DETECTION AND IMAGING OF SLOWLY MOVING TARGET OF AIRBORNE SAR BASED ON THE GMCWD-HOUGH TRANSFORM

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ABSTRACT

In this paper, the features of airborne SAR moving target echoes are analysed, the Generalized-marginal Choi-Williams Distribution-Hough transform is also introduced. According to the echoes model of airborne SAR, a new method of detecting and imaging the slowly moving target of airborne SAR based on the Generalized-marginal Choi-Williams Distribution-Hough transform (GMCWD-HT) is proposed in the paper. Computer simulation results show that this method can be used to perform the slowly moving target detection and imaging of airborne SAR in the low signal to clutter ratio, its detecting performance is better than the common method based on Wigner-Ville distribution.

1. INTRODUCTION

Conventional SAR is usually used to image the fixed targets on the ground. However, in many military applications our interests are concentrated on the ground moving targets and the other echoes from the fixed targets are considered as clutter, which must be eliminated as soon as possible, only the moving target will be imaged. For the moving targets, because their radial velocities relative to the platform are different from that of the fixed targets, namely, they have different Doppler frequencies, it is possible for the moving targets to walk out of the image cell while the platform is moving. Thus the conventional SAR for imaging of the fixed targets can't be employed for the moving targets. On the one hand, the moving targets are blurred and completely inundated in the clutter so that they can't be discernible from the SAR image; on the other hand, due to the smudge of the velocity and cross-range the image of the moving targets could be confused with the image of the stationary targets. To focus the image of a moving target, the Doppler centroid and the Doppler rate of the moving targets must be accurately estimated. Based on the fact that the Doppler frequency shift of a moving target is different from that of stationary objects, a bank of frequency domain may be used to separate the moving target signals from the stationary targets. However, In the practical situation, due to the motion of the airborne radar platform, the echoes spectra of the ground clutter will be extended so that the echo spectra of the ground moving targets may be entirely or partly submerged in the extended ground clutter spectra. Under these circumstances, if the ground clutter is filtered in the Doppler domain, filtering process will inevitably reduce the energy of the useful signals, which makes the detection of the moving targets (especially the slowly moving targets) difficult and requires high pulse repetition frequency. Therefore, on the basis of SAR imaging, making the airborne SAR have the abilities to image and detect the slowly moving targets, to produce high resolution image, is one of the emphases on the technique development of airborne SAR [1].

By realizing that the signature of the airborne SAR echoes from a moving target is always a sloped ramp in the joint time-frequency space, a new approach to image the airborne SAR moving targets is to distinguish the signature of moving target from the stationary ones in terms of their time-frequency characteristics. Winger-Ville Distribution (WVD) is an effective tool of analyzing time-varying signals, but one problem to be considered firstly is how to separate the signature of the moving target from the ground clutter if the WVD is used to image a moving target. The discussion by A.Farina[2] is performed on the assumption that the SAR echoes have been filtered out of the ground clutter. For the moving targets with the low radial velocities, their frequency spectra are to some extent superposed over that of the stationary targets echoes. It is impossible to detect the existence of the slowly moving target using WVD even if the ground clutter is filtered, on the condition that Hough transform is also useless. Based on the above drawback, in the paper we propose time-frequency (TF) method combined with the Hough transform to detect the signatures of multiple SAR slowly moving targets and estimate their parameters. The TF method uses the rational kernel function to replace the conventional TF kernel function, which makes TF distribution sensitive to the rotation angle of the kernel function. Finally the simulated data of the slowly moving targets will be used to demonstrate the efficiency of the combined GMCWD-Hough transform for detecting multiple slowly moving targets and estimating their moving parameters.

2. MODEL OF AIRBORNE SAR ECHOES FROM MOVING TARGET

The geometry of the airborne SAR relative to the ground moving target is illustrated in Fig.1, assuming that radar platform moves, with constant v_a along the X axis, R_0 is

