Evaluation of SAR Image Quality

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Abstract: Synthetic Aperture Radar(SAR) is an active microwave instrument that performs high-resolution observation under almost all weather conditions. Although there are many advantages of SAR instrument, many complicated steps are involved in order to generate SAR image products. Many research and algorithms have been proposed to process radar signal and to increase the quality of SAR products. However, it is hard to find research which compare the quality of SAR products generated with different algorithms and processing methods. In our previous research, a SAR processing s/w was developed for a ground station. In addition, quality assessment procedures and their test parameters inside a SAR processor was proposed. The purpose of this paper is to evaluate the quality of SAR images generated from the developed SAR processing s/w. However, If there are no direct measurements such as radar reflector or scattering field measurement values it is difficult to compare SAR images generated with different methods. An alternative procedures and parameters for SAR image quality evaluation are presented and the problems involved in the comparison methods are discussed. Experiments based on real data have been conducted to evaluate and analyze quality of SAR images.

Keywords: SAR image quality, texture analysis

1. Introduction

Synthetic aperture radar technology provides valuable information in many applications such as mineral exploration, oil spill boundaries detection, sea state and ice hazard maps, and reconnaissance and targeting information of military operations. With the recent emerge of high-resolution SAR images many topographic application also use SAR images. However, use of SAR images for any application which involves comparative temporal or spatial study of the radar reflectivity of extended areas, e.g. in forestry, agriculture, or hydrology, depends on the quality of SAR image products.

A SAR processor (SARProcSi) was developed for the purpose of a ground station system [1]. Different levels of SAR images are generated from raw SAR signals through the developed SAR processor. The goal of this paper is to verify the implemented algorithms in the developed processing system and to evaluate the quality of the generated SAR images by SARProcSi. Performance and quality evaluation procedures will be presented in section 2 and their experiments based on real data are showed in section 3. Conclusion and future works are followed in section 4.

2. Evaluation procedures

The evolution procedure of this study is categorized in two parts. The first part is focused on the verification of the algorithms inside the developed SAR processor. The second part is the evolution of the quality of SAR images generated by SARProcSi.

1) Performance of SAR Processor

The SAR processor consists of several complicated steps to forming SAR image from raw signals. It starts from the raw data correction and performs the following processing steps: range compression, range migration correction, azimuth compression, multi-look processing and systematic geo-coding. During the processing, most important thing is to determine accurate Doppler parameters (the Doppler centroid and Doppler frequency rate). The correct determination of these parameters is not only basic in SAR processing but also it is important to the quality of generated SAR images. The relationship between image quality and Doppler parameters can be conducted from the radar equation [4]. Error in estimation of Doppler parameters result in phase and amplitude errors and cause blur effects on SAR products. Several algorithms for Doppler parameters are already defined in many literature reviews [4]. The simplest way to estimate Doppler parameters is to use ephemeris data provided by a SAR sensor system. However, in order to determine more accurate Doppler parameters, other methods, which automatically calculate the parameters from the received SAR signal without using the ephemeris data, such as energy balancing, spectrum analysis, and map drift methods can be considered. The developed SAR processor also includes these several algorithms and automatically selects optimal one according to the sensor and platform characteristics of input signal [2]. The performance evolution is done by comparing processing parameters with the result of other commercial SAR processing S/W and the values provided by a SAR product agency. Another assessment parameter showing overall performance of a SAR processor is SAR quality factor (Q_{SAR}). It is function of resolution and the number of looks. Since the SAR image quality is constrained by the combination of resolution and the number of looks, it determines the radiometric resolution of the system. In addition, it shows the overall suitability of the SAR image products made by the developed SAR processor. The

Q_{SAR} is defined as follows.

$$Q_{SAR} = \frac{N_{eq}}{R_a R_r} \quad \text{where } N_{eq} = L_{Aeq} L_{Req} \qquad (1)$$

The parameter R_a and R_r refer to the resolutions of the image having L_{Aeq} equivalent looks in the azimuth direction and L_{Req} equivalent looks in the range direction respectively.

