A PRELIMINARY STUDY OF SATELLITE-BASED SYNTHETIC APERTURE RADAR MISSION PLANNING USING IMAGERY AND ORBIT SIMULATION

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ABSTRACT: During the system evaluation stage, the first step in planning the overall system parameters is conducting mathematical simulations of critical parameters. In the international arena, SAR images with similar system parameters are used for reference. This stage allows the evaluation of essential parameters, such as image resolution, radiometric resolution, range swath, return energy, and incident angle for different locations and observation modes. In image acquisition, various data acquisition modes such as Stripmap and Spotlight are simulated based on real or ideal land structures and land use. To verify image quality, point-like structures, such as dihedrals or spheres, are utilized as targets for evaluating noise equivalent sigma zero (NESZ) of sigma naught, and other relevant parameters. Following the principles of system engineering, each module in the sub-system is further divided into specific components. Numerous small functional parts require thorough verification and testing. During this stage, parameters, regardless of their nature, are highly likely to be modified. Therefore, understanding how these modifications may affect other parameters is our primary concern. This paper addresses the aforementioned issues and introduces a simulator that incorporates satellite path trajectory and echo signals for synthetic aperture radar systems. In this paper, we simulate SAR echo signals with different data acquisition modes, using both simulated and real satellite state vectors. These data, combined with all system parameters in meta files, are essential for later processing in the focusing algorithm. Due to the diversity of parameters in the development stage, the SAR echo data generated is substantial. These simulations serve as a crucial basis for modifying system or hardware parameters, with cross-validation ensuring accuracy. The software orientation simulator's flexibility allows for the inclusion of parameters affected by real environmental factors, such as dielectric constants due to land use and land surface elevation. Different surface materials influence the backscattering return power and clutter effects. Varied elevation levels, dictated by natural landscapes, affect the focusing parameter estimations for Doppler centroid and slant range distances. Additionally, distinct geodetic locations influence the local incident angle, determined by the local Earth's radius. Different slant ranges impact the point accuracy and swath, which may cause geo-reference mismatching. Furthermore, this simulator also supports the development of focusing algorithms for verifying accuracy and accommodating various data acquisition modes and land use environments.

1. INTRODUCTION

1.1 Motivation

According to the previous plan to collect solutions adopted by international synthetic aperture radar (SAR) teams, in the 2021 research case, it is planned to select various parameters related to the orbit, mainly involving the measurement error of radiation performance, including transmission power. , antenna gain, pointing control accuracy, slant range error, propagation attenuation, etc. In the 2022 research project, many correction projects are planned, including antenna field model effects, antenna pointing effects, absolute radiation correction effects, focusing imaging tests for imaging errors, etc. Because the simulation method used in this research project is mainly A corrective effect will be proposed in orbit. Especially in the last item of imaging error, by adjusting the parameters of the simulated SAR echo signal, more unknown variables in the SAR imaging process are provided. The main contribution of this research project will be to faithfully reflect and analyze the image quality loss caused by these variables through imaging results.

2. SIMULATION FOR ORIBIT RELATIVE TEST

2.1 Simulation definition

According to the purpose of the project, in order to obtain the "image effects caused by various factors" in the project, the following is a list of verification projects related to orbit and SAR echo signal/image simulation during the project progress stage, including: Antenna gain, Pointing control accuracy, Slope range error, Propagation attenuation.

2.2 Simulation procedure

This chapter will describe how to perform SAR echo signal simulation and SAR imaging processing through acquired terrain data and simulated/extracted orbit parameters. The detailed flow chart is shown in Figure 1.

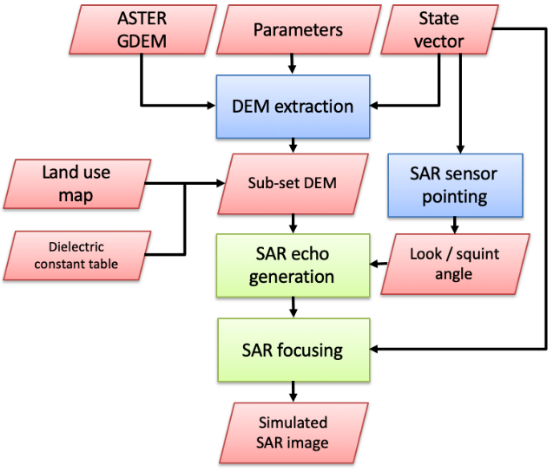

Figure 1. Block diagram of simulated image processing flow.

