VIRTUAL SAR TARGET IMAGE GENERATION AND SIMILARITY

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ABSTRACT

Target image database is of great significance in SAR automatic target recognition (ATR). Recently, some convenient and low cost approaches of database simulation were proposed. However, the similarity between virtual SAR images obtained by these simulation approaches and real SAR images is still under study. To solve this problem, we will model the virtual target with three-dimensional (3D) modeling methods, and acquire SAR image via the simulated RCS data which is generated by computational electromagnetic software. Then, we propose a method to measure the similarity between the virtual and real SAR images, which provided better support for data training and recognition of virtual target. Experiment results demonstrate the formation of the virtual SAR images and validate the effectiveness of our proposed method.

***Index Terms*—** SAR ATR, Image Similarity, Electromagnetic Simulation, Target Recognition

1. INTRODUCTION

SAR automatic target recognition (ATR), as an important aspect of SAR application, has become an international focus of research [1]. SAR target image database plays an important role in the SAR ATR algorithm theory study. Target recognition of tanks and other vehicles on the ground requires a lot of real data to build and expand the SAR target database, which is used to support the training, clustering and feature extraction of SAR ATR. Some public databases, used for SAR target recognition performance evaluation, contains various target image categories, such as tanks, armored vehicles and other vehicles. However, when we use the data of database to recognize some unknown targets or extract the features of some certain angles, it seems that the data is not enough. When we want to get the data of all ground targets by experiment, it seems to be unrealistic because of large cost and complex operations [2].

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In order to expand the existing database, the study in Ref. [3] has proposed a new method through electromagnetic simulation, which is easy to operate and can solve the large cost and complex operation problems, etc. This method that simulates the virtual target to get the scattering information data and then processes the data to get the virtual SAR image shows how to generate SAR images [4]. However, it dose not state whether these SAR images can be used to do target recognition [5]. We need to know the relationship between the virtual and real SAR images, so that the virtual SAR images can be used to support our SAR ATR study. However, research in this area is rare.

Based on proposed electromagnetic simulation method to generate virtual SAR images, in this paper, we establish similarity between the virtual and real SAR images to measure difference between the virtual target and real target. The relationship can provide better support for data training, feature extraction, clustering and recognition of virtual target.

Sections in this paper are as follows: Section 2 describes the method that how to model the virtual target and generate the virtual SAR image. Section 3 evaluates the similarity between the virtual and real SAR image. In section 4, experiments based on MSTAR database show that virtual SAR images generated are very similar to the real ones, and the images can be used in SAR ATR effectively.

2. TARGET GENERATION AND IMAGING

To simulate a virtual image, the first thing is to make sure the type of targets, such as tanks, aircrafts, artilleries. Once the target type is determined, the three-dimensional (3D) model to represent the target itself is established. Then, we will use the target 3D model and calculate RCS of the model using electromagnetic methods. Finally, we process the RCS data and acquire the virtual SAR image.

2.1. Virtual Target Generation

We model the virtual target using the following steps:

2.1.1. *Target 3D modeling*

According to the real target size, we use solid modeling technique to create 3D components of the target, and then combine the components together [6].

2.1.2. *Parameter settings*

After 3D model of the target has been created, we need to set the specific parameters according to the demand. These parameters are helpful to obtain the final SAR image. The parameters and values are as follows [4]:

Table 1. PARAMETER SETTINGS

Parameter	Symbol	Value or Range
Pitch angle	θ	$[0°, 90°]$
Amuzith angle	φ	$[0°, 360°]$
Polarization direction	none	H, V
Frequency range	(f_L, f_H)	$f_c = (f_L + f_H)/2$
		$B = (f_H - f_L)$
Sampling points	$N_x \times N_y$	$N_y = \frac{Y_{max}}{\Delta y}$
		$N_x = \frac{X_{max}}{\Delta x}$
Bandwith	B	$B = \frac{C}{2\Delta x}$
Azimuth observation range	Ω	$\Omega = \frac{\lambda_c}{2\Delta y}$

Where, V and H stand for vertical and horizontal polarization. f_c is the center frequency of the incident wave. $c = 3 \times 10^8 m/s$ is the light velocity. Δx, Δy are range resolution and azimuth resolution. X_{max}, Y_{max} are the max range and azimuth size of the 3D model.

2.1.3. *Meshing*

The wavelength of the incident wave(λ) determines the model meshing cell size. With different solving methods, different meshing cell size should be considered. Generally meshing cell size takes from $\lambda/10$ to $\lambda/8$, Physical Optics Method (PO) can take the maximum size of $\lambda/3$ [6].