2) SAR Image Quality Assessment

Theoretically, SAR system is performed by an analytical assessment of image quality parameters: Spatial and radiometric resolution, signal-to-noise ration, ambiguity rations and dynamic range. In previous research, quality assessment procedures for SAR processor were defined in [7]. The assessment procedure is summarized into three steps by the processing levels: raw data quality assessment, complex data quality assessment, and final image data quality assessment. These assessment steps are applied on raw data, complex single-look slant range images and multi-look image respectively. The raw data quality assessment is based on well-defined statistical evaluations, the complex data quality assessment performed on the detected coherent correlation function and the signal phase distribution, and the image data quality assessment use impulse response function (IRF) of targets. The first assessment procedure analyzes raw signals and calculates several parameters from input signal, such as mean and standard deviation of each channel, bias, gain imbalance, non-orthogonality, saturation and so on. This assessment enables a direct on-line monitoring while the raw data is received. Other assessment procedures of complex and final image data involve physical transponders or reflectors in ground as well as absolute radiometric calibration. Ideally, the absolute method using transponder or reflector is best way to verify a SAR processor. However, in practical it is difficult to establish those physical reflector configurations without a specific SAR ground station. Moreover, since this study is dedicated to show the feasibility of SAR ground station, the evaluation procedures for other two steps are performed indirectly by using digital image processing techniques. Because the most common feature in radar images is texture [4,5,6,8], the quality evaluation involves texture analysis of the generated SAR products with that of other commercial products. Moreover, since texture analysis is common method in SAR applications, it also shows the potential availabilities of SAR products of SARProcSi in applications.

Texture analysis means to acquire texture characteristics through image processing techniques and then obtains quantitative or qualitative descriptions of texture. Texture is defined as a function of the spatial variations in pixel intensities. However, texture features in radar image need to consider the texture elementary unit - smallest homogenous element of the same radiometry constituting the texture. Thus, texture in radar image can be divided into three components according to the size of textural element unit: Macro-texture, Meso-texture, and Micro-texture. Micro texture is a speckle that appears as grains of the same size as or larger than the resolution cell, and having a random brightness. This texture is inherent from the coherent radar system itself; it does not from the real variation of resolution cells. Meso-texture (or scene texture) is the natural variation of average radar backscatter on a scale of several resolution cells or more, and Macro-texture is variations in radar brightness over many resolution cells such as boundaries, forest shadows, and roads. Therefore, the most useful texture unit in interpretation of radar image is Meso-texure. There are many texture analysis methods, such as statistics-based, structure-base and spectral-based method [3,8]. While structural texture analysis focuses on identifying periodicity in texture or on identifying their placement rules, statistic method describes the basic cell of texture or random and spatial statistics character in local pattern, such as GLCM (Grey-Level Co-occurrence Matrices), wave transforms and fractal representation. In many applications and research texture analysis has been extensively used to classify remotely sensed images. Researchers have been showed that co-occurrence features give the best performance on classification if it compared with other filtering features [5,6,8]. Therefore, texture analysis for the evaluation of SAR images uses the most effective and widely used statistical texture approach - GLCM. If texture features extracted from the generated SAR images can be compatible with that of commercial SAR products, it shows the appropriateness of the generated SAR images in many applications as well as ensuring the quality of that. GLCM describes the relative frequencies of different gray tones with a defined spatial relationship within a fixed sub-image [3]. The involved parameters of GLCM are quantization of the intensity values, inter-pixel distance and angle, size of the sub-image and texture statistic to the matrix. GLCM is the 2-d matrix of joint probabilities $P^2_{\delta,r}(i,j)$ between pairs of pixels, separated by a distance (δ), in given direction(r). There are several features defined from co-occurrence matrix: second moment (or energy), entropy, contrast, homogeneity, correlation, and inverse different moment. Among them, experiments in this research are conducted with the following three parameters.

$$\text{Contrast}: \ f_C = \sum_i \sum_j (i-j)^2 P_d(i,j) \qquad (2)$$

$$\text{Entropy}: \ f_E = -\sum_i \sum_j P_d(i,j) \log P_d(i,j) \qquad (3)$$

$$\text{Homogeneity}: \ f_H = \sum_i \sum_j \frac{P_d(i,j)}{1+|i-j|} \qquad (4)$$

$$\text{where } P_d(i,j) = (P_{\delta,0°} + P_{\delta,45°} + P_{\delta,90°} + P_{\delta,135°})/4$$

3. Experiments

The defined parameters in section 2 are experimented in this section with real SAR images.

1) Test Data Descriptions

The developed SAR processor (SARProcSi) was designed to handle any kinds of space-born SAR data[2]. The processor was tested with several space-born sensors, such as ERS, JERS, and RADARSAT. Recently the processor is testing with ENVISAT. However, experiments in this research are conducted with following ERS data to examine the performance of SARProcSi.

