Investigation of Ununiform Ship Phase Observed in High-Resolution TanDEM-X ATI-SAR using Electromagnetic Simulation

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ABSTRACT: Along-Track Interferometry (ATI) is one of the synthetic aperture radar interferometry (InSAR) technique which extracts surface velocity. These data are generated while transmitting and receiving signals while moving two SAR antennas on the same orbit (or back and forth on the same platform) at short distances. In the TerraSAR-X and TanDEM-X satellites system, because getting the SAR data along the same path, we can make ATI data.

As the SAR data becomes more high resolution, an object can be observed in more detail. TerraSAR-X also get high-resolution SAR images using X-band, so a single object such as a ship will come out in multiple pixels. With this data, we can more accurately measure surface object velocity using ATI-SAR method. Thus, the phase value of object in ATI image must have the same because it indicates the speed of the object.

In case of TerraSAR-X, however, the calculated speed of ship from image has some problem that each pixel in the boat has different phase values. It can be assumed that the value of ATI contains other information besides velocity. In this study, we want to know what these factors are and how they affect the results. We will study this problem using the electromagnetic simulator (EM simulator) and TerraSAR-X geometry information. These are made by the controlled environment, so that accurate phase values can be measured. Therefore, it is possible to separate the phase value by other parameters.

1. INTRODUCTION

InSAR is a technique for extracting surface information by obtaining phase difference using two or more complex SAR data. Along-Track Interferometry (ATI) is a system that uses the phase difference caused by the geometric difference of two signals obtained with a short time interval. The two SAR antennas are moved to the same orbit (or back and forth on the same platform) at short distances to transmit and receive signals to get data. After the SAR data is acquired from each antenna, the4 interferogram image of the two data is generated, so that the speed of the moving object on the surface can be measured. These systems are mainly used in airborne SAR systems. In spaceborne, Shuttle Radar Topography Mission (SRTM) and TerraSAR-X are support ATI mode.

TerraSAR-X has a higher instrument noise level and a shorter follow-track baseline than SRTM. Thus, higher pixel resolution permits more spatial averaging for the same effective resolution. TerraSAR-X simulations assumed that the effective along-track baseline is short. and that the backscattering characteristics of the water surface are homogeneous, so the images are not affected by strong artifacts associated with azimuth ambiguities, such as ghost images of nearby regions of increased backscatter in regions of low backscatter (Romeiser et al. 2010).

Using these features, studies are actively carried out using TerraSAR-X ATI data such as ocean currents, river speed monitoring, traffic congestion monitoring, and ship tracking at sea.

As the ATI data becomes more sophisticated, it is necessary to consider not only the speed of the object but also variables such as acceleration and shaking of the object. In the case of ATI data using two satellites such as TerraSAR-X, it added the phase that the altitude information of the object. This is because the orbit between the TSX and the TDX is not same exactly. It knows that the phase values added by these other factors will affect the results, but it is hard to know how much of the actual ATI data will affect them.

Used an Electromagnetic simulator (EM simulator) to determine the effect of object altitude, acceleration, and shaking on ATI results. The EM simulator is software for analyzing the scattering characteristics of a target by electromagnetic waves.

In the SAR field, Studies using EM simulations are mainly related to Inverse Synthetic Aperture Radar (ISAR). For example, there is a research on the construction of a target recognition database using the scattering characteristics of the target digitized by Computer Aided Design (CAD) for real target (Mishra and Mulgrew 2005).

In this study, generate two-pairs of SAR images using the EM simulator as the data that digitizes the analysis object with CAD. These are the result by the controlled environment, so that accurate phase values can be measured.

2. METHODOLGY

2.1 EM Simulator

Simulations have played an important role in SAR applications. This is mainly due to two reasons: difficulties in obtaining the ideal data and collecting data in a controlled environment. In order to analyze the scattering characteristics of the target by electromagnetic waves, a general analytical solution or a numerical solution must be obtained through a differential equation or a Maxwell equation expressed as an integral equation. The EM simulator provides a solution to the complex and diverse numerical analysis. In this study, Newfasant software was used to calculate Electric Field values of scattering characteristics.

The actual size of the ground target is electrically large. Therefore, although the EM simulator supports the method of calculating the moment of the scattering method, it is practically impossible because it takes a lot of memory and time. So, the physical optical method (PO) with multiple bounces is the best fit for the current task (Figure 1.). Because PO replaces surfaces with small triangular facets (Moreno et al. 2013). In this study, using the PO method, Analyze the scattering characteristics of electromagnetic waves to an object.

