A FREQUENCY DOMAIN RAW SIGNAL SIMULATOR FOR SAR

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ABSTRACT:

A raw signal simulator for synthetic aperture radar (SAR) is a useful tool for the design and implementation of SAR system. Also, in order to analyze and verify the developed SAR processor, the raw signal simulator is required. Moreover, there is the need for a test system to help designing new SAR sensors and mission of SAR system. The derived parameters of the SAR simulator also help to generate accurate SAR processing algorithms. Although the ultimate purpose of this research is to presents a general purpose SAR simulator, this paper presents a SAR simulator in frequency domain at the first step.

The proposed simulator generates the raw signal by changing various simulation parameters such as antenna parameters, modulation parameters, and sampling parameters. It also uses the statistics from an actual SAR image to imitate actual physical scattering. This paper introduces the procedures and parameters of the simulator, and presents the simulation results. Experiments have been conducted by comparing the simulated raw data with original raw SAR image. In addition, the simulated raw data have been verified through commercial SAR processing software.

KEY WORDS: raw signal simulator, frequency domain, SAR

1. INTRODUCTION

Synthetic aperture radar (SAR) is a coherent radar system that generates high-resolution remote sensing image. As an active system, SAR provides its own illumination and is not dependent on the light from sun, thus permitting continuous day/night operation and all-weather imaging. As such, SAR can be considered an invaluable tool for remote sensing.

In our previous research, the SAR focusing software was developed. In order to analysis and verify the developed SAR software, the raw signal simulator is required. Moreover, there is the need for a test system to help designing new SAR sensors and mission of SAR system before it realized.

SAR Simulation has aided engineers and scientists in many ways including (Wray, 2001):

- selecting an optimum acquisition mode from a suite of sensor and viewing options prior to purchasing a costly scene
- understanding the effect of illumination angle and terrain relief on SAR images
- testing and optimising interferometric SAR processing algorithms
- modelling the image formation algorithm

Simulator can be classified into various types based on the focus. However it might be as follows based on Marconi's notation (Marconi, 1984).

- system simulator
- product simulator
- SAR image-based simulator

System simulator is complete end to end mathematically rigorous model of the entire radar imaging process which takes an arrangement of point targets, computes the raw SAR signal and processes the final signal through an internal SAR processor. This model focuses on an accurate representation of the scene's reflectivity function. Product simulator uses SAR processor sections with a SAR image model for computing image statistics and terrain geometry. There is a trade-off between simplicity of the product simulator and the accuracy of the system simulator. SAR image-based simulator is sometimes noted as a subset of second type. Using statistics from an actual SAR image, simulated images of an alternate viewing configuration is created.

Proposed simulator in this paper is SAR image-based simulator without target simulation, processed in frequency domain, and has several purposes such as follows.

- mission analysis and optimal system design
- performance test of data processor or estimator

- pre-development of application / product demonstration
- SAR sensor calibration, validation, and anomaly handling

Figure 1 shows the block diagram for mission analysis and system design. It consists of three main stages. In the first stage, given SAR image, satellite parameters and sensor parameters, raw signal is simulated. In the second stage, the simulated raw signal is processed using the proven commercial SAR processing software and the processed image quality is assessed. In the third stage, checking if quality satisfies the top level requirements using the quality assessment results, the appropriate system specifications are designed.

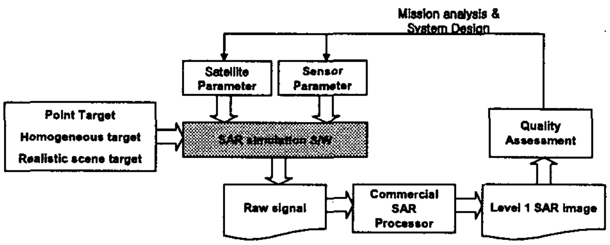


Figure 1. System Block Diagram

The paper is organized as follows. In section 2, the simulator schemes are briefly described. The result is analyzed in section 3, where simulation examples are also provided in order to assess its effectiveness. Finally, in section 4, some final remarks are reported.

2. SIMULATION METHODS

In this section, we evaluate the SAR raw signal using the SAR image in frequency domain. Although the ultimate purpose of this research is to develop a general purpose SAR simulator, in this paper, we implemented a SAR simulator which simulates the raw signal of an alternative viewing configuration using statistics from an actual SAR image without target simulation in strip mode only, and processes in frequency domain. In general, frequency domain algorithms have lower computational power than that of time domain algorithm.

