of the model calculation need to know the sensor orbit information. Along with the development of inertial navigation technology, currently a number of SAR satellites have been able to provide very. When there is no accurate sensor orbit, the sensor orbit can be inversed with a certain amount of image control points.

2.2 Image Simulation Parameter

Simulation parameters mainly contain simulated imaging orbit parameters and simulated image parameters. Orbit parameters are mainly orbital altitude, orbital direction, image parameters are mainly imaging resolution.

Generally, the simulated orbital altitude is approximately equal to the original SAR image orbital altitude. The re-sampling direction is the same as the range direction of original image normally, and perpendicular to the orbital direction. For example, the orbital direction for Spaceborne SAR is roughly north-south direction, simulated imaging orbit can be true north-south direction and re-sampling direction is west-east direction. Simulated image resolution depends on mapping resolution or mapping scale. The following briefly on what set the principle of simulated orbital parameters.

Imaging region can be determined by the coordinate of four corners of the original image. The simulated orbit direction is set to be Y direction. Then in the Fig.1 is a re-sampling scan line. The bound coordinate X_b is from imaging region, orbital altitude is set to be H . R_0 is equal to the nearest slant range of original image. So the orbital X -axes coordinate is X_s :

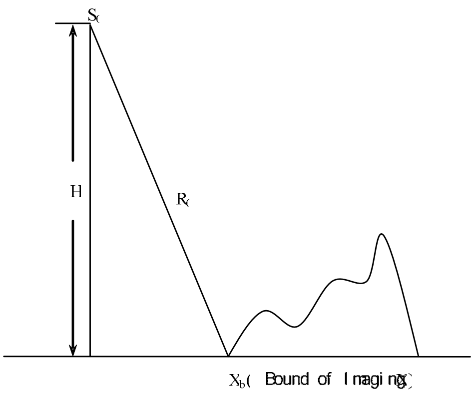


Figure 1. Simulation Parameter

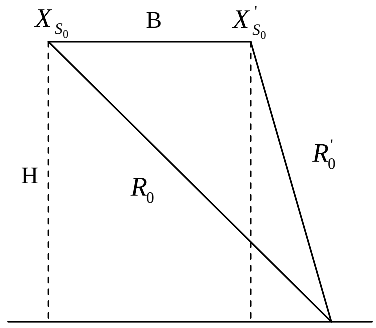


Figure 2. Baseline

In order to obtain well imaging results, the base-height ratio should be designed before simulation. The designed base-height ratio can be obtained with moving simulated imaging orbital position. As the Fig.2, the orbit is moved, and then the orbital X -axes coordinate after moving is X_s' .

2.3 Simulated Image Geo-location

It is necessary to establish the map between simulated image coordinates and geographic coordinates. The geographic coordinate Y of corresponding point on simulated image can be obtained from the orbital position, while X needs to be solved with DEM and simulation imaging model (central projection imaging model or slant-range projection imaging model. The coordinate X and the elevation is obtain through iterative solution, the principle is:

1). set initial value of elevation h_0 ;

2). solve X_0 with the initialization;

3).interpolate h_1 from DEM with X_0 and Y ;

