AUTOMATIC TARGET RECOGNITION IN HIGH RESOLUTION SAR IMAGE BASED ON BACKSCATTERING MODEL

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Abstract: In this work we present a new algorithm that enable to perform automatic target recognition (ATR) in high-resolution synthetic aperture radar (SAR) data. According to the microwave backscattering theory and the three-dimension model of target, we calculate radar cross section (RCS) and correspondingly obtain the high resolution inverse synthetic aperture radar (ISAR) image of target. In order to discard most of the false alarms, a discrimination algorithm integrated two discriminators is proposed. Then, the target is recognized rapidly and accurately based on the simulated signatures. Finally, evaluation of ATR performance using high-resolution SAR image of the Chinese airborne SAR system is conducted.

Keyword：SAR, ISAR, high resolution, radar cross section, target recognition

1. INTRODUCTION

With the rapid development of synthetic aperture radar (SAR) technology, the need for automatic processing of large-size SAR data is put forward, especially for rapid response to disaster monitoring and mitigation. Automatic target recognition (ATR) of SAR images is an area of ongoing research by all branches of large research institutes[1, 2] which meets this requirement. The most common ATR system consists of three modules. They are (1) focus of attention that filters out all but regions of interest (ROI), (2) indexer that labels target candidates and (3) predictextract-match-search (PEMS) subsystem that verifies target identifications by matching predicted signatures in database with measured signatures.

In this work, our primary interest is to implement automatic target detection and recognition based on Chinese airborne high resolution SAR images. Although some researches have performed ATR using man-made data based on MSTAR object and background images[3], little work has been done with real high resolution SAR images in China. The objective of this work is to generate SAR target signatures based on 3-D models and develop new matching algorithms. In this paper, the high-resolution SAR image-modeling problem is first studied, and then a high-speed target detection algorithm based on CFAR technique and target variance character is proposed.

2. OBJECT'S SCATTERING PROPERTIES

Radar sensors respond to electromagnetic (EM) waves which are scattered when the propagation of incident waves is disturbed by the presence of an object. The physical mechanism can be described as: the incident fields induce currents bounded by the object to generate field, subject to constraints imposed by boundary conditions. To determine the object's scattering properties, we must visualize the object features which stimulate the scattered fields. A quantitative, spatial distribution of scattered fields is determined by the integrated effect of the current distribution. The latter cannot be measured directly by radar. Nevertheless, we strive to obtain, from measurements of scattered fields by a remote sensor, any information leading to the spatial separation of object features responsible for the scattering. That is what the imaging do[4,5].

In order to get the object's scattering properties, three stages are: (1) 3-D model of objects generation, (2) the object's scattering calculation, (3) production of the spatial distribution of scattering (Fig. 1).

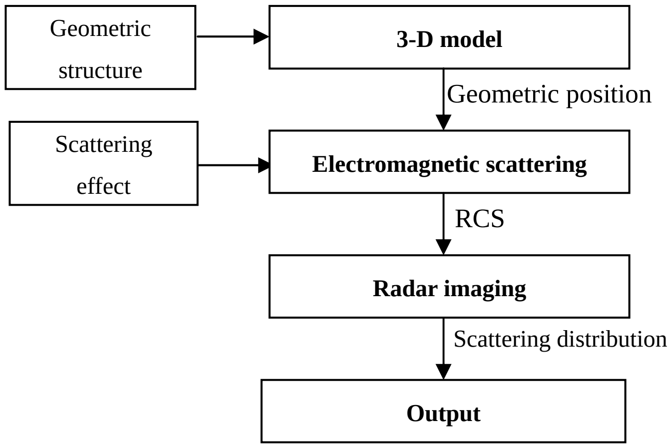

Fig. 1 The scheme of EM scattering properties calculation

2.1 EM Scattering

RCS calculation is based on scattering mechanism of EM scattering theory, using the computer algorithm to estimate RCS in all conditions[4].

Using facet to construct the object, the RCS computation is to consider the plane and edge effect to the incident field. Before scattering we need to consider the shade, after scattering the second bounce. We use the physical optics (PO) to calculate the scattering field, use the geometry to judge the shade and second bounce effect.

(1) For facet system, the shading effect can be deal as: whether a facet is in shade is decided by that if the center of the facet is in shade.

(2) Second bounce will be judged before calculation.

(3) Physical Optics (PO) is widely used to calculate the perfect conducting object's scattering. PO uses the integral equation representation for the scattered fields. The PO scattering of all facets is summed up to get the total field[6].

2.2 Spatial Distribution of Scattering Properties

The imaging is to generate the spatial distribution of scattering properties from RCS data. Wide signal bandwidths and synthetic aperture are combined to resolve objects. ISAR imaging is described as follows:

(1) A transducer with sufficient angular beam width to uniformly irradiate the object is held fixed and used to transmit and receive microwave signals.

