IRF Analysis Considering Clutter Background for SAR Image Qualification

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Abstract

A new IRF (Impulse Response Function) analysis technique in high resolution SAR image is presented by taking into account the real clutter environment. In order to investigate the realistic effect of clutter background on the impulse response function of SAR image, an ideally generated impulse response function is superimposed with a large number of background clutter data which are extracted from the various regions of an actual SAR image. As a performance measure, PSLR (Peak Sidelobe Ratio) of the clutter-contained IRF is presented in the various groups of clutter background, and finally the results are compared with the stochastic model.

Key Words : SAR image quality, IRF, PSLR, SCR, Clutter background

Introduction

Synthetic aperture radar (SAR) is capable of obtaining the two-dimensional fine resolution image of area of interest using a complex image formation process. The performance of the SAR system can be qualified by the evaluation of the final SAR image obtained from the ground test site [1]. In order to maintain the given image quality from the SAR system requirement, the accurate prediction and validation of the image quality are needed throughout the full system development phase from the initial concept design stage to the final in-flight operation stage. A point target analysis model is commonly used to predict the basic system performance in initial design stage, but actually, it may not reflect an influence of the realistic environments because this ideal case does not take into account the clutter and noisy background from the real environment. In practical situation, the response of a point scatterer is usually obtained from corner reflector or transponder on the ground test site, and thus the realistic data always contains the noisy clutter from the backscatters [2].

One way to approach this problem is to estimate the clutter effect by establishing a stochastic model. Recently, the study on the estimation method of impulse response function (IRF) taking into account a clutter environment has been reported [3]. Based on a stochastic model, the estimation method of image quality and the error bound of quality requirement were suggested for the high performance system design. The best way of approaching the clutter problem is actually to examine the real clutter, which surrounds a physical reference reflector on the ground, through a flight test. In order to obtain a wide

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variety of clutter distribution and inspect the influence of the measured clutter on impulse response, it is necessary to observe the various clutter regions surrounding a number of reference reflectors deployed. Therefore, investigating the comprehensive range of clutter distribution is not desirable in real environment due to the high cost and time for data collection through the flight test. In this paper, a new technique for IRF analysis is presented by considering clutter background obtained directly from an actual SAR image, not from the statistical model, nor from the corner reflector. This approach needs to generate the ideal impulse response and extract the clutter patches from the real SAR image. In order to give the realistic effects of clutter environment, the ideal impulse response is corrupted with the extracted clutter data. A large number of clutter patches can be extracted from various regions in order for diverse and statistical confidence of clutter distribution. Effect of clutter background on IRF performance is then analyzed with respect to the degree of clutter background, and the simulation result is compared with the stochastic model.

IRF Analysis Based on Stochastic Model

Signal to Clutter Ratio

In practical situation, SAR system calibration or image quality assessment is normally performed through the impulse response obtained from reference target such as a corner reflector or an active transponder deployed on the ground test site. Due to the clutter and noisy environment on the ground, the clutter contribution adjacent to ground-fixed reference target should be taken into account for the performance estimation. Representative parameter describing the degree of clutter contribution is signal-to-clutter ratio (SCR) and is defined as (1).

$$SCR = \sigma_P / (\sigma_0 A_{res}) \tag{1}$$

where σ_p is the backscattered energy of a reference point target and $\sigma_0 A_{res}$ represents the mean backscattered energy of the clutter within a resolution cell, A_{res} [4]. Since the amplitude of clutter background is very dynamically fluctuated, PSLR depending on the peak level of IRF has a serious effect more than IRW depending on the width of IRF.

