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Error Effects on SAR Image Resolution using Range Doppler Imaging Algorithm

Su Su Yi Mon, Fang Jiancheng

***Abstract*—**Synthetic Aperture Radar (SAR) is an imaging radar form by taking full advantage of the relative movement of the antenna with respect to the target. Through the simultaneous processing of the radar reflections over the movement of the antenna via the Range Doppler Algorithm (RDA), the superior resolution of a theoretical wider antenna, termed synthetic aperture, is obtained. Therefore, SAR can achieve high resolution two dimensional imagery of the ground surface. In addition, two filtering steps in range and azimuth direction provide accurate enough result. This paper develops a simulation in which realistic SAR images can be generated. Also, the effect of velocity errors in the resulting image has also been investigated. Taking some velocity errors into account, the simulation results on the image resolution would be presented. Most of the times, algorithms need to be adjusted for particular datasets, or particular applications.

***Keywords*—**Synthetic Aperture Radar (SAR); Range Doppler Algorithm (RDA); Image Resolution

I. Introduction

SAR system gives geographic description reflectivity versus range and Doppler (cross range). Range resolution is accomplished through range gating. Fine range resolution can be accomplished by using pulse compression techniques. The azimuth resolution depends on antenna size and radar wavelength. Fine range resolution is enhanced by taking advantage of the radar motion in order to synthesize a larger antenna aperture.

On account of large amount of signal processing required in SAR imagery, the early SAR designs implemented optical processing techniques. Although such optical processors can produce high quality radar images, they have several shortcomings. They can be very costly and are, in general, limited to making strip maps. Motion compensation is not easy to implement for radars that utilize optical processors. With the recent advances in solid state electronics and Very large Scale Integration (VLSI) technologies, digital signal processing in real time has been made possible in SAR systems [1]. The motion between radar and targets is also the problem for SAR system.

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It is very important to know what the extent of the radial velocity which works on synthetic range profile and the combination of the azimuth synthetic aperture processing with the range profile to obtain high resolution image in two dimensions. Therefore, first, the method of SAR image processing is presented. Range Doppler Algorithm (RDA) for SAR processing is discussed and implemented in this paper.

II. Range Doppler Algorithm

RDA is the most common algorithm for SAR processing which produces the best quality of image result. It mainly works matched filtering, a common technique in communication. Matched filtering is the correlation of a template signal with an unknown signal, which has the same purpose of convolution of an unknown signal with a time reversed, to detect the presence of the template signal in the unknown signal. Fig 1[2] is the block diagram of RDA showing the steps of processing.

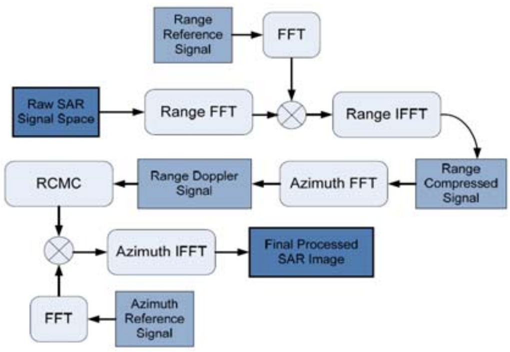

Fig.1 RDA block diagram

As described in Fig 1, RDA follows the three major tasks. These are Range Compression which covers Range FFT, IFFT from Raw SAR signal, Range Cell Migration Correction (RCMC) and Azimuth compressing, which includes azimuth FFT, IFFT.

Point target SAR geometry is illustrated in Fig 2. While the aircraft files by a point target on the ground, the return signal has a Doppler frequency (Doppler histories). These Doppler histories are separated by the time delay required to fly between target scatterers and varies approximately linearly with time over the duration of the synthetic aperture flight time.

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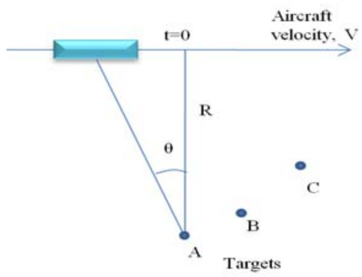

Fig.2 Point target SAR geometry

The frequency slope of the return signal is directly proportional to the square of the platform velocity and inversely to the target range as shown in (1).

$$K = 2V^2 / R\lambda \quad (1)$$

It can be assumed that the variation in range (R) from the radar to the given target (A), over the duration of the synthetic aperture, is less than the range resolution of the radar so that the target will remain within the confines of a given range resolution cell for the duration of the synthetic aperture flight time. If this assumption is violated, RCMC process must be used.