First of all, the first project will be to obtain the relevant data of the digital terrain (Digital Elevation Model, DEM) through the ASTER GDEM system, mark the center point position of the icon and import it into the ASTER GDEM system to obtain the longitude in one degree. and world-wide numerical terrain information in one-degree latitude grids. The second part is the SAR sensor pointing calculation, which is different from the data stage of numerical terrain extraction mentioned above. It aims to obtain the center of the image frame through the orbit. In this processing procedure, clearer and more accurate pointing information will be needed. Through this information, the simulator must be able to clearly inform the simulator of the relevant information about the look angle and the squint angle. Since this simulation system does not directly add Doppler parameters to the signal, but these parameters will be directly reflected in the simulated SAR echo signal through the direction of the antenna, this method can more directly express the The phenomenon of Doppler shift caused by the relationship between oblique angles.

In addition, after numerical terrain extraction, the image size is still very large, and the range we need to simulate is usually only a small part of the entire one-degree latitude and longitude icon, so we will do a small range of the obtained numerical terrain data. Selection, and this small-scale selection depends on several things, including: Land use map and Dielectric constant table. The two parts mentioned above are mainly used to distinguish different properties of ground objects, and these properties will directly affect the value of the dielectric constant required in the calculation, and such value will be directly reflected in the echo signal. The strength and weakness.

2.3 SAR focusing processing

After simulation, collecting such echo signal data still requires the processing of converting signals into images. This step is usually called "imaging processing". The algorithm we use is the Range Doppler algorithm (RDA for short), which is a classic SAR imaging algorithm that is used to process SAR raw data to generate high-quality imaging images.

2.4 Full scaled DEM model

This experimental area is based on a three-dimensional terrain elevation map covering the Taipei area's Tamsui River outlet and part of the Yangmingshan area. This three-dimensional terrain data comes from the ASTER GDEM database, a project initiated by NASA. Extract part of it based on the northern Taiwan area and simulate it.

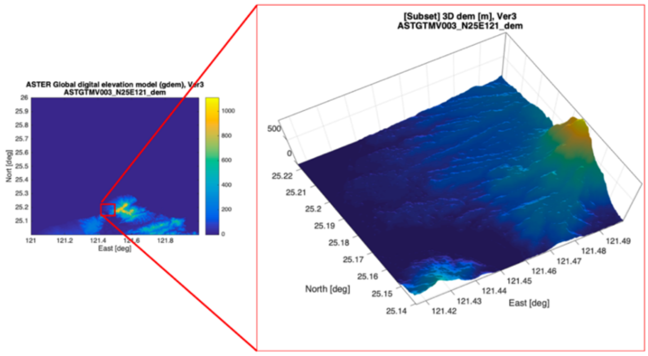

Figure 2. 3D DEM model for terrain simulation.

The picture below is a SAR amplitude image after the echo signal is processed by a SAR imaging processor. In addition to the intensity of the scattering points, it reflects the feature the structure and appearance of the target through the concentration of different scattering points.

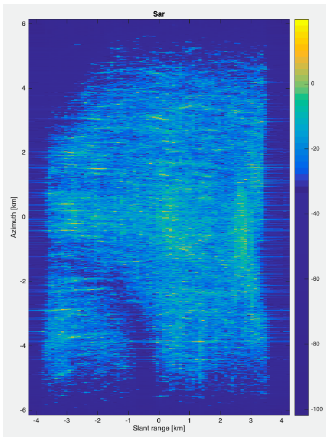

Figure 3. SAR amplitude imagery in dB.

2.5 Down scaled DEM model

Since the calculation of a full-scale digital elevation model covers too wide a range, it takes a huge amount of time to calculate and verify. Therefore, if you only want to check the simulation effect, a scaled-down model is usually used to speed up the generation of simulation result maps. We often reduce the size of a model with a side of 2 kilometers square to a reduced model of 90 meters square, and the appropriate basis is wrong! The reference source cannot be found. The data is adjusted to meet the parameters required for scaling. The changes to the scale model can be seen in Figure 9. The height is as low as 8.9 meters, from 890 meters to 890 meters.

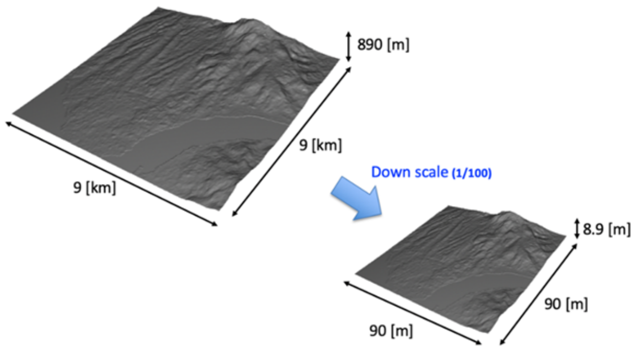

Figure 4. The 3D scene model after down-scaling.

