Precise Scattering Center Extraction for ISAR Image using the Shooting and Bouncing Ray

Dal-Jae Yun, Jae-In Lee, Ky-Ung Bae, and Noh-Hoon Myung
Department of Electrical Engineering, KAIST, Guseong-dong, Yuseong-gu, Daejeon 305-701, Korea

***Abstract* - In this paper, improvement in accuracy of scattering center extraction for inverse synthetic aperture radar (ISAR) image is presented in order to facilitate precise signature prediction. The original CLEAN, which is typically used to compute scattering center model from ISAR image formation using the shooting and bouncing ray (SBR) technique, is based on the assumption; effect from noise interference is negligible. However, the assumption is limited in practical case. Thus, the point spread function (PSF) correlation technique is applied for the 2D ISAR image formation to improve accuracy. By extracting subsequent scattering centers using cross correlation between the PSF and residual image, point source location error from additive noise is highly mitigated. The proposed 2D CLEAN is demonstrated for ideal point target and practical 3D CAD models through comparisons of the reconstructed image.**

***Index Terms* — Inverse synthetic aperture radar, Imaging techniques, Scattering center extraction, CLEAN algorithm.**

1. Introduction

In signature prediction studies, ISAR image is widely used to visualize scattering phenomenon for realistic and complex targets. In particular, the scattering center model abstracts the electromagnetic scattering using only finite number of point sources and represents the image efficiently [1]-[3]. Therefore, improvement in accuracy of the scattering center extraction will highly facilitate precise target signature prediction.

Diverse researches have been published on the scattering center extraction for ISAR image. Particularly, because the coherent CLEAN finds peak in the image and subtracts the PSF, centered at the peak and weighted its amplitude, repetitively, it is feasible to apply the CLEAN for ISAR image using the SBR technique [1]. However, the original CLEAN is based on the assumptions; the maximum peak in each iteration is the response to real target and interferences from noise and the other point targets are negligible, which are limited to use in the practical targets [4]-[6].

In this paper, therefore, PSF correlation technique [6] is applied to the 2D image, which is generated using the SBR technique, to alleviate scattering center location error from noise. In the original CLEAN, the strongest peaks in the image is shifted in location and amplitude because of the other target and noise. Thus, peak mislocation problem occurs in realistic target case. However, using PSF correlation technique, which minimizes target mass of the residual image, i.e. energy of the residual image, scattering center is extracted accurately regardless of the interferences from noise. Although the interferences from noise and other targets still distorts the strongest peaks in the image, the scattering center is extracted at the maximum correlation location between the image and PSF, which is similar to a matched filter. Thus, the interferences hardly distorts the extraction procedure.

This paper is composed of four sections. First, the scattering center model and scattering extraction algorithm are presented in Section 2. In Section 3, the scattering center results are reported. Section 4 gives conclusions.

2. Improvement of Scattering Center Extraction

(1) Scattering Center Model

High frequency radar target signature including 2D backscattered field and ISAR image can be represented by scattering center model, which is composed of a finite set of point scatterers [1]-[3].

$$E(k,\theta)=\sum_{n=1}^{N}A_n\cdot e^{-2j\mathbf{k}\cdot\mathbf{r}_n}\ , \quad (1)$$

$$O(z,x)=\sum_{n=1}^{N}A_n\cdot h\left(x-x_n,y-y_n\right)\cdot \quad (2)$$

Where, N is the number of scattering centers, A_n and (x_n, y_n) are the amplitude and location of the n-th scattering center, respectively, and $h(x, y)$ represents 2D PSF.

(2) Improvement of 2D Scattering Center Algorithm

Using the PSF correlation technique, the location and amplitude of the scattering center at each iteration are calculated based on the cross correlation function between the PSF and residual image [6]. The proposed 2D CLEAN is the dimension extended version of the previous work. The estimated location and amplitude are expressed as follows straightforwardly:

$$\left(\hat{x}_n,\hat{y}_n\right)=\arg\max\left\{R_{hI}\left(\hat{x}_n,\hat{y}_n\right)\right\}, \quad (3)$$

$$\hat{A}_m=R_{hI}\left(\hat{x}_n,\hat{y}_n\right)/M_p\ . \quad (4)$$

Where, R_{hI} is the cross correlation function between the PSF and residual image, which is defined as follows:

$$R_{hI}\left(\hat{x}_n,\hat{y}_n\right)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}h^*\left(x-\hat{x}_n,y-\hat{y}_n\right)I(x,y)dxdy\ . \quad (5)$$

M_p is the auto correlation function of the PSF.