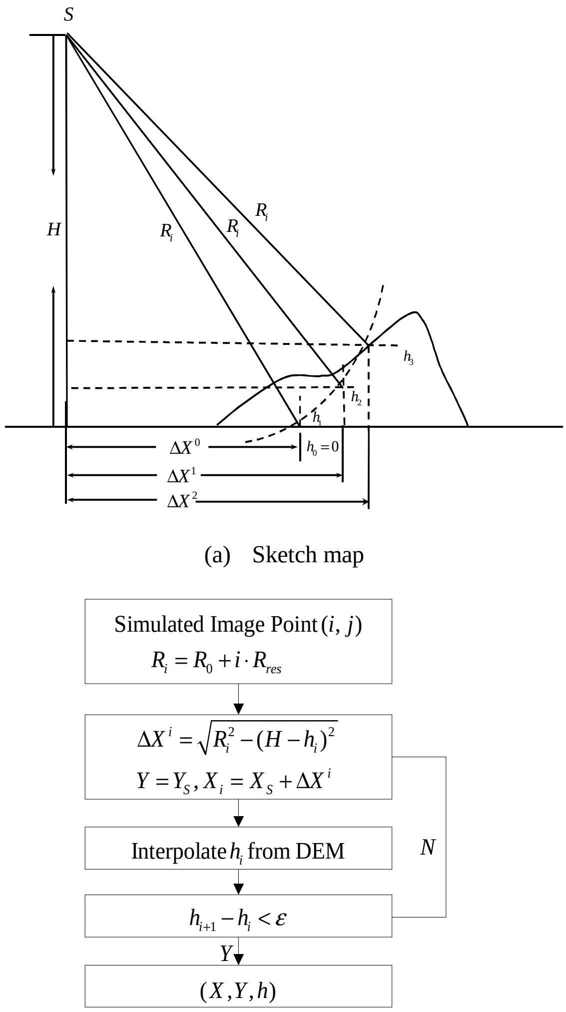
4).solve X_1 with h_1 ;

5).circling iteratively until $|X_{i+1} - X_i| < \varepsilon$, the geographic coordinate is (X_i, Y, h_i) ;

For the slant-range projection imaging model, the iterative solution depends on the slant-range equation:

$$R_i = \sqrt{(\Delta X^i)^2 + (H - h_i)^2} \tag{2}$$

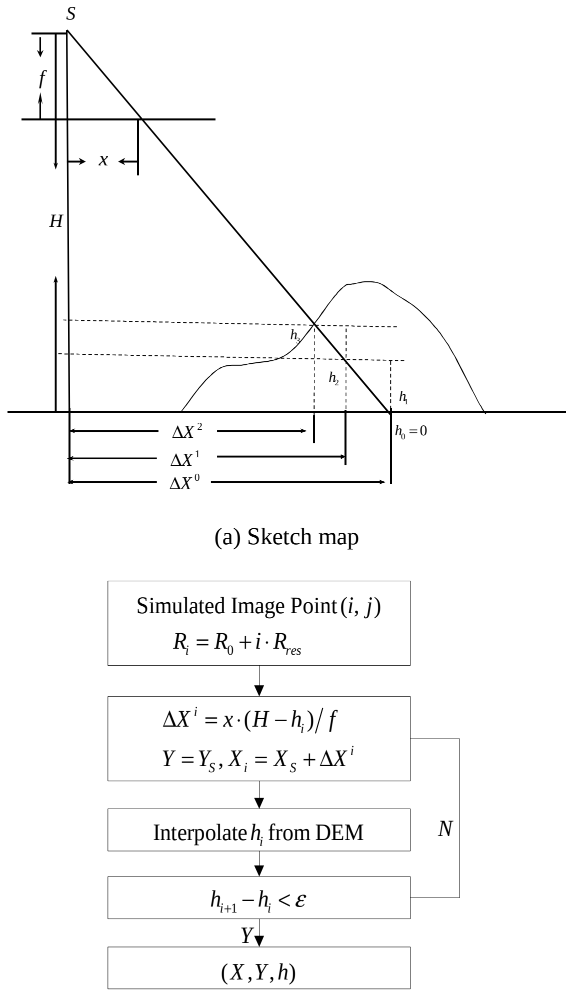
Get elevation information from DEM and solve the geographic coordinates. The Fig.3 is sketch map and procedure of iterative solution.



(a) Sketch map

(b) Procedure

Figure 3. Geo-location of slant-range projection



(a) Sketch map

(b) Procedure

Figure 4. Geo-location of slant-range projection

For the central projection imaging model, the iterative solution depends on the collinear equation:

$$\frac{f}{H - h_i} = \frac{x}{\Delta X^i} \quad (3)$$

The Fig.4 is sketch map and procedure of iterative solution.

2.4 Re-sampling

Choose indirect sampling as re-sampling style, start with image point on target stereoscopic image, get pixel gray value from the corresponding image point on original SAR image. The procedure is as follows:

1).Get imaging bounds with geo-location of original image, calculate the size of simulated image according to simulated imaging resolution;

2).Solve corresponding geographic coordinates from simulated image point;

3).Calculate the original image coordinates with geographic coordinates

4). Set gray value of the simulated image point to be the original image gray value.

