

# VISUALIZATION OF SPACEBORNE SYNTHETIC APERTURE RADAR DOPPLER PARAMETER ESTIMATION AND ITS APPLICATION IN TOPOGRAPHIC SURVEYING AND MAPPING

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## ABSTRACT:

Synthetic Aperture Radar (SAR) image is not easy to interpretation because of its image unique characters, and there is a close relationship between the Doppler parameter and the quality of SAR image, these factors actually impact the application of SAR image in topographic surveying and mapping, although it is a active sensor and it is less affected by the weather and time. This paper focuses on the impact of the SAR image quality and SAR image interpretation in the application of topographic surveying and mapping, which caused by the low accuracy of SAR Doppler parameter and range migration, and as well as on a more practical way to improve the precise of SAR Doppler parameter with a visualization approach, so a better Doppler parameter can be utilized in topographic surveying and mapping.

## 1. INTRODUCTION

SAR is an advanced sensor with full weather and full time, and because of its unique performance, it is now wide spread in many fields like topography、agriculture、mining、water resource, etc. However, no matter in which field or application, we need to get accuracy enough SAR image, and in some fields, it should be interpreted correctly. In the process of SAR imaging, there are two main factors affect the quality of SAR image-Doppler parameter and Range migration. In fact, according to reason the range migration formula, it will be found out that range migration is close related to Doppler parameters (Z. Bao et al., 2006). And in the topographic surveying and mapping, the accuracy and the image quality is required (J. X. Zhang et al., 2004).

The structure of this paper is as follows: section 2 gives an introduction of Doppler parameter, section 3 gives an introduction of range migration, section 4 shows the visualization approach and results and finally, section 5 presents the conclusion and further research.

## 2. DOPPLER PARAMETER

Doppler parameter affects the image quality directly; the image will be defocused if there are errors presented in the estimation of Doppler centrid frequency, because of range migration, the accuracy of Doppler parameter estimated plays an important role in the correction of range migration.

Firstly, let us review the phenomena of Doppler. The Radar antenna received frequency is not the original frequency  $f_0$  transmitted by the Radar antenna, but plus an additional frequency  $f_d$ , that is to say, the frequency received by Radar

antenna is  $f_0 + f_d$ , the  $f_d$  is Doppler frequency offset.

Figure 1 show the relationship between them:

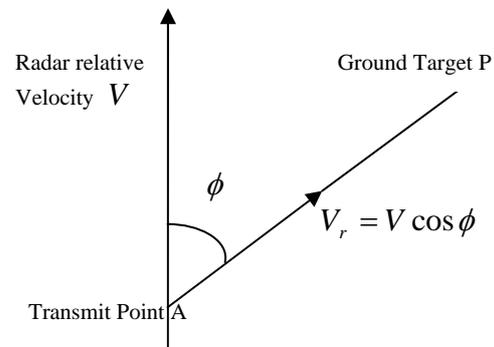


Figure 1: the geometric between ground target and Radar

$f_d$  close to Eq.(1)(C. Z. Han et al., 2006):

$$f_d = \frac{2V_r}{\lambda} = \frac{2V}{\lambda} \cos \phi \quad (1)$$

If the  $V_r$  is much less than the velocity of light  $C$ ,  $\lambda$  is the signal wave length, and from Eq.(1) knows that: 1)  $f_d = 0$ , if  $\phi = 90^\circ$ , it is perpendicular side-looking, that means the instance frequency the radar received just is the frequency the radar system transmitted; 2) the frequency received by radar will be various because of different ground target has different  $f_d$ , if  $\phi \neq 90^\circ$ , that's non-perpendicular side-

looking. Doppler centrid frequency will vary because of the echo signal phase changed by the distance difference between the Radar and the ground target. According to the relation between slant distance and phase and frequency, it is easy to prove the Doppler centrid frequency if the ground target is in the center of echo wave (Y. H. Zhang et al., 2000, C. Z. Han et al., 2006):

$$f_{DC} = -\frac{2}{\lambda} \times \left. \frac{\partial R}{\partial t} \right|_{t_0} = \frac{2 \sin \theta_0 V_r}{\lambda} \quad (2)$$

Here  $\theta_0$  means the direction angle between the ground target and the antenna direction. From (2): 1) Doppler centrid frequency  $f_{DC}$  changed if  $\theta_0$  changed, in fact it is caused by the slant distance, so it is wise estimate Doppler centrid frequency in different range cell; 2) In a synthetic aperture time, Doppler centrid frequency can be viewed as linear transformation if the radar wave width is defined. So the Doppler centrid frequency estimation is clear, according to the Doppler frequency spectrum of the ground target echo signal, retrieve the Doppler frequency corresponded to the centre of the azimuth power spectrum, and the estimation value of the Doppler frequency is the Doppler centrid frequency.