In Figure 5, the upper left corner is the result of simulating the echo signal and removing the transmitted signal. The horizontal axis represents the frequency, and the vertical axis represents the Doppler frequency. The magnitude is displayed in dB. The middle picture in the upper half shows the result of compressing the original data with slant range. The horizontal axis represents the slant range, and the vertical axis represents the position of the azimuth term. From the picture, it can be found that there are many strong scattering points, and It is recorded in the Src image in a hyperbolic manner, which means that the effect of the migration of the slant range term is included in this simulated image. The Srd of Src diagram in the upper corner represents the Doppler plane of the slant distance corresponding to Src, so the vertical axis is replaced by the Doppler frequency. As in theory, the scattering points at the same slant distance are in agreement. Slope distance - on a curve in the Doppler plane. The Srcmc in the lower middle is the spatial domain graph after slant distance migration correction. Compared with the Src graph above, it is obvious that the curve can be straightened. The corresponding Srd graph in the lower left shows the corrected slant distance.

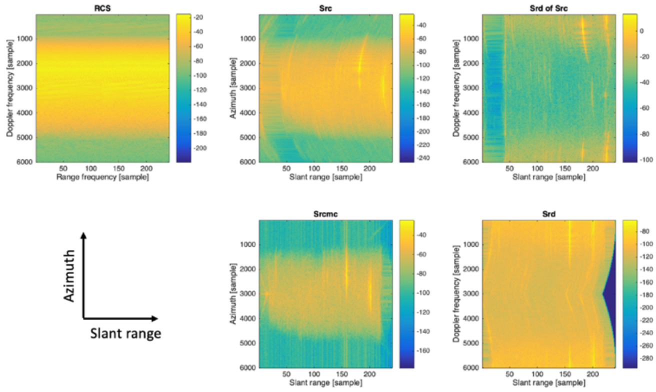

Figure 5. Echo signal of down-scaled DEM model.

Figure 6 is a SAR amplitude image after the echo signal is processed by a SAR imaging processor. In addition to the intensity of the scattering points, it reflects the structure and appearance of the target through the concentration of different scattering point features.

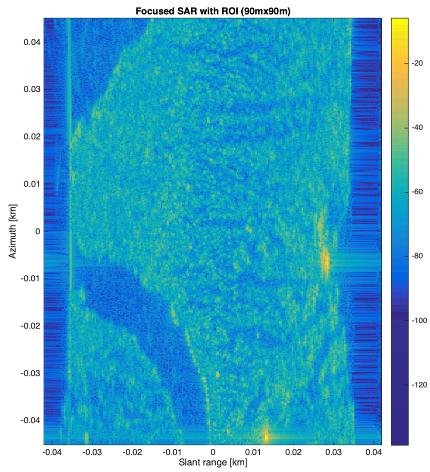

Figure 6. Focused SAR amplitude imagery in dB.

2.6 Down scaled urban model

In order to observe more complex structural properties, using models with complex structures and complex materials is a reasonable choice. We conducted simulation tests based on the information we obtained about buildings and some mountainous areas around Taipei 101. The model type is shown in Figure 20. No material information was included in the mid-term period and will be adjusted after the mid-term period. The number of triangles in the complex model reaches 178,802, the spatial range is 77 meters by 96 meters in scale, and the corresponding maximum height (101 Building) is 13.16 meters. The airborne SAR observation geometry used in the simulation is also shown in Figure 7.

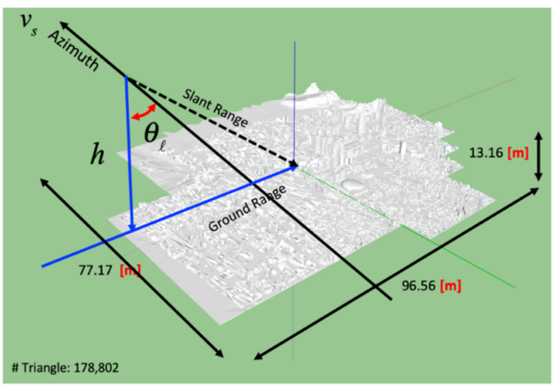

Figure 7. Geometry of urban model and SAR observation.

The simulation parameter data used is still based on MSTAR to modify the SAR imaging results. In the imaging stage, please refer to Figure 8, which only shows the HH polarization image. The left side of the above line represents the amplitude image of the SAR echo signal simulation, which can correspond to the performance of the radar cross section (RCS). The horizontal axis represents the slant range frequency point, and the vertical axis represents the Doppler direction position point. In the middle of the upper row is the amplitude image formed after slant range compression. The horizontal axis represents the distance in the slant range direction, and the vertical axis remains unchanged. It is no longer possible to clearly see any independent brighter curve. Instead, there is a collection of many curves. If you look carefully, these curves are still curved. Similarly, the RDA method will be converted to the Doppler frequency domain, as shown in the graph on the right side of the above row, where the vertical axis represents the Doppler frequency. These curves intersecting with the slant range will overlap on the slant range/Doppler plane, so the slant range migration correction will be performed directly on such a graph. The corrected results are presented in the middle of the row below. This picture can correspond to the middle picture in the above row. It can be clearly compared that the problem of slant range migration is completed and the correction will be completed. Finally, matching filtering in the azimuth direction will be performed, usually returning to the slant range/Doppler plane, supplemented by Doppler. The oscillator performs azimuth compression. After the azimuth compression results, the results are shown in Figure 8.