2.1 Transfer Function

The SAR raw signal can be expressed as follows (Franceschetti, 1992, Franceschetti, 1995):

$$h(x'=vt_n, r'=\frac{ct'}{2}) = \iint dxdr\gamma(x,r)\cdot g(x'-x, r'-r; x, r) \quad (1)$$

$$g(x'-x, r'-r; x, r) = w^2\left(\frac{x'-x}{X}\right) rect\left[\frac{(r'-r)}{c\tau/2}\right]\exp(j\phi) \quad (2)$$

$$\phi = -\frac{4\pi}{\lambda}\Delta R + \frac{\alpha}{2}\left(t' - \frac{2r}{c} = \frac{2\Delta R}{c}\right)^2 \quad (3)$$

$$\Delta R = \sqrt{(x'-x)^2 + (R_0 + r)^2 + s^2} - R_0 - r \quad (4)$$

where x, r, ϑ : coordinates in the cylindrical coordinate system

$\gamma(x,r)$: scene reflectivity pattern
c : speed of light
τ : pulse duration time
$w(\cdot)$: azimuth illumination diagram of the real antenna over the ground
$X = \lambda R_0 / L$: real antenna azimuth footprint
L : azimuth dimension of the real antenna
λ, f : carrier wavelength and frequency of the transmitted signal
R : distance from sensor position to the generic point of the scene
R_0 : distance from the line of flight to the center of the scene

In order to simulate the raw signal, we first compute its Fourier transfer:

$$H(\zeta,\eta) = \iint dxdr\gamma(x,r)G(\zeta,\eta;x,r)\exp(-j\zeta x - j\eta r) \quad (5)$$

$$G(\zeta,\eta;x,r) = \iint dpdqg(p,q;x,r)\exp(-j\zeta p - j\eta q) \quad (6)$$

This Fourier transform can be computed in 2D frequency domain. However, we perform the 1D frequency processing in each direction, range and azimuth to reuse the developed focusing algorithm and conform the step results (Kwak, 2003).

If we ignore the r-dependency of $g(\cdot)$, i.e., if we let $r = R_0$, then (1) is easily recognized as the convolution in Fourier transformed domain:

$$H(\zeta,\eta) = \Gamma(\zeta,\eta)G_0(\zeta,\eta) \quad (7)$$

Then, the SAR raw signal $h(x',r')$ is simply obtained by the performing an inverse Fourier transform. Figure 2 shows the flowchart of simulation following steps:

- generation of the scene reflectivity pattern $\gamma(x,r)$ using the SAR image
- azimuth processing in frequency domain
- range processing in frequency domain
- analogue to digital conversion, to finally obtain the SAR raw signal $h(x',r')$

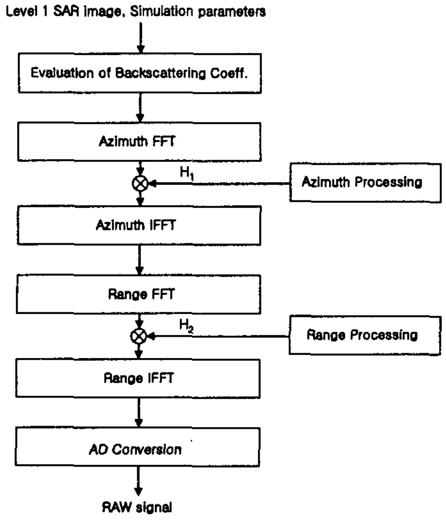


Figure 2. Flowchart of simulation

2.2 Simulation Parameter

The design of the SAR system is generally dependent on the application for which it is intended. Typically, specifications are provided to the design engineer by the end data user and by the available platform resources and mission design. Given these inputs, the system specifications are determined: system gain, RMS amplitude error versus frequency, RMS phase error versus frequency, receiver noise figure and system stability. In this paper, we defined the parameters as follows.

- chirp bandwidth
- chirp center frequency
- pulse repetition frequency (PRF)
- radar wavelength
- radiometric depth
- antenna pattern
- antenna power

Range resolution is defined as $c/2*B$, where B is chirp bandwidth. Chirp center frequency is related with backscattering coefficient and ambiguity. A low value of PRF increases the azimuth ambiguity level due to increased aliasing of the azimuth spectra. On the other hand, a high PRF value will reduce the interpulse period and result in overlap between the received pulses in time. The range dispersion is proportional to λ^2; at shorter wavelengths the ambiguous energy will be more focussed and the peak azimuth ambiguity to signal ratio (AASR) increased. The effect of the radiometric depth depends on the relative level of other noise sources in the system. For most system designs, the signal to distortion noise ratio (SDNR) should be small relative to the signal to thermal noise ratio (SNR). This is based on the radiometric calibration requirements. The antenna's dimensions in range and azimuth approximately determine the 3dB beam width. These affect the resolution in azimuth and the available swath width in range. The shape of the antenna beam is also key to the performance of the radar system (Curlander, 1991).

3. SIMULATION EXAMPLES

The simulator use the ERS-2 level 1 data as an input and its parameters are following Table 1.

Table 1. ERS-2 Parameters

Parameter	value
Carrier Frequency (f)	5.3 GHz (C band)
Polarization	VV
Orbit Altitude (h)	780 Km
Look Angle (ϑ)	23 degree
Pulse Duration (τ)	37.1 μs
Pulse Bandwidth (Δf)	15.5 MHz
PRF	1640 ~ 1720
Peak Power	4.8 KW
Quantization	5 bits

In Figure 3, each images show the results from each steps. The left image is an input image, ERS-2 level 1 data. The center image shows azimuth processed data, which is the same as range compressed data in focusing algorithm. The right image is range processed data, which is scaled raw data.