2.1.4. *Method selection*

There are many computational electromagnetic methods in the electromagnetic simulation software, such as Moment Method (MOM), Multilevel Fast Multilevel Method (MLFMM) , Physical Optics Method (PO), etc. However, considering the computing accuracy and complexity, the PO method will be used to calculate the RCS for electrically large target [7].

Once all of the above steps completed, we can calculate electromagnetic scattering of the 3D model.

2.2. Virtual Target Imaging

It's easy to acquire the SAR image, once the RCS of the 3D model has been calculated. Generally small-angle 2D-FFT algorithm, filtered back projection algorithm and 2D-FFT algorithm in the Cartesian coordinate system can be used to image. In this paper, we adopt the small-angle 2D-FFT algorithm to process the RCS data achieved from section A. The detailed processing methods flowchart shown as Fig 1 consists of Cartesian coordinate conversion, windowing, zero padding and 2D-IFFT [4]

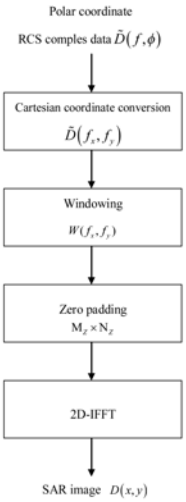

Fig1. Target imaging flowchart

3. IMAGE SIMILARITY ANALYSIS AND EVALUATION

When the virtual targets SAR image is created, we need to evaluate the degree of similarity of virtual and real images. In other words, we need to analyse features containing information in virtual image that can well representing the real target. So the following section introduces some parameters to represent the similarity of virtual and real images. All the virtual images and real images are processed with preprocessing methods [8].

3.1. Appearance similarity

Appearance similarity is to measure the appearance accuracy of the targets in virtual SAR image and real SAR image, which comprises two parts: targets area of similarity(AS) and targets perimeter similarity(CS).

The calculation equation of AS as follows:

$$AS = \frac{A_{SR}}{A_R} \times 100\% \tag{1}$$

A_{SR} is the identical area of targets in the virtual and real SAR images. A_R is the area of target in the real SAR image. Similarity degree increases with the increase of AS. $AS = 1$ means the same size area of the target in the same position of the virtual and real SAR images.

$$CS = (1 - \frac{|C_S - C_R|}{C_R}) \times 100\% \tag{2}$$

In equation (2), C_S and C_R stand for the targets perimeter in the virtual and real SAR image, respectively. $CS = 1$ means the virtual SAR image and real SAR image are completely similar. The virtual target can completely characterized the surface profile information of the real target.

3.2. Scattering information similarity

This part we characterize the scattering information similarity of targets with image mean similarity(μS), variance similarity(σS) and information entropy similarity(HS).

$$\mu S = \frac{1}{e^{|ln(\mu_S) - ln(\mu_R)|}} \times 100\% \tag{3}$$

Where μ_S and μ_R stand for mean of the virtual and real SAR image. Image mean reflects the average brightness of image. If $\mu S = 1$, the virtual and real SAR image has the same average brightness.

Same to μS definition, σS can be expressed as bellow.

$$\sigma S = \frac{1}{e^{|ln(\sigma_S) - ln(\sigma_R)|}} \times 100\% \tag{4}$$

σ_S and σ_R represent the virtual and real SAR image variance, respectively. Image variance is a measure of spread of the gray values in the image. The larger the value of image variance, the more discrete grey value distribution, and the more information can be retrieved from the image. When $\sigma S = 1$, the degree of image grayscale distribution in virtual and real SAR image is identical.

$$HS = \frac{1}{e^{|ln(H_S) - ln(H_R)|}} \times 100\% \tag{5}$$

In the above equation, H_S and H_R are the virtual and real SAR images average information entropy. Information entropy increasing means more information in the image. Information entropy similarity degree increases with the increase of HS.

3.3. Structural similarity (SSIM)

Structural similarity is a study regarding internal structure relationship of image, which is also known as images luminance, contrast and structural properties [9].

The specific steps to calculate SSIM are: to use same size window to slide from the upper left pixel points to down right pixel points in virtual SAR image and real SAR image respectively, with the sliding route from left to right, up and down and pixel by pixel, and calculating the luminance comparison $l(S, \mathrm{R})$, the contrast comparison $c(S, \mathrm{R})$, the structure comparison $s(S, \mathrm{R})$ and SSIM at the same position of the window in each image.

$$\mathrm{SSIM} = l(S, \mathrm{R}) \times c(S, \mathrm{R}) \times s(S, \mathrm{R}) \tag{6}$$

SSIM reflects the local structure similarity degree of image.