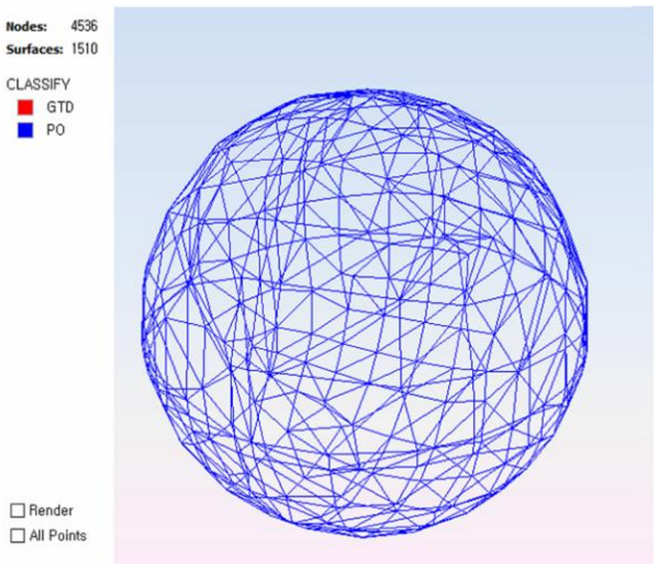

Figure 1. PO method of the sphere model

2.2 Generation of SAR Raw data using EM Simulator

In the EM simulator, swept frequency is used to implement chirp signals like pulse-based SAR systems. The Swept Frequency changes the frequency at each step to gain the value of each frequency (f_τ) obtained from the target.

The data obtained using EM simulator is frequency domain data (Figure 2)**.** to get the time domain range profile, calculated by the inverse discrete Fourier transform (IDFT) (Figure 2) (Mensa 1991).

$$IDFT_{range}E(f_\tau, \eta) = \ S_{rc}(\tau, \eta) \tag{1}$$

The range profile obtained from the response signal is considered to reflect the characteristics of the target (Van Trees 2004).

2.3 Focusing SAR image Algorithm

Compression of SAR raw data is performed using a variety of algorithms such as the Range Doppler Algorithm (RDA), the Frequency Scaling Algorithm (FSA), and the Ω-k algorithm (Cumming and Wong 2005).

Generally, image restoration algorithm performed in the frequency domain. This is for easy calculation of the convolution. The impulse response becomes longer as the distance between the target and the antenna becomes longer, resulting in a range cell migration curve. In order to use discrete Fourier transform (DFT) to change this image in the frequency domain, Range Cell Migration Correction (RCMC) is used because the impulse response must be aligned to the same position. However, RCMC uses an approximation, which leads to errors.

On the other hand, the Back-Projection Algorithm (BPA) is a method that reconstructs images in time domain instead of frequency domain (Nguyen et al. 2004). This is an algorithm that is used in topography and Magnetic resonance imaging.

In Simulation, we know exactly the geometric location between the target and the antenna. used BPA for image focusing. The time (t_d) between the pixels (x_i, y_j) in the coordinate system where the image is projected and the position of the antennas (u_m) can be defined as follows (Soumekh 1999) (2).

$$t_d = \frac{2}{c}\sqrt{x_i^2 + (y_j - u_m)^2} \tag{2}$$

Using the distance $R_d(t\ , \eta\ )$, find the signal in the RCM image and add all the signals to the pixel (x_i, y_j) (Figure 2-6). Conjugate convolution with the reference signal (S_0^*) removes the phase corresponding to the distance component (3), (4).

$$\sum_y \sum_x \sum_m S_{IF}(t_d, u_m) \times S_0^*(t_d\ , u_m) \tag{3}$$

$$S_0^*(\tau_d, \eta) = \exp\left\{-j2\pi\left(\frac{2R_d}{\lambda}\right)\right\} \tag{4}$$