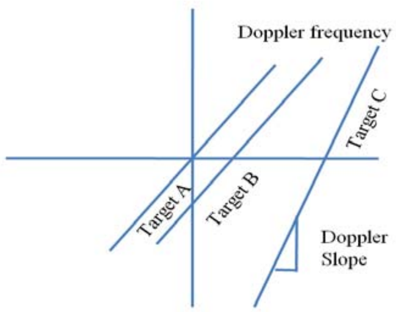

Fig.3 Doppler history illustration

The Doppler frequency is denoted by f_d and can be described as:

$$f_d = 2V\sin\theta / \lambda = 2V^2 t / R\lambda \quad (2)$$

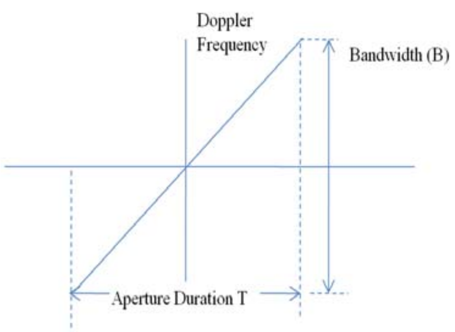

Fig.4 Received signal from point target

Fig 3 shows the received signal from a point target and its bandwidth B can be derived by:

$$B = 2V^2 T / R\lambda \quad (3)$$

III. Resolution And Velocity Estimation

The fine resolution SAR image is mainly focus on the resolution cell of range and azimuth. The range resolution ΔR, can be calculated by Fig 4.

$$\Delta R = c\tau / 2 \quad (4)$$

Where τ is the pulse width and the amount of the ground range cell ΔR_g is derived by (5),

$$\Delta R_g = c\tau(\sec\alpha)/2 \quad (5)$$

The azimuth resolution is determined by the Doppler bandwidth of the received signal and can be computed as L/2, where L is the antenna length.

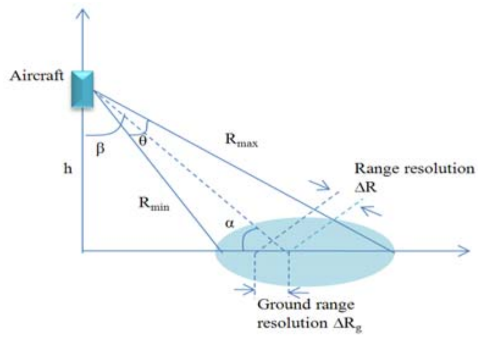

Fig.5 Resolution cell illustration

To prevent aliasing the minimum Pulse Repetition Frequency (PRF) should equal the maximum Doppler spread across the radar beamwidth, θ. Therefore, PRF can be defined as:

$$PRF \geq 2V\theta / \lambda \quad (6)$$

The velocity of a moving object candidate is obtained by estimating their displacement vectors, which give the displacement of the candidate in pairs of two successive images of the generated sequence. The displacement vector is obtained using a modified block matching algorithm (Bierling, 1988) [7].

This algorithm searches for the best match between blocks in two successive images with regard to the normalized cross correlation function as matching criterion. In the second of a pair of images the block is set centered around a candidate. Then in the previous image that position is searched which leads to the maximum correlation between the two blocks. The difference of the positions is taken as displacement vector. It is measured in the unit pixel per image. This displacement vector is then used to calculate the velocity components [7].

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The maximum radial velocity between radar and target can be given by

$$V_{\max} = |V \cos\theta| \qquad (7)$$

The limit of the shift and spread due to the radial velocity should be controlled within one range bin for fine range resolution.

IV. Simulation Results

The following airborne-based SAR parameters are used for synthesizing the received signal array. The same set parameters, with minor differences, and X-band data will be used for the simulation.