The proposed 2D CLEAN finds peak in the 2D image based on the matched filtering approach. Thus, it is feasible to apply in the additive white Gaussian noise case including contiguous target, which consists of many point targets are densely distributed.

3. Numerical Results

At first, comparisons of the scattering center extraction algorithm based on the ideal point target are performed to demonstrate the proposed 2D CLEAN. A center frequency of 10 GHz, bandwidth of 500 MHz, and aspect angle width of 6° is used in the simulations. The range bins in down and cross range are 32 and the oversampling ratio is taken to be 2. Fig. 1 represents the reconstructed image of the 9 ideal point targets based on (2) and the image with SNR of 4 dB.

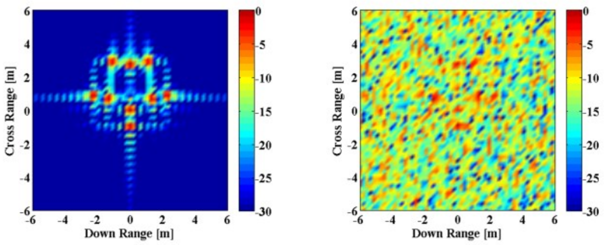

Fig. 1. Reconstructed image and the image with noise.

Fig. 2 represents the results of the original 2D CLEAN (left) and the proposed 2D CLEAN (right). The algorithms are applied to the image with SNR of 4 dB.

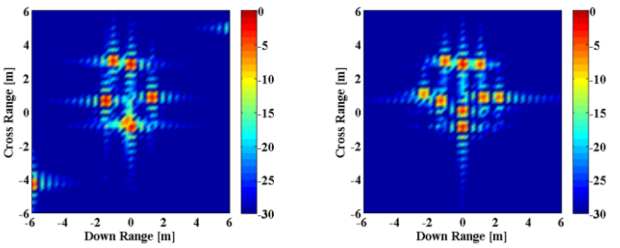

Fig. 2. Results of the original 2D CLEAN (left) and the proposed 2D CLEAN (right).

Due to the high noise, the ideal point targets are mostly invisible. Thus, the original CLEAN result, which simply finds maximum peaks, is inconsistent with the reference image. However, the proposed 2D CLEAN extracts 9 ideal point targets precisely compared to the original CLEAN.

Next, the proposed 2D CLEAN is demonstrated for the realistic and practical tank CAD model. A center frequency is 10 GHz, bandwidth is 350 MHz, and aspect angle width is 4° in the simulations. Fig. 3 describes the 3D tank CAD model (left) and ISAR image using the SBR technique for the CAD model (right).

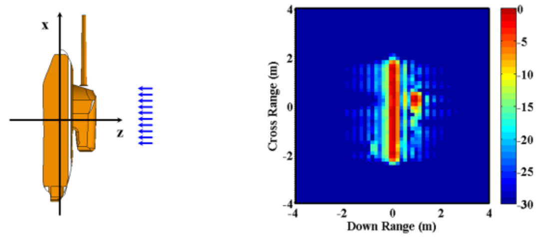

Fig. 3. Tank CAD (left) and ISAR image (right).

Fig. 4 presents the results of the original CLEAN (left) and the proposed CLEAN (right) for the ISAR image with SNR of 7 dB.

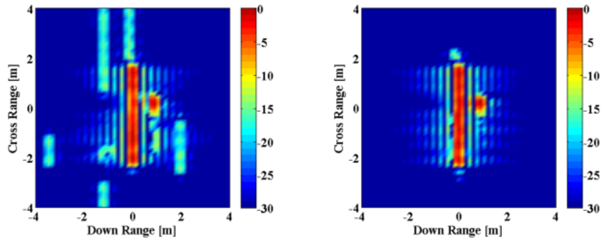

Fig. 4. Results of the original 2D CLEAN (left) and the proposed 2D CLEAN (right).

The proposed CLEAN extracts scattering center precisely.

4. Conclusion

In this paper, improvement of 2D CLEAN using PSF correlation technique is presented. Specifically, scattering centers are extracted based on the cross correlation function between the PSF and residual image, not maximum amplitude. Thus, distortions in terms of interferences from noise and the other targets are mitigated. The proposed 2D CLEAN is demonstrated for a canonical point target and realistic 3D tank CAD model.

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