RCS Measurement of Large Target in Non-cooperative Near Field Environments

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Abstract— Generally speaking, Radar Cross Section (RCS), which is an important indicator to value the electromagnetic scattering characteristic of a target, has been paid more attention as time goes by since WWI. As we know, when RCS measurement is carried out, the accuracy of RCS measurement results always depends on the testing site and the system, and if the target is too large or the frequency is too high, a cooperative and vast measuring area or a costly compact range facility will be needed. As the testing site sometimes is not large enough for some cases, so the radiation pattern of the transmitting-receiving antenna can't be dealt as the far filed pattern. To solve these problems, this paper presents a new method of RCS measurement basing on SAR imaging by a scanner in near field. And also we employ a new SAR imaging method instead of the traditional ISAR imaging method to transform the electromagnetic scattering near field data of target to the far field RCS. That's saying, the near field data is collected by a portable 1-D scanner SAR imaging system, with the new method, we can obtain the far field by the transformation. Furthermore, in order to get the accurate far-field RCS data of the target, we use a new method to correct the effects of transmitting-receiving antenna's radiation pattern and the difference of the distance from scattering center of the antenna to target in near-field imaging measurement, which we usually call corrected-imaging method. The compared results of theoretical simulation and experimental data show that RCS obtained by the proposed method is satisfied the condition and can be used widely.

1. INTRODUCTION

RCS is an important gist to assess the electromagnetic scattering characteristic of the target, and is traditionally obtained by measurement in a far-field range requiring a long distance between target and antennas, or with a compact range facility requiring a high-quality reflector and suffering from edge diffraction which limits the size of the quite zone. Therefore, the transformation method is used to obtain target's RCS which is based on ISAR-Imaging in near field. ISAR-Imaging measurement needs a turntable, and the position precision of the turntable will be very high if the target is too large or the frequency is too high.

To overcome these problems, a new transformation method between the near-field and the far-field scattering data is introduced in this paper which is based on SAR-Imaging.

2. THEORY

The new method that target's RCS is obtained by SAR-Imaging near-field consists of four steps: Firstly, back-scattering echo of target is obtained with the Spotlight-SAR Imaging measurement system; Secondly, target's accurate scattering-data in near-field is obtained with the filter-process; Thirdly, target scattering-image (or target scattering-center distribution) is obtained with the FBP (filter back-projection) imaging algorithm; Lastly, target's RCS is obtained by vector sum of the target scattering-centers with the radar equation.

2.1. Spotlight-SAR Imaging Measurement

SAR Imaging of the target is based on Spotlight-SAR theory which is illustrated in Figure 1.

That high cross-resolution is obtained with the synthetic-aperture which is made by the transmit-receive antenna moving along the line-rail from the position-A to position-B, and the azimuth angle of the antenna beam is steered continuously to illuminate the target during the antenna's moving. High range-resolution is obtained by transmitting wide-band sweeping signal, and then we can obtain the two-dimensional high resolution image of target.

Two-dimensional high resolution can be expressed as

$$\begin{cases} \delta_y = \frac{\lambda R}{2L_e} \\ \delta_x = \frac{C}{2B} \end{cases} \tag{1}$$

where δ_x is range-resolution, δ_y is cross-resolution, C is wave propagation speed, λ is the radar wavelength, L_e is the synthetic-aperture length, R is the distance between the antenna and terrain scattering-center, B is the sweeping-band.

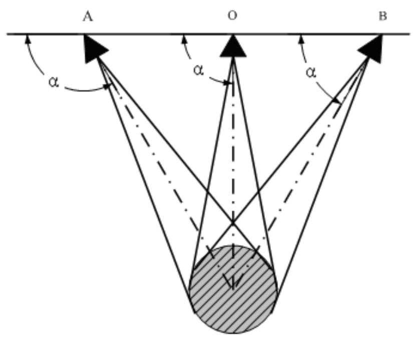

Figure 1: Spotlight-SAR Imaging theory sketch map.

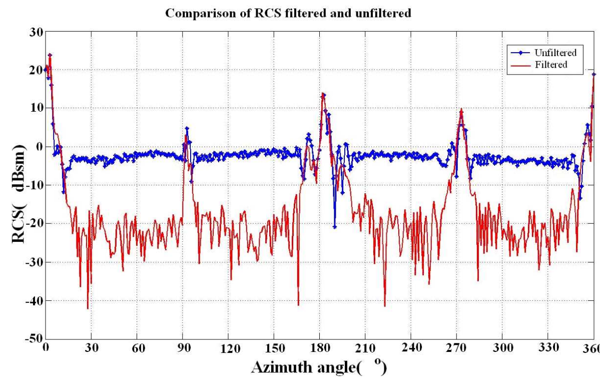

Figure 2: Comparison of RCS filtered and unfiltered.