### 3. INTRODUCTION OF RANGE MIGRATION

Range migration is an importance step in radar imaging, it is composed of two main factors, one is range linear motion, and the other is the range curve, however, to correct them in the process of imaging, Doppler parameters is required.

In figure 2 (Z. Bao et al., 2006), it shows the relation between the ground target and the Radar in a synthetic Time.

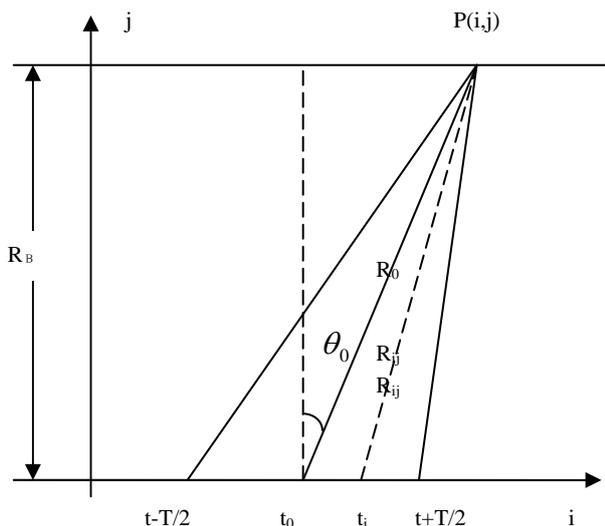


Figure 2: The ground target in a synthetic Time

In the triangle  $\Delta t_0 P t_i$ , the slant distance  $R_{ij}$  of the ground point P is showed as follow (Z. Bao et al., 2006):

$$R_{ij} = \sqrt{R_0^2 + (Vt_i - Vt_0)^2 - 2R_0(Vt_i - Vt_0)\sin\theta_0} \quad (3)$$

Form the above formula (3), with the difference of  $R_{ij}$ , the echo signal phase is differed as well, but here it is along with the Radar movement velocity (azimuth time-fast time domain) and the signal transmit velocity (range time-slow time domain), the so called range migration is the slant distance variety observed by the Radar system, there are two difference time-lapse, one is the fast-time domain time-lapse, the other is the slow-time domain, because of the variety of the time-lapse, the echo signal of a ground target disturb in different range cell in the range direction, in the figure 2, the difference of  $R_{ij}$  and  $R_0$  is defined as the amount of range migration between  $t_i$  and  $t_0$ , the range migration correction is needed if the amount of range migration beyond a range pixel. Using the formula (3), we get:

$$R_{ij} \approx R_0 - \sin\theta_0(Vt_i - Vt_0) + \frac{\cos^2\theta_0}{2R_0}(Vt_i - Vt_0)^2 \quad (4)$$

Define  $\Delta R = R_{ij} - R_0$  as the amount of range migration, we get:

$$\Delta R = -\sin\theta_0(Vt_i - Vt_0) + \frac{\cos^2\theta_0}{2R_0}(Vt_i - Vt_0)^2 \quad (5)$$

$$(Vt_i - Vt_0)^2 = \Delta R_1 + \Delta R_2$$

From the above formula, in a synthetic time,  $\Delta R = R_{ij} - R_0$  is composed of  $\Delta R_1$  and  $\Delta R_2$ . Generally, we define the  $\Delta R_1$  as the range linear movement, the  $\Delta R_2$  as the range curve, the former is mainly caused by the rotation of the Earth, and the latter is mainly caused by the large synthetic time. Also, from the above formula (5), we get (X. K. Yuan, 1994): 1) if  $\theta_0 = 0^\circ$ , that's the perpendicular side-looking, here the range linear movement is zero, there is only range curve in the range migration; 2)  $\theta_0 \neq 0^\circ$ , that's non-perpendicular side-looking, the amount of range linear motion of the target on the ground changes proportionately with the distance difference of the azimuth  $(Vt_i - Vt_0)$ , the scale coefficient is  $\sin\theta_0$ , and it is no business of the vertical distance between the ground point and the spaceborne Radar; although the range linear motion creates the coupling between the range and azimuth, the amount of the range linear motion is the same, that's very convenient for the compensation of the range migration; 3) for the range curve, form the above formula (5), the range curve is always presented in range migration of the echo signal data, if the echo width is defined.