The procedure is as the Fig.5:

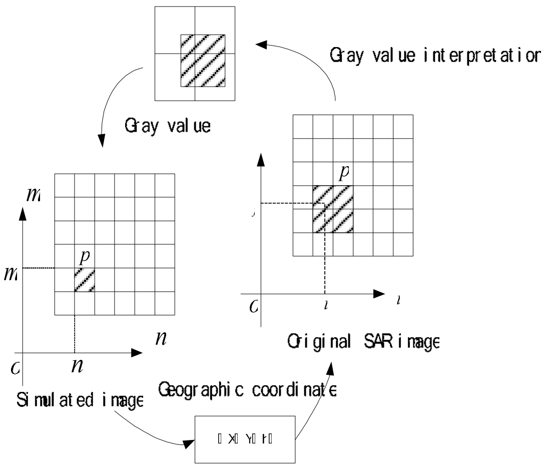


Figure 5. Process of re-sampling

2.5 Stereo Measurement Model

Two stereoscopic images with parallel simulated imaging orbit can make up of a stereoscopic image pair. A stereo measurement model must be established when stereo-mapping with the image pair. Select a different simulated projection imaging model, build a model not the same.

For the slant-range projection model, stereo geometrical model in Fig.6, according to the model:

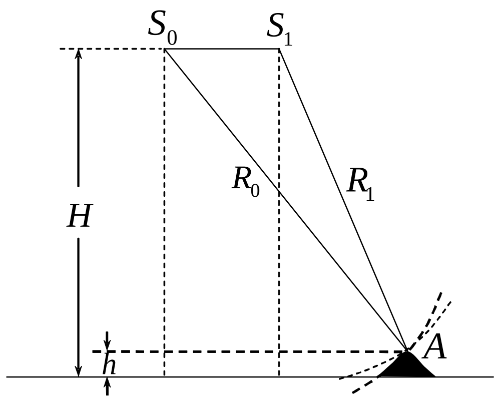
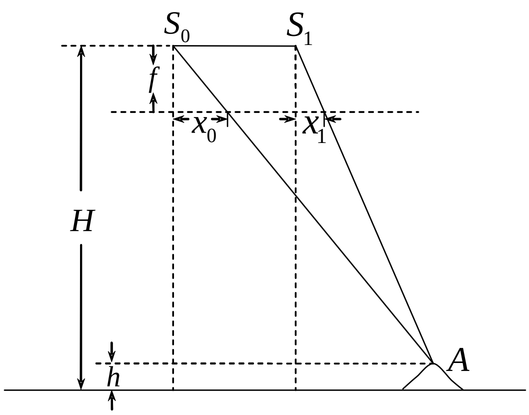


Figure 6. Slant-range projection mode



lFigure 7. Central projection model

$$\left.\begin{aligned} R_{A0}^2 &= (X_A - X_{S_0})^2 + (H-h)^2 \\ R_{A1}^2 &= (X_A - X_{S_1})^2 + (H-h)^2 \end{aligned}\right\} \quad (4)$$

To be stereo measurement equation:

$$\begin{aligned} X_A &= \frac{(R_{A0}^2 - R_{A1}^2) - (X_{S_0}^2 - X_{S_1}^2)}{2(X_{S_1} - X_{S_0})} \\ Y_A &= Y_{S_0} \\ h &= H - \sqrt{R_{A0}^2 - (X_A - X_{S_0})^2} \end{aligned} \quad (5)$$

For the central projection model, stereo geometrical model in Fig.7, according to the model:

$$\left.\begin{aligned} \frac{x_0}{X_A - X_{S_0}} &= \frac{f}{H-h} \\ \frac{x_1}{X_A - X_{S_1}} &= \frac{f}{H-h} \end{aligned}\right\} \quad (6)$$

To be stereo measurement equation:

$$\begin{aligned} X_A &\approx \frac{x_1 X_{S0} - x_0 X_{S1}}{x_1 - x_0} \\ Y_A &= Y_{S_0} \\ h &= H - (X_A - X_0)\frac{f}{x_0} \end{aligned} \quad (7)$$

An ideal stereoscopic image pair from single SAR image is called Mono-source Ideal Image Pair. An ideal stereoscopic image pair from two different SAR images is called Dual-source Ideal Image Pair.