2.2. Filter-process

Echo received by the antenna includes not only the target's signal but also clutter signal such as coupling signal between the transmitting and receiving antennas, multipath signal between the target and the ground, the background signal, and so on.

RCS measurement accuracy can be improved by opting time domain RCS measurement method based on the sweep, using windowed processing to eliminate those clutter signals. Figure 2 shows the comparison of a special trapezoid composite RCS filtered and unfiltered which shows RCS dynamic is increased after filter-process

2.3. FBP Imaging Process

According to the Spotlight-SAR Imaging measurement theory introduced in Section 2.1, target echo received by the antenna is expressed as

$$F(k, y') = \iint_{x\ y} f(x, y) \exp(-j2\pi kR) \mathrm{d}x\mathrm{d}y \tag{2}$$

where (x, y) is the coordinate of the target scattering-center, (x', y') is the coordinate of the antenna.

Two-dimensional high resolution image of target can be obtained by 2-D FFT transformation with the far-field measurement condition satisfied, the far-field measurement condition is expressed as

$$R = \frac{2D^2}{\lambda} \tag{3}$$

where R is the least far-field measurement distance, D is the maximum wide length of the target. For example, the target with the wide length of two meter is measured at 16 GHz, the least far-field measurement distance (R) will be larger than 400 meters which our measurement-condition can't satisfy, so the really target imaging measurement is usually carried out in near-field. We usually use horn-antenna to finish the target imaging measurement, and the horn-antenna's irradiation to the target is figured as Figure 3.

From Figure 3, we can see firstly that the radiation intensity is different with the radiation angle, and the difference will cause the terrain image's scattering-intensity distortion. Secondly, for a large target measurement in near-field, the distance from the target scattering-centers to the antenna is different, and the difference may be one time which will cause 15 times terrain image's

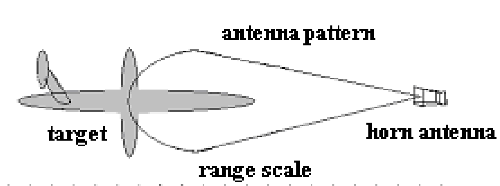

Figure 3: Horn-antenna's irradiation to the target.

scattering-intensity distortion. Therefore, we must correct the effects of antenna radiation pattern and distance factor in near-field measurement.

FBP (filter back-projection) algorithm in near-field can correct the difference of the radiation intensity via importing the antenna radiation pattern, and can correct the difference of the distance from the target scattering-centers to the antenna via importing the distance factor, and the algorithm is expressed as

$$\begin{cases} P_l\left(l_s\right)=\int\limits_0^{k_B}\left(k+k_{\min}\right)F\left(k+k_{\min},y'\right)\exp\left(\mathrm{j}2\pi k l_s\right)\mathrm{d}k \\ \hat{f}\left(x,y\right)=\int\limits_{-Le/2}^{Le/2}P_l\left(l_s\right)\exp\left(\mathrm{j}2\pi k_{\min}l_s\right)\frac{1}{RG(\varphi)}\frac{R^2}{R_0^2}\mathrm{d}l \\ R=\sqrt{\left(R_0-x\right)^2+\left(y'-y\right)^2} \\ l_s=R-R_0,\quad k_B=\frac{2B}{C} \\ \varphi=\mathrm{a}\cos\left|\frac{R^2+R_0^2+y'^2-(x^2+y^2)}{2R\sqrt{R_0^2+y'^2}}\right| \end{cases} \tag{4}$$

where (x,y) is the coordinate of the target scattering-center, (x',y') is the coordinate of the antenna, R_0 is the distance form the antenna to the target center, R is the real distance form the antenna to the target scattering-centers, $F(k+k_{\min},y')$ is the echo signal of the target after filter-process, $\hat{f}(x,y)$ is the scattering-intensity of the target scattering-center, φ is the angle between the target scattering-center and the antenna-center, $G(\varphi)$ is the antenna pattern.

2.4. Far-field RCS Obtained

The real scattering-intensity or the distribution of target scattering-centers is obtained by FBP process. Once the scattering-image is available, a natural definition of scattering-centers is a discrete set of point scatters, each with position (x_n,y_n) and amplitude A_n, and we will use CLEAN algorithm to find the dominant scattering-centers from the image.