- ERS-2, Daejon/Korea, Orbit 16762 / Frame 2871 / 05-JUL-1998
- ERS2 SAR.RAW (Seoul, Korea) - Orbit 28557 / Frame 2853 / 06-OCT-2000
- ERS2 SAR.RAW (Busan, Korea) - Orbit 25465 / Frame 2889 / 04-MAR-2000

In order to compare the performance of the developed SAR processor, the above ERS data are categorized into 5 datasets in table 1 according to a processing level and a producer. It consists of raw data, corrected raw data, and processed data. Different S/Ws such as, SARProcSi, a commercial S/W, and a space agency produced the processed data.

Table 1. Experimental data sets

ID	Level	Description
D1	Raw	Raw signals provided by ESA
D2	Corrected Raw	Corrected from D1 by the developed SAR Processor(SARProcSi)
D3	MLC	Processed from D1 by the developed SAR Processor
D4	MLC	Processed from D1 by a commercial S/W
D5	PRI	Provided by ESA

2) Experiments for Evaluation Parameters

The performance evaluation parameters of SARProcSi in section 2.1 are summarized as follows.

- Doppler centroid frequency in two different algorithms (Spectrum analysis, Energy balancing), Doppler frequency rate in two different algorithms (Ephemeris method, Map drift method)
- SAR quality factor
- Performance throughput of SAR processor

Figure 1 shows the result of comparison of Doppler parameters among dataset D3, D4 and D5. Figure 1 (a) compares Doppler centroid values in the following five cases:

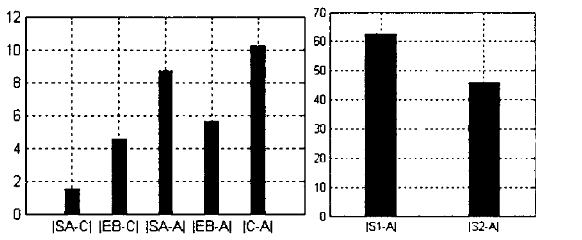
- SA-C, EB-C: comparing spectrum analysis method, and energy balancing of the SARProcSi with the commercial S/W, respectively.
- SA-A, EB-A: spectrum analysis method, and energy balancing method of the SARProcSi and the agency, respectively.
- C-A: a commercial s/w and an agency.

Figure 1 (b) compares Doppler rate values in the following two cases:

- S1-A, S2-A: Comparing ephemeris method, and map drift method of SARProcSi and the agency, respectively.

In Figure 1, the differences of Doppler centroid value between the other reference values are less than 10Hz and the difference of rate is less than 60Hz/sec. Since performance tolerance of Doppler parameters are defined on the order of 5% of the radar PRF, this result shows that the accuracy and reliability of implemented algorithm in SARProcSi.

Fig. 1. Comparison of Doppler parameters



(a) Difference: Doppler centroid (b) Difference: Doppler rate

The computed SAR quality factor (Q_{SAR}) on the experiments data is summarized as follows. For civilian SAR systems, usually this value falls in the range 0.005 < Q_{SAR} <0.5. The typical satellite SAR are lower bounded and larger Q_{SAR} is better. The result in Table 2 shows that the overall performance developed SAR processor is bounded in compatible range.

Table 2. Comparison of SAR quality factor

	SARProcSi	Commercial S/W	Agency
R_a	18.815	4.99510	12.5
R_r	7.90489	11.98826	12.5
N	3	3	3
Q_{SAR}	0.02017	0.031657	0.0192

Table 3 shows the processing throughput times of SARProcSi processor.

Table 3. Throughput time to generate one image

Throughput	Pre-process	39 sec
	Range correction	171 sec
	Azimuth correction	324 sec
	Multi-looking	100 sec
CPU and disk	AMD Opteron Processor 1.79GH, 1.0GB RAM	

3) Experiments for SAR Image Quality

The defined quality assessment procedures in section 2.2 are categorized in three steps. The first procedures are conducted directly on raw data and other two procedures are performed by texture analysis indirectly. Table 4 shows the following statistical parameters of raw data:

- Bias of I, Q,
- Gain imbalance between I and Q (ΔG)
- Non-orthogonality between I and Q ($\Delta\Phi$)

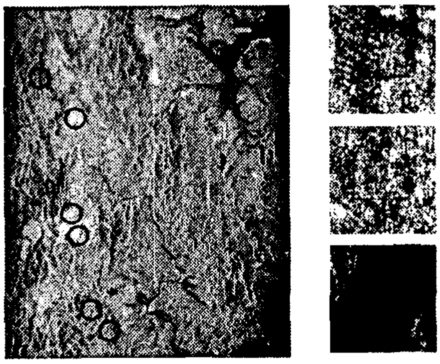
Through the correction step in SARProcSi, the bias, gain imbalance, non-orthogonality are decreased. The remaining errors are from the random noise of instruments.