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the distance between radar platform $(0,0,h_0)$ and moving target $(0,y_0,0)$ at $t=0$, the velocity of the moving target can be decomposed along the range and cross-range, v_r, a_r, v_c, a_c are the radial velocity, radial acceleration, cross-range velocity, cross-range acceleration, respectively. At time t the distance $R(t)$ in the Cartesian coordinates between the radar platform and moving target can be expressed as follows:

$$R(t)=\sqrt{(V_a t-v_c-a_c t^2/2)^2+(R_0-v_r t-a_r t^2/2)^2} \qquad (1)$$
$$|t|\le T_s/2$$

where T_s is synthetic aperture time. After Taylor expansion around $t=0$ the returned radar signal from the moving target can be approximated by

$$s(t)\approx\exp\{-j4\pi R(t)/\lambda\}$$
$$=\exp\{-j4\pi f R_0/c\}\exp\{j2\pi f_d t\}\exp\{j\pi f_r t^2\} \qquad (2)$$
$$f_d=\frac{2v_r}{\lambda} \qquad f_r=\frac{2}{\lambda R_0}[(V-v_c)^2+R_0 a_r]$$

where c is the velocity of the electromagnetic wave propagation. From Eq.(2) we know that the SAR returned signature from the moving target can be modeled by the linear frequency modulated (LFM)signal and the detection of moving targets of airborne SAR becomes the detection of LFM features. The Doppler centroid and the frequency modulation rate of the SAR moving target echoes provide the information about the radial velocity and the cross-range location of the moving target.

3. INTRODUCTION OF THE GMCWD-HOUGH TRANSFORM

3.1. THE GMCWD

Assuming that τ is time delay, the TF distribution of signal $s(t)$ can be represented by the Cohen's class

$$p(t,\omega)=\iiint\exp\{-j(\theta t+\tau\omega-\theta u)\}$$
$$\phi(\theta,\tau)s(u+\frac{\tau}{2})s^*(u-\frac{\tau}{2})d\theta d\tau du \qquad (3)$$

where $\phi(\theta,\tau)$ is the normal kernel function of the Cohen's class. If TF distribution $p(t,\omega)$ has a rotation with angle α and the following holds.

$$\tilde{t}=t\cos\alpha+\omega\sin\alpha$$
$$\tilde{\omega}=-t\sin\alpha+\omega\cos\alpha \qquad (4)$$

$$\int p(\tilde{t}\cos\alpha-\tilde{\omega}\sin\alpha,\tilde{t}\sin\alpha+\tilde{\omega}\cos\alpha)d\tilde{t}$$
$$=\left|(F_{\alpha k+\frac{\pi}{2}}s)(\tilde{\omega})\right|^2 \qquad k=1,2,...,N \qquad (5)$$

where $F_{\alpha k+\frac{\pi}{2}}s$ is the fractional Fourier transform of the signal $s(t)$ with an angle $\alpha k+\frac{\pi}{2}$, the TF distribution $p(t,\omega)$is the generalized-marginal TF(GMTF) distribution.

The GMTF distribution has potential applications for the detection of multiple SAR moving targets echoes in a heavy clutter environment. If the frequency modulation rate of a SAR moving target signal can be estimated, we can design a kernel function with angle parameters, which makes the bilinear TF distribution having concentrated energy and minimal cross-term interference in the TF domain. The generalized-marginal kernel function introduced by Xia[4] is defined by a number of rotation angle parameters. For the Choi-Williams distribution (CWD), $\phi(\theta,\tau)=\exp\{-\theta^2\tau^2/\sigma\}$, where σ is the kernel window parameter, is replaced by the generalized-marginal kernel defined as

$$\phi(\theta,\tau)=\exp\{-\frac{1}{\sigma}\prod_{k=1}^{N}(\theta\sin\alpha_k+\tau\cos\alpha_k)^2\} \qquad (6)$$
$$k=1,\cdots,N$$

where N is the total number of lines to be extracted and α_k is angle parameter estimated from the frequency modulation rate of each line.

3.2. HOUGH TRANSFORM

Hough transform can transfer a line in 2D space into peaks in a line parameter-domain (ρ,θ), the intercept ρ is the shortest distance from the origin of the coordinate system to the line, the slope θ is the angle of orientation of the line[3]. Thus a line detection problem becomes peak detection in the slope-intercept domain and can be handled using threshold method. Assuming that function $F(x,y)$ is defined in image plane, function $G(a,b)$ is defined in parameter plane, after mapping $G(a,b)$ can be expressed as follows:

$$G(a,b)=\sum_i F(x_i,y_i) \qquad (7)$$

among a,b,x_i,y_i is satisfied with $y_i=bx_i+a$, namely (x_i,y_i) are all possible points distributed on the line $y=bx+a$ and defined in the image plane $F(x,y)$ .Changing the value of a and b is equal to changing the slope and intercept of the line in image plane. The polar format of the line can be written as

$$\rho=x\cos\theta+y\sin\theta \qquad (8)$$

and the Hough transform is defined as

$$G(\rho,\theta)=\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}F(x,y)\delta(\rho-x\cos\theta-y\sin\theta)dxdy \qquad (9)$$

where $\delta(.)$ is even function. If the 2D space contains only straight lines, the Hough transform shows sharp peaks at the coordinates of (ρ,θ). The relationship between the polar coordinates parameter (ρ,θ) and the Cartesian coordinates parameter (μ_0, f_0) is followed as

$$\mu_0 = -ctg\theta \qquad f_0 = \rho / \sin\theta \qquad (10)$$

where μ_0, f_0 is the slope and intercept of the line.Fig.4 is the result of Fig.3 by Hough transform. The Doppler centroid and the frequency modulation rate of the LFM signal can be estimated by Eq. (11).