PSLR Estimation considering Background

Recently, the study on PSLR estimation considering the clutter background is investigated based on stochastic model [3]. A deterministic-statistical model of PSLR error is suggested as follows.

$$PSLR_c = \frac{|U_{SL,C}|}{|U_{ML,C}|} = \frac{|U_{SL}| + \Delta|U_{SL}|}{|U_{ML}| + \Delta|U_{ML}|} \tag{2}$$

where $U_{ML}=I_{ML}+jQ_{ML}$ and $U_{SL}=I_{SL}+jQ_{SL}$ are the complex-deterministic amplitude of mainlobe and sidelobe, respectively. $\Delta|U_{ML}|$ and $\Delta|U_{SL}|$ represent the clutter-affected amplitude of mainlobe and sidelobe, respectively. Based on this model, the error of PSLR is derived as

$$PSLR_c = PSLR \pm \sqrt{E_t / E_p}(1 - PSLR)(k/\sqrt{SCR}) \tag{3}$$

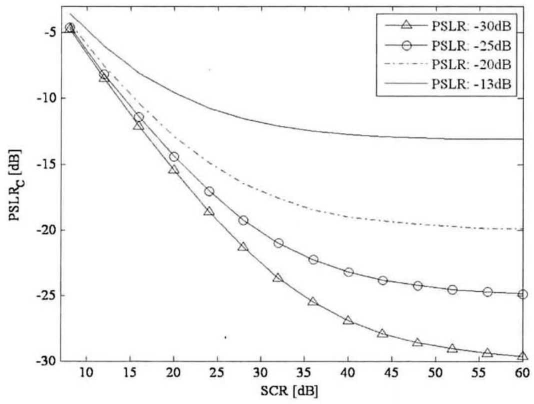


Fig. 1. Error bounds of PSLR for a fixed E_t/E_p=2

In (3), $PSLR_c$ is clutter-affected $PSLR$, k is coefficient to expand confidence interval of the error estimation, E_t/E_p is quality measurement for signal focusing, and SCR is energy based signal-to-clutter ratio. The clutter-affected error bound of PSLR with respect to SCR is derived as shown in Fig. 1.

IRF Analysis using Real Background Data

Procedure of IRF Analysis

In this paper, IRF analysis method using real clutter patches is presented. The procedure of the proposed analysis method is composed mainly of four steps. 1) A hypothetical point scatterer is modeled and generated as an ideal reference target. 2) The clutter patches from various area of interest are carefully extracted from SAR image data taken from a previously or currently operating SAR system such as TerraSAR-X, RADARSAT-1/2, and so on. 3) The generated point response and the extracted clutter patches are expanded by interpolation process for detailed analysis and then, the point target response is overlaid with these extracted clutter patches. 4) The performance of impulse response considering the real clutter background is assessed in terms of IRF. The flow diagram of the overall procedure is presented in Fig. 2.

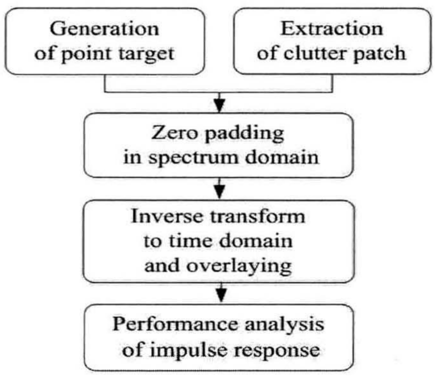


Fig. 2. Flow diagram of IRF

Modeling of Point Target Response

The procedure of the SAR image quality assessment starts with modeling and generation of SAR raw signal for a hypothetical point scatterer as an ideal reference. The system parameters for the generation of a SAR point target signal include the complete geometry of the spaceborne or airborne SAR and the SAR sensor parameters such as altitude, platform velocity, operational frequency, PRF, FM rate, and so on. The two-dimensional point target signal can be modeled as (4).

$$g(t,u) = r_r(t - 2R(u)/c)r_a(u - u_c) \times \exp[-j4\pi R(u)/\lambda]\exp[j\pi K(t - 2R(u)/c)^2] \quad (4)$$

where t is fast time, u is slow time in flight path, $R(u)$ is slant range, u_c is the closest approach time to a point scatterer, λ is wavelength, and K is the frequency modulation rate of the transmitted signal. Since the backscattering characteristic dynamically varies depending upon the wavelength, the centre frequency is chosen in the same frequency band of SAR image used for extraction of background environment. C-band airborne SAR is assumed in this simulation and the key system parameters are listed in Table 1.