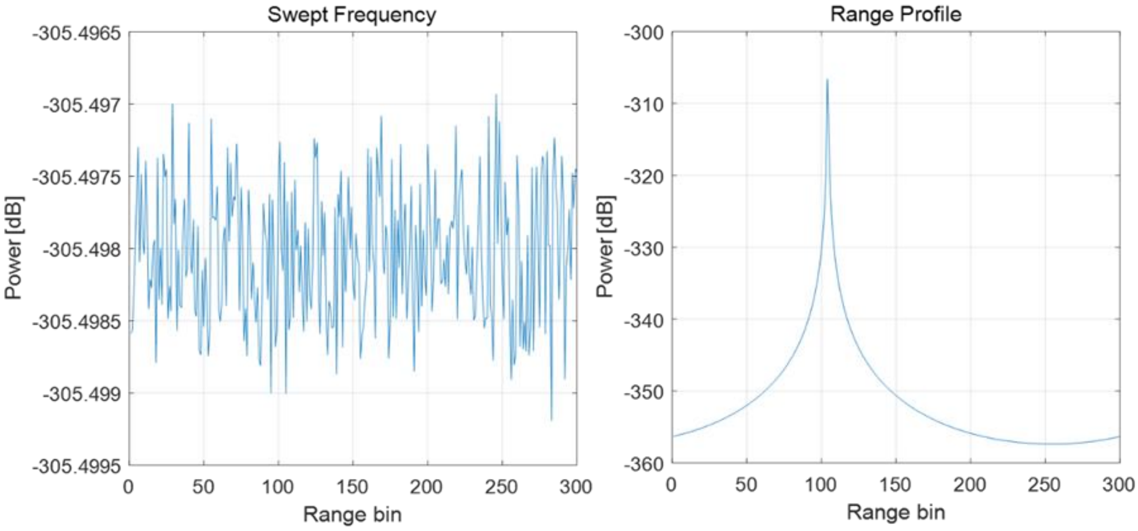

Figure 2. Electric Field (left) and Range Profile (right) of the sphere model.

2.4 Along-Track Interferometry

Compression Along-track interferometry is an interferometric synthetic aperture radar (InSAR) method that can be used to object velocities. using dual-channel SAR data obtained from highly center-separated phase centers on the platform, ATI technology collects data from the center of the phase. the SAR images formed from these two phase centers feature a time base line that is equal to the time required for the platform to move the offset distance between the tracks at the phase center. Therefore, the stationary elements of the rendered scene contribute equally to the two images, but the moving objects of the scene represent phase shifts between the two images. As a result, the interference fringes formed from the two images represent the surface movement of the imaged scene (Chen 2004).

Since the phase difference is proportional to the Doppler shift of the backscattering signal, it is proportional to the range velocity U_r of the scatterer (Duk-jin et al. 2003).

$$\Delta\emptyset = \omega_{\mathrm{D}}\Delta t = \frac{k_i B}{V} U_r = \frac{2\pi B}{\lambda_i V} U_r \tag{5}$$

V is the platform velocity, k_i and λ_i are the incident radar wave vector and wavelength respectively. B is along-track baseline between the antennas (Figure 3).

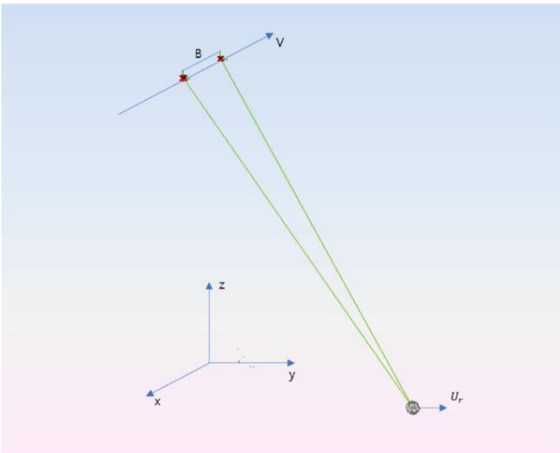

Figure 3. Schematic geometry of the simulation.

3. RESULT OF SIMULATION

3.1 Result of SAR raw data generation

We created SAR raw data for the ship model through simulation. The result of simulation calculation is the same as Figure 4. It has a strong amplitude value when the antenna is closest to the object. The Range profile calculated by IDFT is shown in the Figure 4. below. The range profile shows that if the distance between the object and the antenna is long, the impulse response is delayed. Figure 4. shows the ray of the electromagnetic waves calculated by the PO method.