MSSIM means average SSIM of the whole image.

$$\mathrm{MSSIM} = \frac{1}{T} \sum_{k=1}^{T} \mathrm{SSIM}_k \tag{7}$$

T is the total number of sliding windows, SSIM_k represents the value of time sliding window. The MSSIM values demonstrate much better consistency with the qualitative visual appearance [9]. Bigger value illustrates higher structural similarity of virtual and real SAR images.

3.4. Average similarity

Though AS, CS, μS, σS, HS and MSSIM can be used alone to represent a certain aspect similarity degree of virtual and real SAR images, they are not sufficient to confirm the similarity degree of comprehensive aspects. Average similarity (Sim) of each group image can be calculated as an composite parameter, with appearance similarity, scattering information similarity and SSIM. The equation shown as follows:

$$\mathrm{Sim} = \underset{s.t.\ \sum_{i=1}^{6} \rho_i = 1}{\begin{array}{l} E\{\rho_1 AS + \rho_2 CS + \rho_3 HS \\ +\rho_4 \mu S + \rho_5 \sigma S + \rho_6 \mathrm{MSSIM}\} \end{array}} \tag{8}$$

Where, E stands for the expectation operator. With Sim, we can express the similarity of the images with several aspects. Also, larger value of Sim denotes higher similarity.

4. EXPERIMENTS

In this section, we will complete consecutive experiments to realise image evaluation. The real SAR images selected from the MSTAR dataset is to be used to compare similarity with the virtual SAR images. 3D modeling software CATIA, electromagnetic simulation software FEKO and data analysis software Matlab will all be used in these experiments.

4.1. SAR Target Modeling and Imaging Simulation

According to the real model of T72M1, we use solid modeling method to construct a 3D model with modeling software CATIA. The 3D model is shown in Fig 2. We choose large-element physical optics (LEPO) method of simulation software FEKO to simulate the RCS data, with simulation parameters of bandwidth $B = 500\text{MHz}$, frequency lower limit $f_L = 9.75\text{GHz}$, frequency upper limit $f_H = 10.25\text{GHz}$, range sampling points $N_x = 24$ and azimuth sampling points $N_y = 15$. All of the parameters are taken from equation (1)-(6). The following conditions apply: the X-band incident wave, pitch angle $\theta = 73°$, range resolution $\Delta x = 0.3m$ and azimuth resolution $\Delta y = 0.3m$ known. After imaging through small-angle 2D-FFT algorithm with the simulation data getting from FEKO, we can get the virtual SAR image shown as Fig 3.

(a)Optical image (b)3D-model image

Fig2. T72 tank optical image and 3D-model image

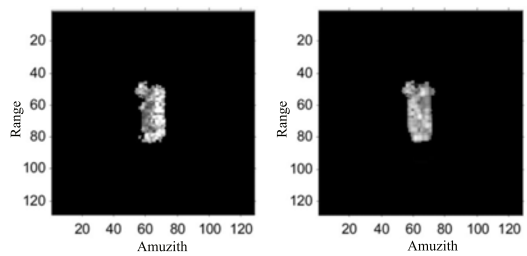

Fig3. Real SAR image (left) and Virtual SAR image (right)

4.2. Accuracy evaluation

After preprocessing 21 groups of virtual SAR images and real SAR images respectively with preprocessing methods including image segmentation, centroid registration and energy normalization, we can calculate the average image similarity of each image group. The results are shown in Table 2. Experimental results show that using image similarity to analyze virtual SAR image is an objective and effective evaluation approach.

Table 2. AVERAGE ACCURACE OF 21 GROUP IMAGES

φ	2°	12°	22°	32°	42°	50°	62°
Sim	0.8832	0.8738	0.8677	0.8690	0.8531	0.8082	0.8365
φ	72°	82°	92°	100°	112°	122°	132°
Sim	0.8313	0.8089	0.8476	0.8258	0.8580	0.8221	0.7994
φ	142°	152°	162°	172°	182°	192°	202°
Sim	0.8754	0.8996	0.8623	0.8689	0.8448	0.8594	0.8793

5. CONCLUSION

In this paper, a method to measure the similarity between the virtual and real SAR images has been proposed. We generate virtual SAR images via the simulated RCS data, which is generated by computational electromagnetic software. Then, we present a method to measure the similarity between the virtual and real SAR images. All the results of experiments show that virtual SAR images generated can be used in feature extraction and target recognition. The similarity measure method we proposed works well in measuring the similarity degree of virtual SAR images and real SAR images.

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