CLEAN algorithm is a robust iterative procedure which successively picks out the highest point in the image, assumes it is a scattering center with the corresponding strength, and subtracts the point spread function $h(x_n,y_n)$ of the scattering center from the image. At the nth iteration, if A_n is the intensity of the highest point in the image with location (x_n,y_n), then the residual image is expressed as

$$(\text{Residual Image})_{n+1}=(\text{Residual Image})_n-A_n\cdot h(x_n,y_n) \tag{5}$$

Target scattering center model can be obtained by CLEAN process. Therefore, target RCS in far-field or at random range in near-field can be obtained by vector sum of the target scattering-centers with the radar equation, and the RCS can be expressed as

$$\sqrt{\sigma}=\sum_{n=1}^{N}\hat{f}\left(x_n,y_n\right)\exp\left(-\mathrm{j}\frac{4\pi R_n}{\lambda}\right)\frac{R_0^2}{R_n^2}G\left(\varphi_n\right) \tag{6}$$

where is $\sqrt{\sigma}$ the vector RCS of the target, $\hat{f}\left(x_n,y_n\right)$ is the nth scattering center's scattering-intensity, R_n is the distance between the antenna center and the target scattering center, R_0 is the distance between the antenna center and the target center, φ_n is the angle between the nth target scattering-center and the antenna-center.

3. MEASUREMENT

To validate the correctness and feasibility of the technology, theoretical simulation and test measurement are made.

3.1. Theoretical Simulation Measurement

In the theoretical simulation measurement, we obtain the special metal plate ($1\,\mathrm{m}\times0.2\,\mathrm{m}$) SAR Imaging data in near-field and the RCS data in far-field with simulation software, and the detailed imaging parameter is

1) R_n (the measurement distance in near-field): 3 m
2) R_f (the measurement distance in far-field): 3 km

3) Scanning scope: $(-3 \sim 3)$ m
4) Sweeping scope: $(8 \sim 12)$ GHz

With the transformation method introduced in this paper, we can obtain the far-field RCS. Figure 4 is the comparison of RCS obtained by simulation and extrapolation, and its average error is less than 1 dB.

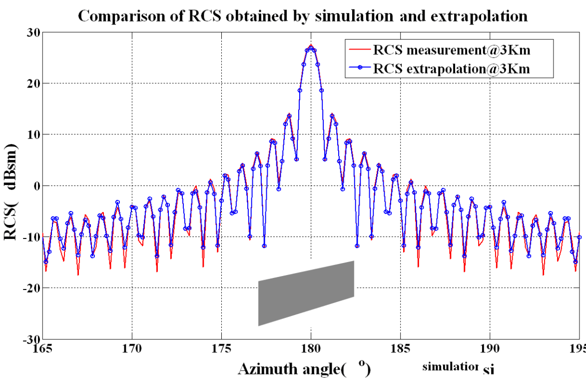

Figure 4: Comparison of RCS simulation and extrapolation.

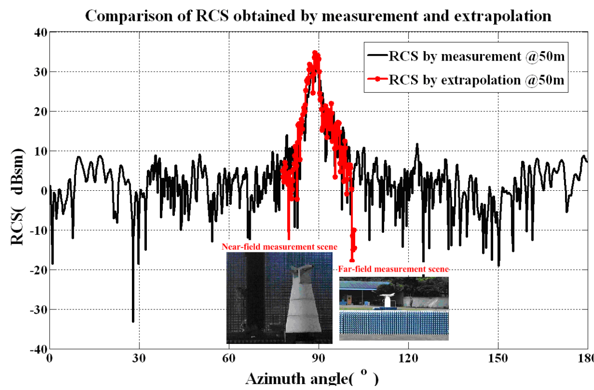

Figure 5: Comparison of RCS measurement and extrapolation.

3.2. Test Measurement

In the test measurement, we obtain the scaled plane model's ($2\,\mathrm{m} \times 2\,\mathrm{m}$) near-field SAR Imaging data with scanner-SAR Imaging system in the darkroom, and obtain the far-field RCS data with ISAR Imaging system in non-cooperative outdoor environments, and the detailed imaging parameter is

1) R_n (the measurement distance in near-field): 5 m
2) R_f (the measurement distance in far-field): 50 m
3) Scanning scope: $(-2.25 \sim 2.25)$ m
4) Sweeping scope: $(8 \sim 12)$ GHz

With the transformation method introduced in this paper, we can obtain the far-field RCS. Figure 5 is the comparison of obtained by measurement and extrapolation, and its average error is less than 2.5 dB.

4. CONCLUSION

Both the theoretical simulation and test measurement results validate the correctness and feasibility of the technology that target's far-field RCS can be obtained with SAR imaging in non-cooperative near-field environments.

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