Table 4. Raw data statistics

Data set	Bias		Channel comparison	
	I	Q	ΔG	$\Delta\Phi$
D1	0.00184	0.002075	0.99687	0.20317
D2	0.00056	0.000010	0.99877	0.00095
Ideal	0	0	1.0	0

The define texture features in section 2.3 are experimented with the dataset D3, D4, and D5 in table 1. ROI (Region of Interest) for texture feature are extracted from SAR images according to the characteristics of ground, such as vegetation(R1), low intensity regions(R2, usually ocean/inland water regions) and residential area(R3). Figure 2(a) shows sample ROIs for texture features on a SAR product.

Fig. 2. SAR Image and ROI (D4)



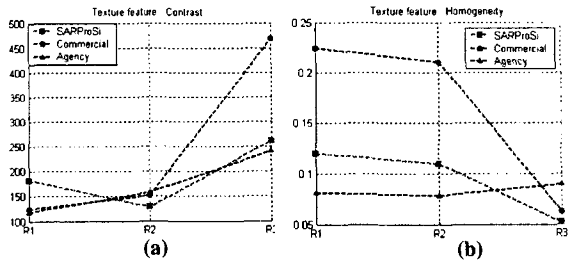
(a) Processed image by SARProSi (b) ROI samples

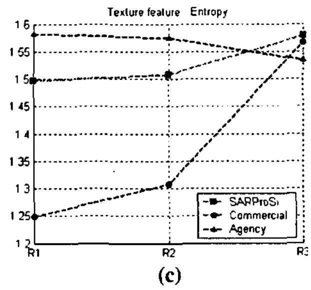
Experimented texture features in figure 3 are computed from the defined ROI of each dataset and averaged on three different input images. Figure 3(a) ~ (c) presents computed contrast, homogeneity and entropy values of the datasets (SARProcSi, a commercial S/W, a space agency) respectively according to the region types. Figure 3 (d) shows difference of these features. The differences of homogeneity and entropy features among those data sets are less than 0.1 and 0.3 respectively. These result shows the similar quality of SAR images of D3 ~ D5. However, the contrast difference between SARProcSi and the agency (|S-A|) is less than 38, while the contrast differences of |S-C| and |A-C| are 90 and 80, respectively. The large differences between the commercial S/W and others may cause from different kinds of algorithms, or inside noise filters which are not specifically mentioned in manuals. Although differences are larger in comparing between the commercial s/w and SARProcSi, the comparing result between SARProcSi and a space agency shows the similar pattern. Thus, the comparing result shows that the SAR products generated by SARProcSi have comparable radiometric characteristics and can be used in various SAR applications.

4. Conclusions

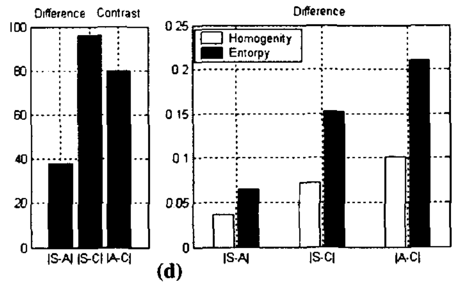
In this paper, SARProcSi performance analysis and evaluation of image quality has been introduced. The experiments used real SAR data to validate the performance of SARProcSi. Processing parameters estimated with several methods are similar and provide properly processed images. Indirect image quality measurements, texture features was presented and have been compared with other reference data sets. The result shows that the processed images by SARProcSi have compatible quality with other commercial SAR products and can be applied in various SAR applications. For future work, physical validation using reflectors will finalize the performance and quality evaluation of SARProcSi.

Fig. 3. Comparison of textual features





|S-A|: comparison between SARProcSi and Agency.
|S-C|: comparison between SARProcSi and Commercial S/W
|S-A|: comparison between Agency and Commercial S/W



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