4. DETECTING AND IMAGING THE MULTIPLE SLOWLY MOVING TARGETS BASED ON THE GMCWD-HOUGH TRANSFORM

In the TF domain, the TF characteristics of the moving targets is used to distinguish moving targets from the stationary ones. But in a heavy clutter environment it is difficult to detect the multiple SAR moving targets (especially the slowly moving targets) by using conventional methods. In this case, a GMTF distribution is very useful tool to enhance the TF distribution. The smoothing kernel function in the bilinear TF transform CWD is modified to include a rotation angle as function parameter. According to Eq.(2) the bound of the frequency modulation rate of the airborne SAR returned signals can be estimated, then the changing bound of the rotation angle required to search is estimated. When the rotation angle matches the frequency changing rate in TF distribution, the GMCWD can have high resolution and minimal cross-term interference. Thus, the GMCWD provides an improved echoes from the slowly moving targets and can enhance the TF signature in a heavy clutter environment. Besides the GMTF transform, a Hough transform based on the intercept-slope is applied to detect and estimate the line formed by the TF signals of the slowly moving targets in TF domain. In heavy clutter environment, the GMTF distribution can enhance the TF signatures of the slowly moving targets. Then a constant false alarm method is employed to determine whether a particular TF cell in the TF signals of received signals belongs to the slowly moving target signal or clutter. The CFAR processing estimates the statistical characteristics of the background noise and clutter from neighborhood of a test cell and sets a threshold based on the estimation. After the TF analysis and CFAR processing have been performed, the Hough transform is applied to the TF signals to estimate the Doppler centroid and frequency modulation rate of the slowly moving target by the set threshold. In terms of the estimated parameters the reference signal can be designed for each slowly moving target, then the reference functions can be used to compensate for the SAR echoes. After azimuth compression for the signals with compensated phase, the clear image for the slowly moving targets can be obtained. The system diagram of detecting and imaging the slowly moving targets of airborne SAR based on the TF-CFAR-Hough processing is shown in Fig.(5).

5. SIMULATION RESULTS

According to the imaging method of airborne SAR slowly moving targets proposed in this paper, the computer simulation experiment is performed. The system parameters are chosen as follows: the platform velocity $v_a (100m/s)$ moves along X at the altitude $h_0 (9000m)$, the two moving targets on the ground are located in the same range cell, at $t = 0$, the radial velocity v_{r1} and cross-range velocity v_{c1} of the target 1 is $1.5m/s, 20m/s$ respectively, the radial velocity v_{r2} and cross-range velocity v_{c2} of the target 2 is $4.5m/s, 15m/s$ respectively, the wave length λ of the transmitted signal is $0.03m$, the antenna aperture D is $2m$,the pulse repetition time PRT is $1.25ms$ .Assuming that the extended ground clutter and receiver noise can be modeled as zero mean gaussian random process.

After motion compensation, range compression and phase correction of the airborne SAR echoes, the SAR image can be obtained by taking the fast Fourier transform across range and cross-range. Images of the slowly moving targets are defocused and smeared in the SAR scene. It is difficult to distinguish the moving targets from the ground clutter as shown in Fig.(6). Due to the difference of TF signals between the slowly moving targets and static background, the detection problem of the slowly moving targets becomes detection of the line feature and estimation in TF domain. Fig.(7) is generated by using the GMCWD for the slowly moving targets, estimated angle parameters are 1.5536,1.5483. The Hough transform is applied to the TF singals of the two slowly moving targets as indicated in Fig.(8).

6. CONCLUSIONS

The detection performance of WVD requires high signal to noise ratio, and it is difficult for the cross-term interference to be eliminated in the case of multiple targets, which seriously affects the detection of the slowly moving target. In this paper the generalized bilinear TF distribution to enhance the resolution and reduce the cross-term interference is studied; the processing method based on the TF-CFAR-Hough transform is proposed to detect and image the slowly moving targets. The simulated experimental results show that in the heavy clutter environment the approach can efficiently detect the slowly moving target and estimate the moving parameters.