The amplitude response of point target is modeled as a trihedral corner reflector composed of three orthogonal triangular plates. The ideal radar cross section (RCS) of corner reflector can be easily computed based on its mechanical dimension according to

$$\sigma_{RCS} = 4\pi l^4 / (3\lambda^2) \quad (5)$$

In (5), l is the inner leg length. The inner leg length of 3 m, which leads the peak response of 50.19 dB, is assumed in this paper.

Table 1. System parameters for point target generation

Parameters	Values
Platform velocity	150 m/s
Center frequency	5.3 GHz
Range bandwidth	50 MHz
Doppler bandwidth	80 Hz
Slant range	20 km

Extraction of Clutter Background

The main objective of clutter extraction is to emulate the real environment for the purpose of observation of the undesirable effect on IRF performance. In order to examine the wide range of clutter distribution, the clutter patches are extracted from various regions, which are grouped in 8 different clusters of clutter background, as shown in Fig. 3. In this case, a sampled SAR image, of which is acquired from RADARSAT-1 (fine beam No.2) in the area of Vancouver, is selected for extraction of clutter background which represents a various clutter surface scattering such as mountain, urban area, farm land, river, and sea. A sampled SAR data is used in the form of level-0, raw data which is composed of complex echo data. By using the range Doppler algorithm (RDA), a high resolution scene image is reproduced for this study.

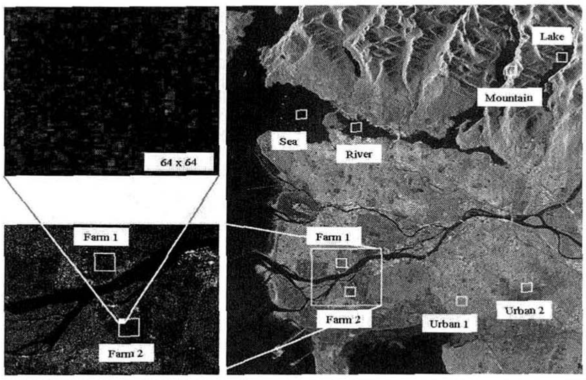


Fig. 3. Extracted clutter patch

Data Expansion and Fusion

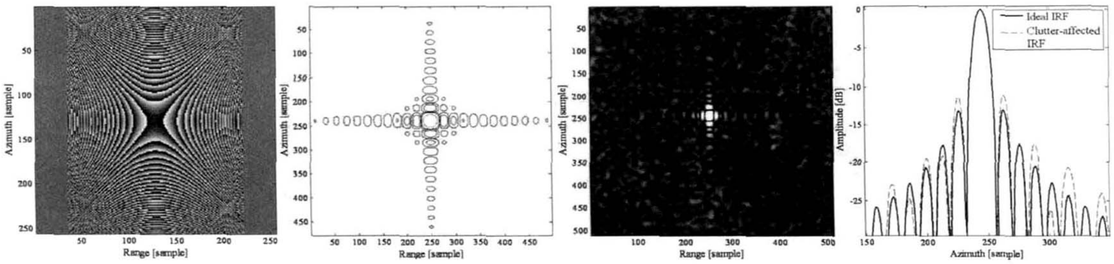
After the extraction of the background data, the FFT interpolation method is applied for detailed analysis. In this method, the small size of input data is padded with zero in spectrum domain for the arbitrary data expansion [5]. Once the interpolation process is conducted for each data of the point target response and the clutter patches, the expanded impulse response is overlaid with the expanded clutter patch in superposition manner. The performance analysis of the impulse response can now be conducted within the real clutter environment.

Simulation and Discussion

As previously mentioned, a point target raw signal is first generated based on both the SAR geometry and system parameters, and then the point target signal is focused by using RDA. More detailed analysis of the impulse response can be performed by employing FFT interpolation, which utilizes the large zoomed data patch from the given small sized data. The phase component of the generated raw signal is shown in Fig. 4(a), and its focused and expanded impulse response is shown in Fig. 4(b).