3. EXTXPERIMENT

In this paper, experiment is done with a TerraSAR-X stereo image pair which locate at west of China. The resolution of the two images, S_1 and S_2, is 3m. Their polarizations are all HH. The incidence angle of S_1 is 46°, and that of S_2 is 29°. In Fig.8 is single-model stereoscopic image pair generated from S_1. In Fig.9 is dual-model stereoscopic image pair generated from S_1 and S_2.

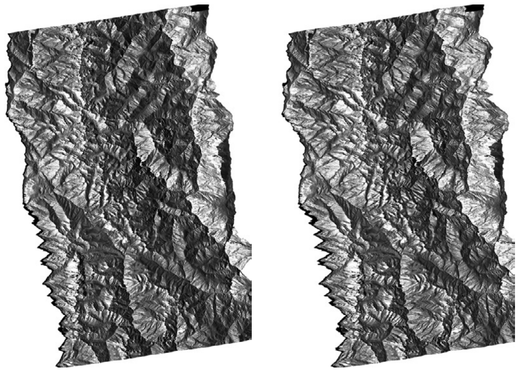


Figure 8. Mono-source image pair

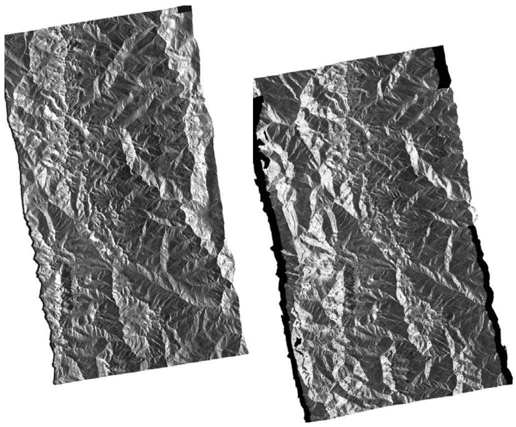


Figure 9. Dual-source image pair

Well stereoviewablity can be get with the image pairs under stereo observation condition. The vertical parallax was eliminated effectively. Contour lines of some parts in this region were mapped with the dual-model image pair. The precision of contour lines was checked using DEM, and the result confirmed that the contour lines could be used in making topographic maps. In Fig.10 are the contour lines.

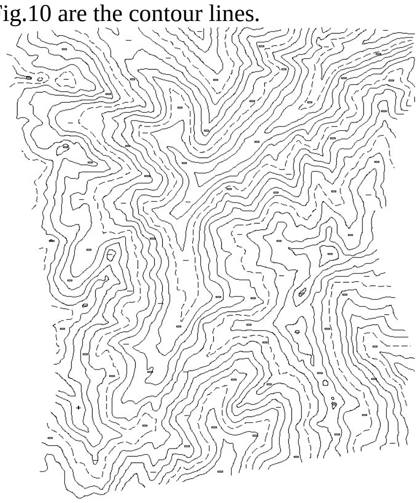


Figure 10. Contour lines

4. CONCLUSION

Mono-source and dual-source method for generation of ideal stereoscopic image pair based on DEM are raised in this paper for stereo-mapping of SAR images. Image pairs were generated in the experiment with high-resolution spaceborne SAR images. We achieved well stereoscopic vision, and well elimination of vertical parallax. The contour lines mapping with the image pairs can meet the needs of producing topographic maps. Experiment confirmed that the method proposed in this paper is feasible.

There are still many problems to be resolved in SAR analytical stereo-mapping. For example, shadow and layover are significant features of SAR image because of side-looking imaging method, and cause lack of information in these areas. The problem cannot be avoided in SAR analytical stereo-mapping. Extracting information from SAR images obtained from different side-looking direction in the same area is an effective solution of this problem.

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