(2) The complex object response is measured for a fixed aspect angle as a function of frequency.

(3) The object is rotated and measurement is repeated.

(4) The frequency responses for each aspect angle are processed by Fourier transform to obtain range profiles.

(5) The signal contained in each range cell as a function of rotation angle is processed by Fourier transforms to obtain the cross-range profile.

(6) The simulated ISAR image is the magnitude of the resulting signal as a function of range and cross range[4].

3. ATR ALGORITHM

Figure 2 gives the flowchart of ATR based on simulated ISAR images.

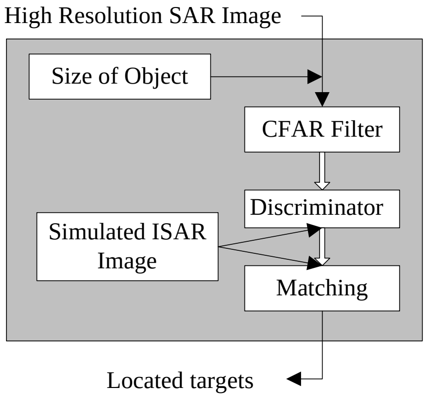

Fig. 2 Flowchart for automatic target recognition based on scattering model

Firstly, possible targets are found out by the CFAR filter, and the size of reference window is evaluated according to the resolution of SAR image and the target size. After the CFAR stage some efficient discriminators should be applied to reduce the false alarms. Finally applying Radon transformation to the possible targets and the simulated target image, the matching algorithm is performed to identify target successfully.

3.1 CFAR filter

CFAR detection is always available to radar and communication field, the technology has been used to detect targets in SAR images during recent years, especially to detect targets fast in high-resolution SAR images.

The basic principle of CFAR operator is as follow: for every pixel x_c, a certain neighborhood around it is defined as reference window, and a threshold x_0 is determined according to the statistically character of reference window. x_0 satisfies the following detection process which should have a Constant False Alarm P_{FA}:

$$\begin{cases} x_c \ is\, target\ pixel \quad if \quad x_c > x_0 \\ x_c \ is\, background\ pixel \quad otherwise \end{cases} \tag{1}$$

where, $P_{FA} = \int_{x_0}^{\infty} f_x(X / clutter) dX$.

In our experiments, the width of reference window is selected as one pixel, the size of which doubles the maximal size of targets. In order to improve computing efficiency, the reference window is divided into two adjacent reference windows: horizontal reference window and vertical reference window .There are only two different pixels in neighboring horizontal reference windows, the same with neighboring horizontal reference windows. The superposition of adjacent reference windows speeds up the parameter estimation.

3.2 Discriminator

Defining $[A_1, A_2]$ as the ROI of possible targets, A is the area of ROI, then the area discriminator (AR) can be expressed as follows:

$$\begin{cases} if\left(A_1 \le A \le a_2\right) \quad then \quad ROI\ is\ possible\ t\arg et \\ \qquad\qquad\qquad else \quad ROI\ is\ false\ alarm \end{cases} \tag{2}$$

The Peak Power Ratio (PPR) is defined as the power ratio between the top 10% pixels and the total pixels in the ROI. The PPR is

$$\begin{cases} if\left(PPR > T\right) \quad then \quad ROI\ is\ possible\ t\arg et \\ \qquad\qquad\qquad else \quad ROI\ is\ false\ alarm \end{cases} \tag{3}$$

where T is the threshold estimated by training data.

3.3 Recognition based on the ISAR image

The feature of target is quasi-invariant under Radon transformation. After Radon transformation, the simulated ISAR images and the possible targets can be expressed as the vectors $L = \left[L_1, \cdots, L_N\right]$ and L' separately, where N is the number of possible targets. Similarity measures are performed by matching schemes between L and $L_N^{'}$, the optimal recognition results can be achieved until the peak matching value will be reached[7].

4. EXPERIMENT RESULT AND SUMMARY

The test data is Ku-band SAR data acquired by China Electronics Technology Group Corporation airborne SAR system in NW China in 2002. The look angle of SAR imaging is 74.2°, and the range is about 15km. The resolution of data is 1m*1m. Fig. 3 shows the scene of SAR image, which is 3200 pixels*3200 pixels.