Here we have a look the relation between the formula (5) and the Doppler parameter, in the figure 2, we define the  $(Vt_i - Vt_0)$  is  $Vt$ , that's the distance the radar have moved, so according to the formula (4), we get:

$$R_{ij} \approx R_0 - \sin \theta_0 Vt + \frac{\cos^2 \theta_0}{2R_0} (Vt)^2 \quad (6)$$

So if  $t_0$  is center of a synthetic time, the instance phase  $\Phi(t)$  of the echo wave signal received by the radar in a synthetic time can be viewed as:

$$\Phi(t) = \frac{4\pi}{\lambda} R_{ij} = \frac{4\pi}{\lambda} (R_0 - \sin \theta_0 Vt + \frac{\cos^2 \theta_0}{2R_0} (Vt)^2) \quad (7)$$

According to the derivative of  $\Phi(t)$  and divide it by  $2\pi$ , we get the instance Doppler frequency:

$$f_D(t) = -\frac{1}{2\pi} \frac{\partial \Phi(t)}{\partial t} = \frac{2 \sin \theta_0 V}{\lambda} - \frac{2 \cos^2 \theta_0 V^2}{\lambda R_0} t \quad (8)$$

In the center of a synthetic time, the Doppler frequency is the Doppler centrid frequency, the value is:

$$f_{DC} = -\frac{2}{\lambda} \times \frac{\partial R_{ij}}{\partial t} \Big|_{t_0} = \frac{2 \sin \theta_0 V}{\lambda} \quad (9)$$

And we get the Doppler :

$$f_{DR} = -\frac{2}{\lambda} \times \frac{\partial R_{ij}^2}{\partial t} \Big|_{t_0} = -\frac{2 \cos^2 \theta_0 V^2}{\lambda R_0} \quad (10)$$

Substituting (9)、(10) into (8) we get:

$$f_D(t) = f_{DC} + f_{DR}t \quad (11)$$

Substituting (9)、(10) into (5) we get(Z. Bao et al., 2006, C. Z. Han et al., 2006):

$$\Delta R = -\frac{\lambda f_{DC}}{2} t - \frac{\lambda f_{DR}}{4} t^2 = \Delta R_1 + \Delta R_2 \quad (12)$$

From formula (5) to formula (12) we get the close relation between Doppler parameter and the range migration definitely, so before correcting the range migration, get better Doppler parameter is guaranteed.

#### 4. VISUALIZATION APPROACH AND RESULTS

According to the above discuss, we use RD algorithm and visualization of the Doppler parameter, we get the following results, figure 4 is the SAR image without the estimation of

Doppler parameter; figure 5 is the SAR image with the result of Doppler parameter estimation. Finally, these Doppler data is well applied in the topographic surveying and mapping.

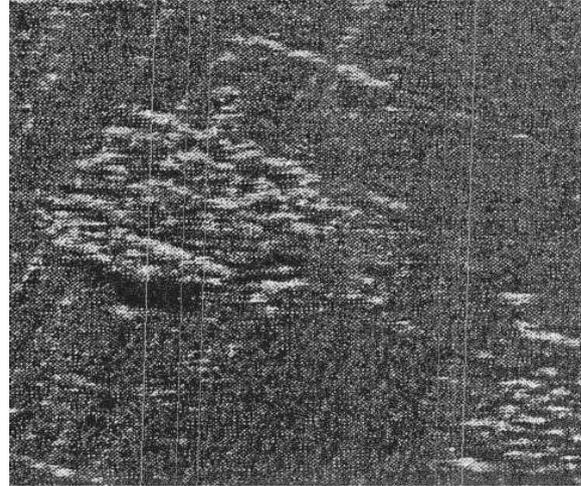


Figure 4: Without Doppler parameter estimation

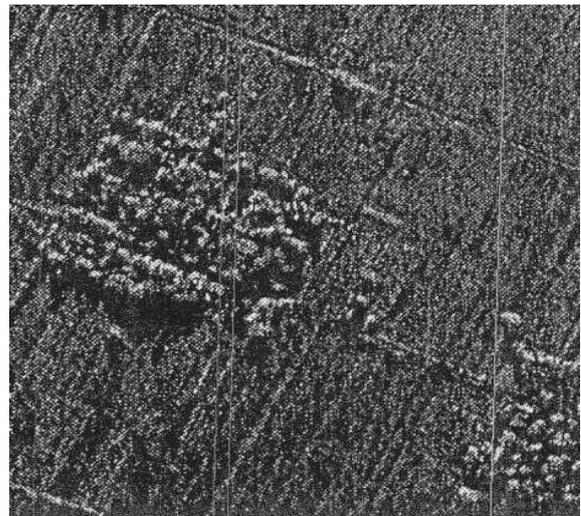


Figure 5: With Doppler parameter estimation

#### 5. CONCLUSIONS AND FURTHER RESEARCH

Through the experiment and analysis, Doppler parameter estimation is a complex process, not only the Doppler parameter itself, but also it is related to the range migration, and it is also play an important role in topographic surveying and mapping. And the results we get approve that visualization of Doppler parameter estimation is a feasible approach in practice.

In conclusion, Doppler parameter estimation is a hard task, but it is the fundament of SAR imaging it needs further research.

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