TABLE I
PARAMETERS USED IN SIMULATION

Parameter	Symbol	Value
wavelength	λ	0.03m
LFM time duration	*T*	5μs
Closet range	*R0*	8000m
Sampling frequency	*fs*	200MHz
Radar speed	*V*	80m/s
Antenna Length	*L*	2m
Radar 3-dB beamwidth	*θ*	0.015radian
Pulse Repetition Frequency	*PRF*	202Hz

Finally, the complex SAR image that is simulated in Matlab programming is obtained. Fig 6 and 7 shows the results of simulation without consideration radial velocity movement (with fixed velocity. If the velocity compensation is not considered, it makes the miserable image resolution after adding velocity error as shown in Fig 8.

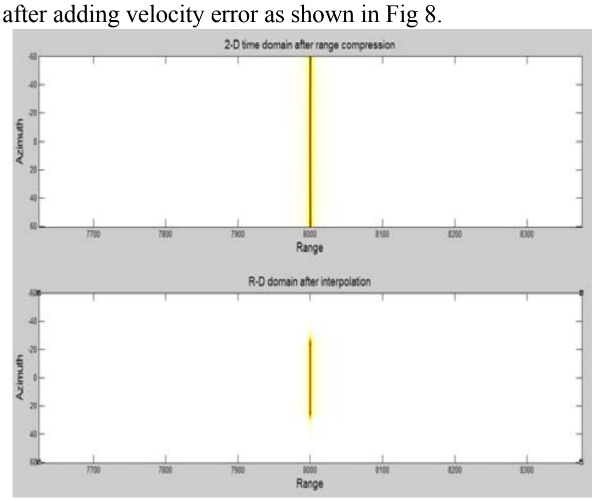

Fig.6 Point Target Simulation results after range compression and RCMC (with fixed velocity)

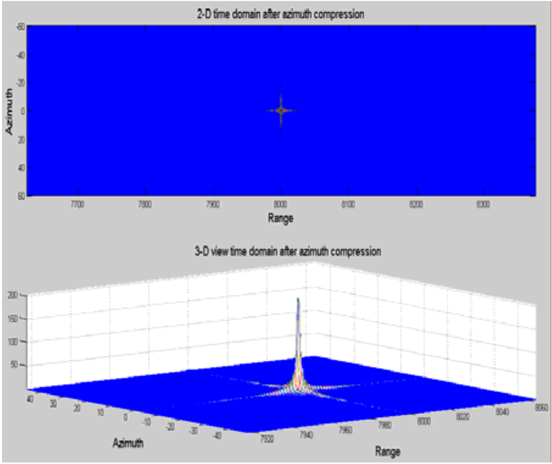

Fig.7 Point target simulation results, after azimuth compression and three dimensional view (with fixed velocity

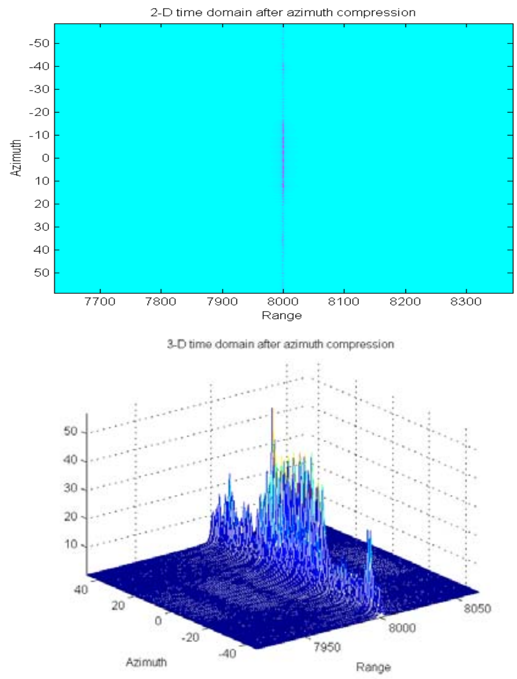

Fig.8 Point Target Simulation results without velocity compensation (adding velocity error)

V. Conclusion

Compared with the SAR image without compensation, the range and azimuth resolution of the compensated image have been greatly improved. It is obvious that speed (velocity) error makes the resolution lack of accuracy. Therefore the velocity compensation is required in the range compression.

The computational load for the azimuth fast convolution is based upon an FFT length equal to three times the operation length. For pulse compression and azimuth processing of RDA algorithm, fast convolution process is more efficient to implement the correlation process. Future research will be focused on the error correction, especially for the cases of movement error that effects on range direction in which the geometry is more complicated.

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