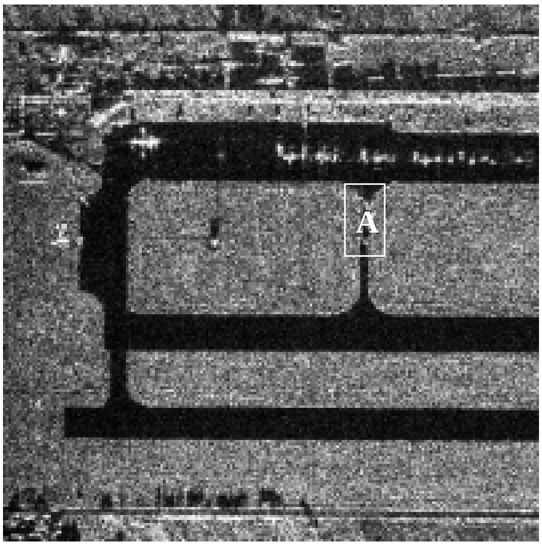

Fig. 3 Ku band SAR data (the flight direction is parallel to the direction of main runway)

The objective of our experiment is to identify H6 airplanes in the region A shown in Fig. 3. The enlarged image of region A is shown in Fig. 4(a), the Qucikbird image of same region shown in Fig. 4(b).

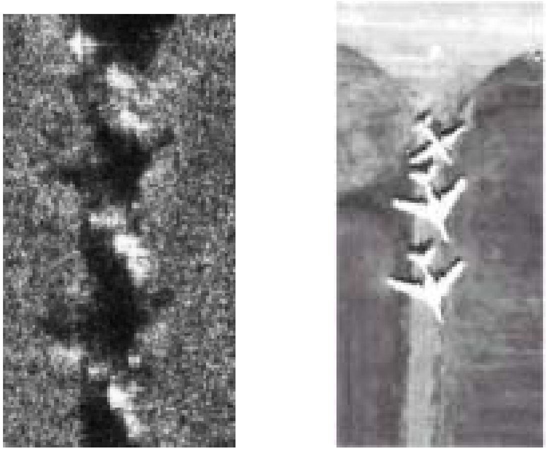

Fig. 4 (a) the enlarged SAR image;   (b) Quickbird image

The CAD model of airplane is established, which is composed of 206 nodes and 358 triangles (Fig. 5(a)). The SAR target signatures are generated, in which the frequency is 10 GHz and the band width is 1.28 GHz. Our algorithm uses CAD models with several viewing and articulation variations, Fig. 5 (b) shown one of the simulation results.

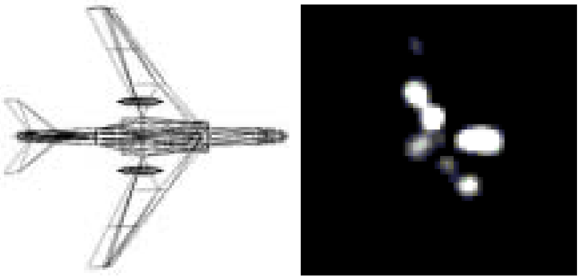

Fig. 5 (a)The CAD model of airplane,   (b)simulated SAR signatures (the azimuth angle is 161 degree according to the incidence of radar beam).

The next work is to perform CFAR detection. The size of reference window is determined by the actual size of this airplane and the resolution of the SAR image. After CFAR filter there are 65 possible targets in whole scene. In order to decrease the dimensions of search space, a discrimination algorithm integrated AR discriminator and PPR discriminator is implemented to discard some false alarms. After that, the number of ROI reduced from 65 to 32.

Finally, after Radon transformation, the airplane is recognized by the matching scheme based on similarity measures between L and $L_N^{'}$. The result is shown in Fig. 6.

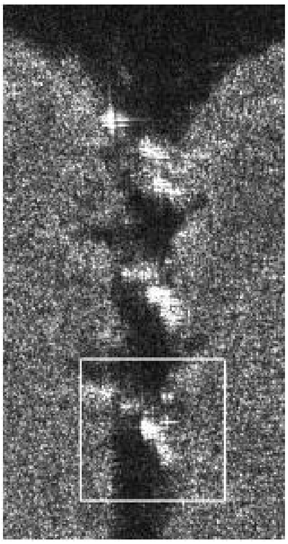

Fig. 6 ATR result in the enlarged SAR image

Referring to Fig. 4(b), the algorithm fails to detect another airplane of same type. The similarity measurement of this plane is just ranked fifth in the list. This case may be caused by factors as follows: (1) the simulated SAR signatures are distorted due to artifacts of the CAD model; (2) the background is not considered in the scattering model.

In this paper, we present a new algorithm that enabled automatic target recognition (ATR) in high-resolution SAR data. The algorithm is verified using high-resolution SAR data acquired by the China airborne SAR system. In the future, the interactive scattering between target and its environment should be considered, and the matching algorithm should be improved to ensure the robustness of ATR systems.

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