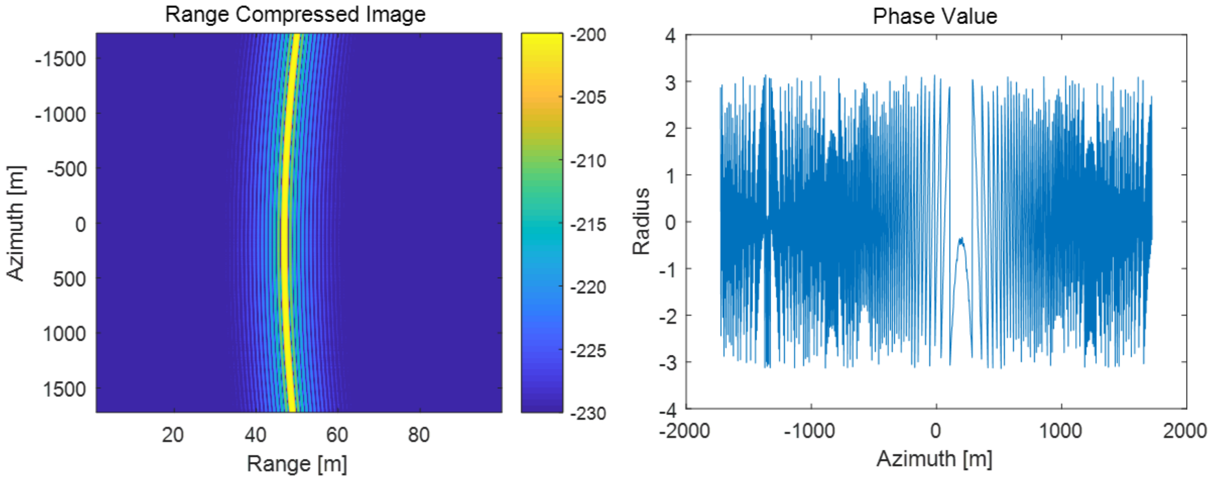

Figure 4. The result of range compressed image (left) and phase value (right)

3.2 Result of Focusing SAR image

The image made by EM simulator can be restored by using the distance between the pixel of the coordinate system in which the image is projected and the position of the antenna. The reconstructed image is shown in the following Figure 5. The side lobe in the range direction related to the range compression quality. we think is a result of having a low spatial resolution in the direction of the range.

The image reflected the scattering characteristic of the object selected by the PO method. The interesting thing is that there are strong amplitudes at the preceding three points. This is the result of concentrated ray because the area selected by PO is narrow.

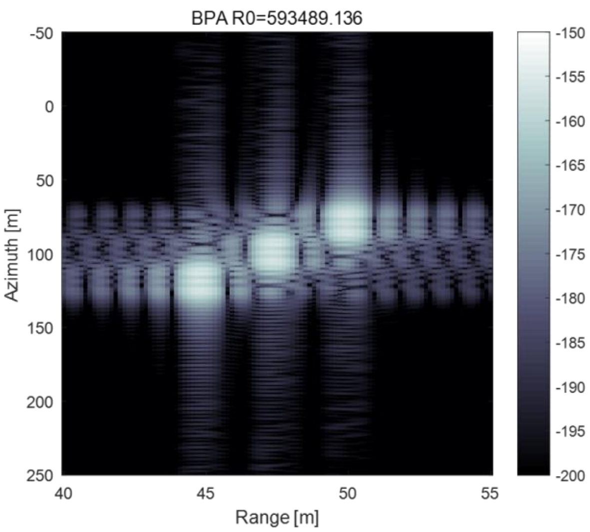

Figure 5. reconstructed image using BPA.

3.3 Result of Along-Track Interferometry

To check the velocity of an object, we experimented when the object being stopped and moved. The ATI result when the object is stopped is shown in the upper figure of Figure 4. From the results, there is almost no change in phase. Therefore, there is no speed of the object. On the other hand, if there is an object velocity, the phase changes as shown in the lower of figure 6. In this situation, it is difficult to extract the exact speed of the object. Because the phase is repeated. Therefore, it is difficult to extract the exact velocity of an object with only a single target, and only the movement can be estimated.

4. CONCLUSION

In an environment like TerraSAR-X and TanDEM-X, raw data for point targets was generated using EM simulator. Based on the generated SAR raw data, ATI components were extracted. Simulations were performed in a controlled environment to get accurate baseline settings and location of point targets.

It was difficult to extract the exact velocity of an object with a single target. To solve this, we will make two bistatic ATI SAR images using an electromagnetic simulator (EM simulator), which digitizes the analysis target with computer aided design (CAD). And will analyze the actual satellite data based on the simulation data.

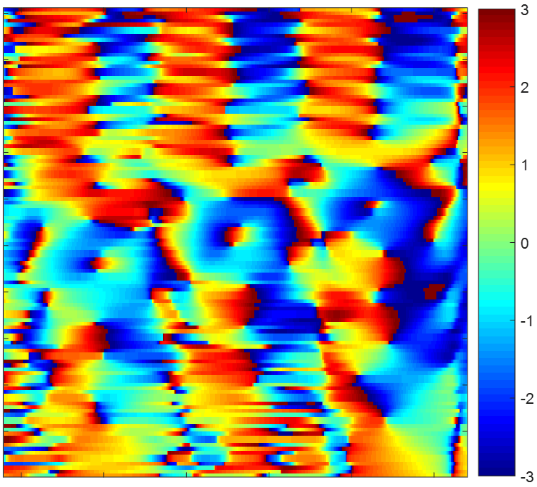

Figure 6. The Phase value of Along-Track Interferometry.

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