The expanded impulse response is overlaid with clutter patch of homogeneous region, in which the extracted patch is also expanded by same manner, in order to perform the analysis under the realistic environment. The point target response considering the real clutter environment is given in Fig. 4(c). Due to the randomly fluctuated noisy environment, the performance of IRF might be degraded by background environment. In order to investigate the influence of noisy environment, the original and clutter-corrupted IRF profile azimuth direction is presented in Fig. 4(d). PSLR reduction due to the clutter background is clearly seen in this IRF profile. It is noted that the magnitude fluctuation of clutter background directly affects the shape of IRF, thus PSLR is significantly affected by clutter background.

The size of extracted clutter patch is 64 x 64 pixels and the total number of data extraction is 10,000 in each clutter group in order for statistical reliability. The magnitude of scaled impulse response is superimposed onto the each clutter patches. Finally, the clutter-affected IRF is analyzed for various clutter distribution. The clutter-affected PSLR with respect to SCR is shown in Fig. 5. Due to the roughness of the mountain and man-made object in urban area, the clutter-affected PSLR in these areas shows relatively higher variation than that of the areas of farm, lake, river, and sea, which characterize uniform and homogeneous clutter.



(a) Phase component of point target (b) Expanded impulse response (c) Point target response with clutter (d) Clutter-affected IRF profile