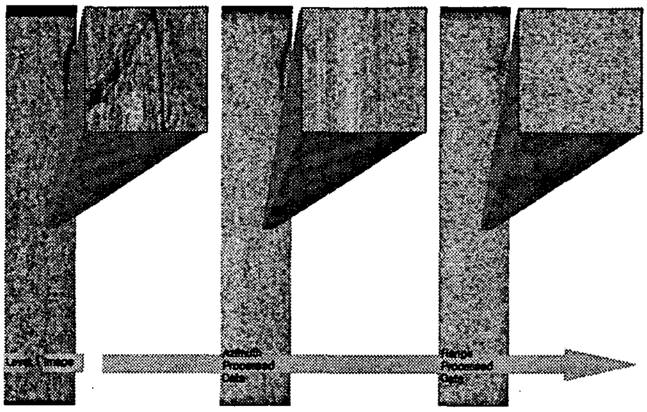


Figure 3. Simulation Process Result: input data(left), azimuth processed data(center), range processed data (right)

To verify the simulator performance, the generated raw signal without changing simulation parameters was used as an input to commercial SAR processing software and we checked if we got the correct images.

Figure 4 shows the commercial software results using the simulated raw signal step by step.

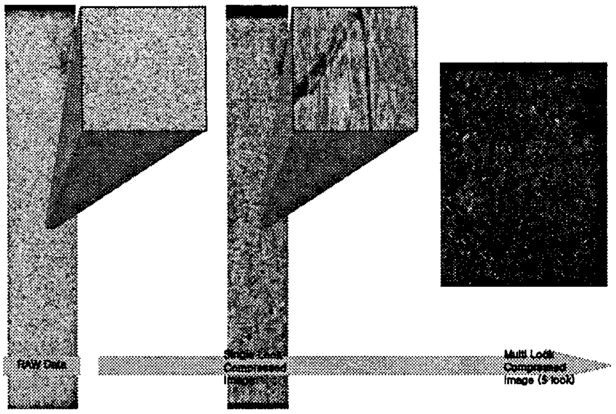
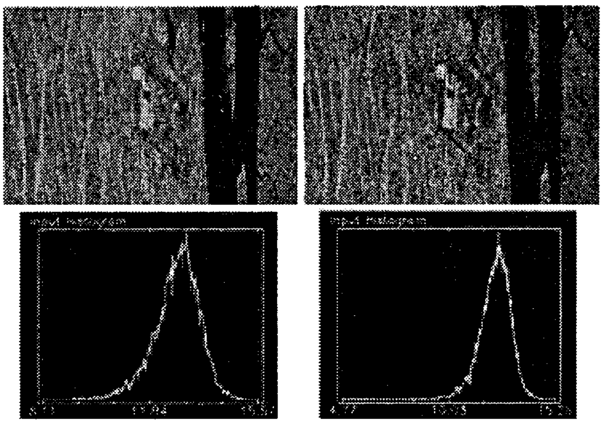


Figure 4. Commercial Software Result: input data(left), single-look compressed image(center), 5-look detected image(right)

Another method to verify the simulation performance, we compared the commercial software results from two different input images.

- The raw signal received by ESA
- the simulated raw signal

Figure 5 shows histogram of each image and we could find the similarity between two histograms.



(a) (b)

Figure 5. Histogram: raw signal received by ESA(a), simulated raw signal(b)

The next figure shows the result at the different simulator parameter sets.

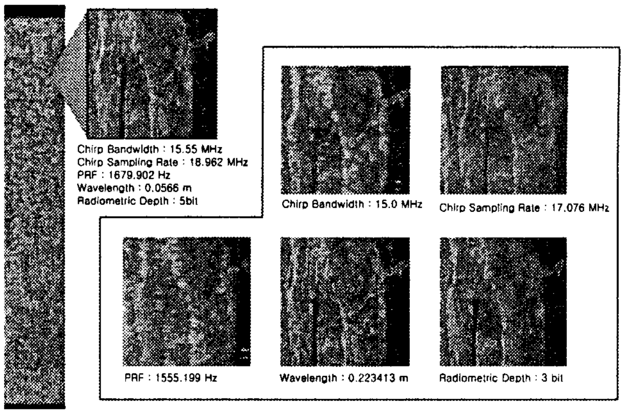


Figure 6. Simulation results

4. CONCLUSIONS AND FUTURE WORKS

Our simulator was developed to be utilized for SAR system design. The simulator generates raw signals and generates processed image from the raw signal. Also our simulator can perform quality assessment to check if the quality satisfies mission requirements defined in satellite design process. Hence the simulator can be used for designing system specification.

Our future plans are as follows:

- spotlight mode and scan mode simulation
- facet modelling
- more accurate quality assessment

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