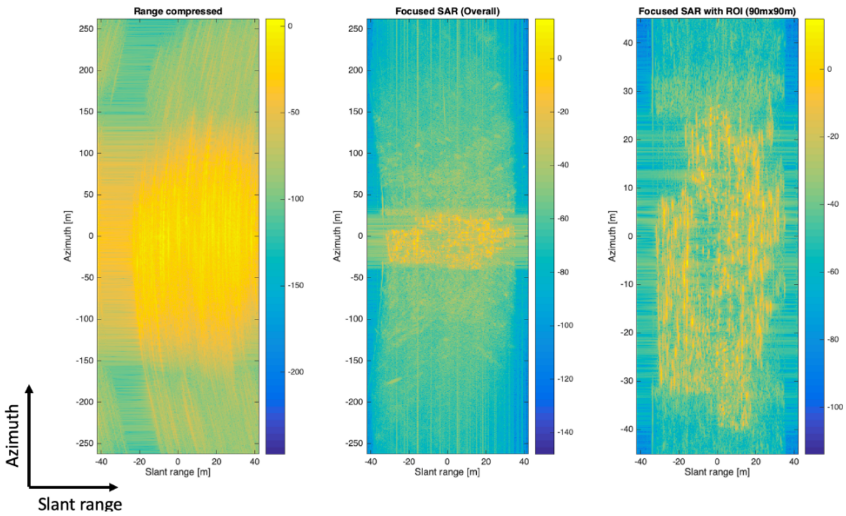

Figure 8. SAR amplitude imaginary of down-scaled urban in dB.

3. CONCLUSION

The main goal of this stage is to first establish an echo signal simulator for synthetic aperture radar simulation, which includes three key projects: orbit simulation, radar echo signal simulation and SAR imaging processing. The main hope is that through such simulation The establishment of the instrument enables subsequent analysis of the impact of various orbit-related parameters. First, in terms of orbit simulation, the demonstration orbit was simulated based on two rows of parameters, in which the impact on SGP4 orbit prediction was also accumulated. These orbit simulation results provide us with configuration guidelines for selecting the best prediction method to ensure that the simulated SAR system can achieve the best imaging effect. In addition to making predictions directly from the two-line parameters, directly extracting orbital information from ALOS-1 real image data is also one of the methods of choice. Since commercially used satellite data are mainly sold globally, orbital data covers the southern hemisphere. With the Northern Hemisphere, a large number of interpolation point techniques must be added to the existing orbital state vector in the use of data. In addition, radar echo signal simulation is the focus of this phase of research, which allows users to gain an in-depth understanding of the reflection characteristics of radar signals by target objects. In order to obtain more realistic simulation information, based on the land use map and dielectric material parameter table, the correspondence between the two can be closer to the electromagnetic wave response in the real world when simulating SAR echo signals. By simulating a full-scale dihedral corner reflector, we verified the accuracy and reliability of the SAR simulation in terms of geometry and relative energy. This achievement will help us better understand the radar characteristics of target objects and conduct SAR imaging more accurately. In terms of SAR imaging processing, we used the well-known RDA method to initially process the simulated echo signals and obtained high-quality SAR images. For appropriate ray density, changes in the ground structure can be clearly seen in the SAR image after imaging. These images not only display the fine texture of the target object, but also exhibit excellent spatial resolution and contrast. Finally, in terms of actual simulation results, our study simulated target objects of different sizes, from full size to reduced size, and took the area around Taipei 101 as a case. This diverse simulation design allows us to evaluate the applicability and effectiveness of SAR technology in different scenarios. The simulation results show that under various conditions, the SAR echo signal and imaging effects are excellent, which is also in line with our expectations for this simulator. This study highlights the importance and advantages of orbit simulation, radar echo signal simulation, and SAR imaging processing through rich SAR simulation results. Our research not only provides strong theoretical support for the further development of SAR technology, but also provides valuable reference for SAR tasks in practical applications. After the midterm, we will further develop the simulation tool established above. In addition to adding more simulation cases, we will also apply this tool to orbit-related parameter evaluation operations.

4. REFERENCE

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