Fig. 4. IRF characteristics

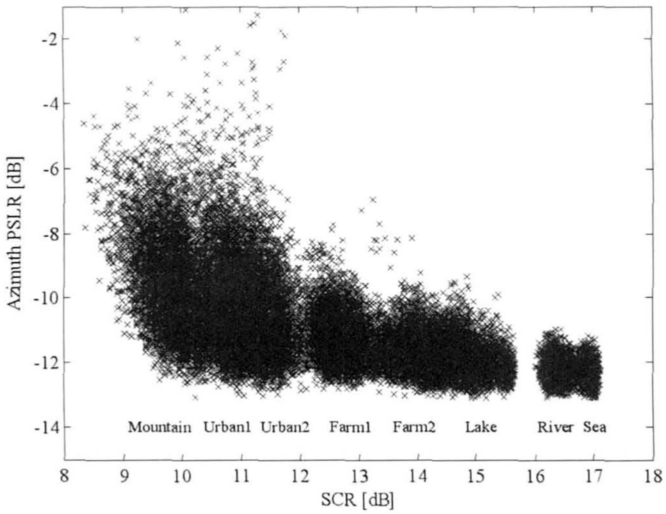


Fig. 5. PSLR variation in various clutter groups

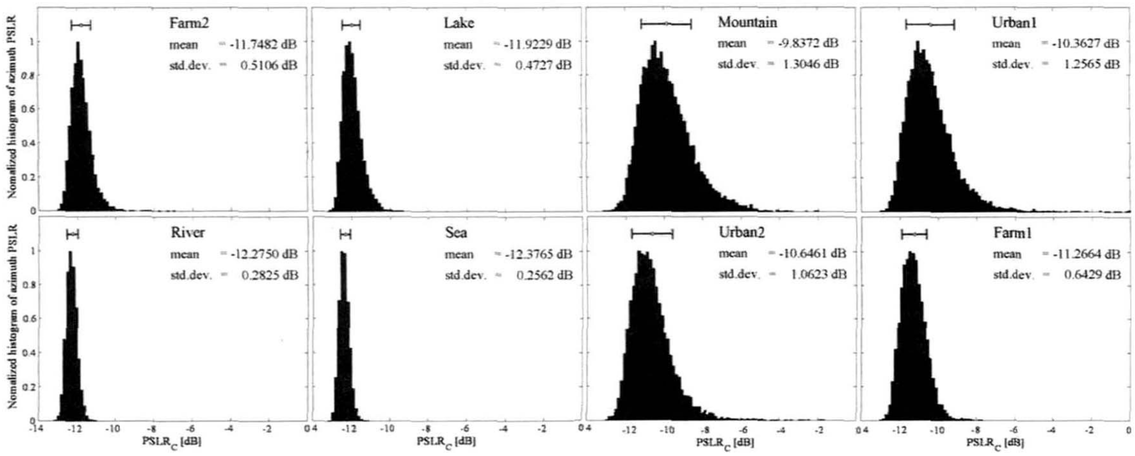


Fig. 6. Normalized histogram of clutter-affected PSLR

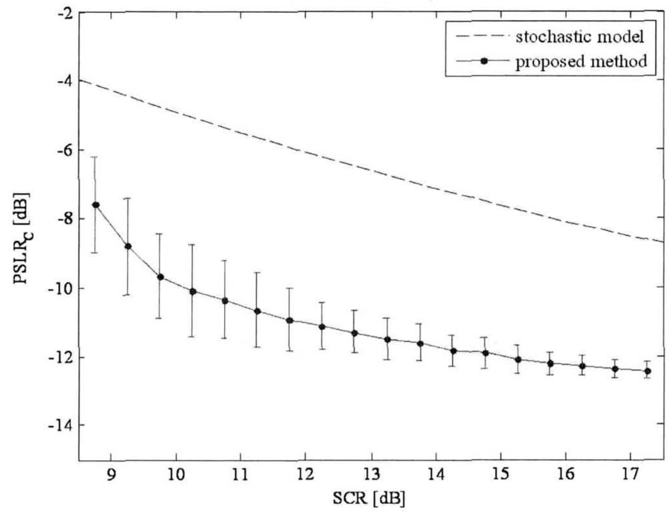


Fig. 7. Comparison of clutter-affected PSLR

For the analysis of statistical characteristic of PSLR variation, the normalized histograms of clutter-affected PSLR for each group are presented in Fig. 6. In these figures, a horizontal line denotes the central density of PSLR variation which is distributed within +/- 1 standard deviation of mean value. The average value of clutter-affected PSLR in the mountain and urban areas shows approximately -10 dB which results in 3 dB difference compared to the ideal PSLR of -13.14 dB. The standard deviation of PSLR error is also higher than 1 dB. Thus, the average PSLR error is about 2 ~ 4 dB in these areas. On the other hand, for the farm areas, the average PSLR error and its standard deviation are observed less than -11dB and 0.5 dB, respectively. Thus, the average PSLR error bound of about 2 dB is expected on this area. As a result, the minimum PSLR error bound of 2 dB should be considered even in the homogeneous area for the evaluation in the real environments.

For the purpose of comparison with the stochastic model in (3), the PSLR error curves with respect to SCR are presented in Fig. 7. In this figure, a vertical line denotes the central density of clutter-affected PSLR within standard deviation of +/- 1 from the mean value. This figure shows that the PSLR error of the proposed method has a similar trend to the theoretical model, but its relative level is much lower than the case of the stochastic model which means the worst case of PSLR error bound caused by clutter background. Therefore, the PSLR results show that the proposed technique presents the more realistic measure than the stochastic method, because most of PSLR error bound exists within the average value over the wide range of clutter background environments. It is noted that the estimation error of PSLR is significantly increased at the low SCR. Therefore, it is recommended that the RCS of a reference reflector for SAR system calibration and validation must be high enough so that the effect of clutter background can be minimized. In addition, since the PSLR error is observed even in the uniform area, the location of the reference reflector should be carefully selected to achieve the high level of SCR for the calibration.

Conclusion

Accurate measure of the SAR image quality is important as a means of the qualification of the designed SAR system performance. In this paper, the IRF performance of the real SAR image is analyzed as a performance measure in the clutter background. As a performance measure, PSLR of the corrupted IRF is presented in the various groups of cutter background, and finally the results are compared with the stochastic model. It is recommended that the RCS of a reference reflector for SAR system calibration and validation must be high enough so that the effect of clutter background can be minimized.

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