7. REFERENCES

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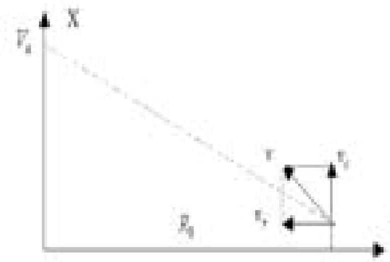

Fig.(1) The airborne SAR observation geometry

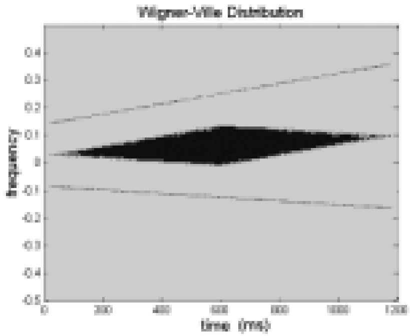

Fig.(2) WVD of the two LFM signals

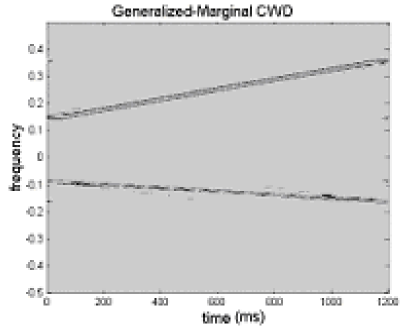

Fig.(3) GMCWD of the two LFM signals

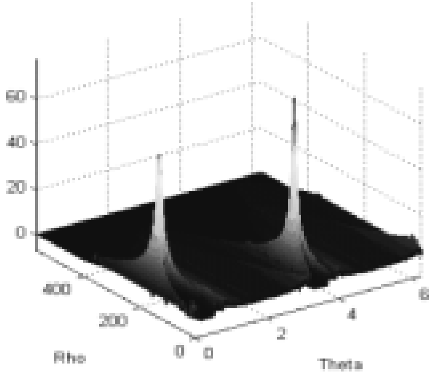

Fig.(4) The result of the GMCWD signal

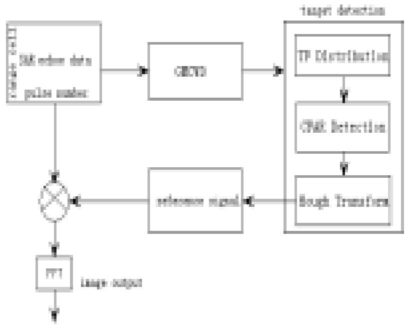

Fig.(5) The system diagram of detecting and imaging the slowly moving targets of the airborne SAR after Hough transform

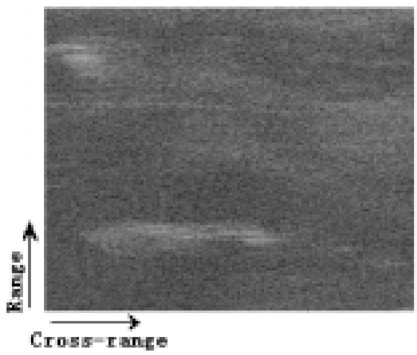

Fig.(6) SAR image of moving targets

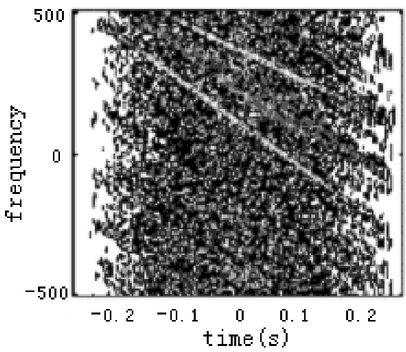

Fig.(7) The TF distribution after the GMCWD

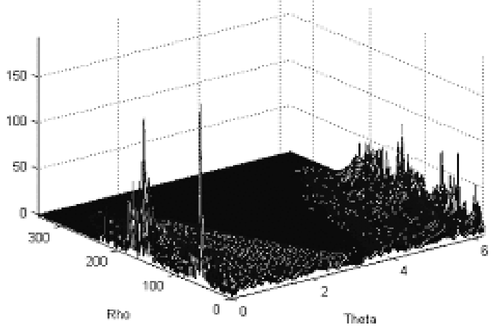

Fig.(8) The result of GMCWD signal after Hough transform