RECIPROCAL SPECTRUM ALGORITHM FOR RADAR IMAGING WITH FREQUENCY SAMPLING WAVEFORM

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1. INTRODUCTION

Synthetic Aperture Radar (SAR) has been researched deeply for remote sensing, target identification and surveillance, and the imaging algorithms are the soul of the radar sensor for different applications. As for the imaging quality, it depends on the transmitted waveforms and corresponding echo processing algorithms significantly. Waveforms such as LMF chirp signal, non-linear chirp signal and stepped frequency pulse train signal have been widely used and the algorithms such as Range Doppler Algorithm (RDA), chirp scaling algorithm and their modified versions have made contributions to improve the image resolution accompanied with motion compensation algorithms[1][2], and reference [3] and [4] provide methods for signal analysis and imaging evaluation for SAR/ISAR. However, the algorithms proposed in related literatures are either sensitive to target motion status or complicated in calculation up to now. In this paper, we adopt frequency sampling waveform to design an imaging method named reciprocal spectrum algorithm (RSA) for bi-static synthetic aperture radar on the unmanned aerial vehicle (UAV) to detect moving targets on the ground. Theory analysis to RSA indicates that the algorithm is insensitive to target moving status, and it can get finer azimuth resolution under certain radar waveform parameters than that given by traditional RDA algorithm. A performance criteria named correlation coefficient is proposed to evaluate the imaging difference between a standard virtual target and the RSA imaging results under different circumstances. Simulation results show that the RSA algorithm can get fine azimuth resolution and good focus performance, and it may result in recognizable images for the relative low SNR on the receiver.

2. SIGNAL ANALYSIS AND ALGORITHM DESIGN

Assume that there are P range cells along the range direction, and each range cell, which is r_p away from the SAR, has its RCS value σ_p, $p = 0,1,2,...,P-1$, the frequency sampling waveform is

$$s(t) = \sum_{n=0}^{N-1} e^{j2\pi f_n t} \varepsilon\left(\frac{t-(n+0.5)\tau_p}{\tau_p}\right), \qquad f_n = f_c + n\Delta f \tag{1}$$

τ_p is the pulse width and the $\varepsilon(\cdot)$ is a rectangle window function.

Then the inverse Fourier transform of echoes results in the range profile of each pulse burst $\hat{r}(t)$.

$$\hat{r}(t)=\sum_{n=0}^{N-1}R(n)e^{j2\pi f_n t}=\sum_{p=0}^{P-1}\sigma_p\Gamma(t-t_p)e^{j2\pi f_c(t-t_p)},\qquad \Gamma(t)=\frac{\sin\left(\pi N\Delta f t\right)}{\sin\left(\pi\Delta f t\right)},t_p=\frac{2r_p}{c} \tag{2}$$

Along the azimuth direction in range cell *p*, there are *M* scatters with RCS value ρ_{pm} at (x_p,y_m) respectively, $m=0,1,2,..,M-1$, as shown in figure 1, we can get $\sigma_p=\sum_{m=0}^{M-1}\rho_{pm}\delta(y-y_m)$.

In range cell *p*, which is r_p distance from the radar, the demodulated data can be written as

$$\hat{r}_p(u)=\sum_{m=0}^{M-1}\rho_{pm}e^{-j\frac{2\pi}{\lambda' r_0}(u-y_m)^2}=\left(\sum_{m=0}^{M-1}\rho_{pm}\delta\left(u-y_m\right)\right)*\left(e^{-j\frac{2\pi}{\lambda' r_0}u^2}\right),\lambda'=\frac{c}{N\Delta f} \tag{3}$$

u is the radar location along the *y* axis.
In spatial frequency domain, the Eq.(3) can be formulated as

$$\hat{R}_p(k)=R_p(k)\Xi(k) \tag{4}$$

According to Eq.(4), the RSA is designed as follows:

Step 1. Calculate the reference signal $\xi(u)=e^{-j\frac{2\pi}{\lambda' r_0}u^2}$;

Step 2. Calculate the echo's spatial frequency spectrum $\hat{R}_p(k)$ and spatial frequency spectrum $\Xi(k)$ of $\xi(u)$;

Step 3. Let $\tilde{R}_d(k)=\sum_{p=0}^{P-1}\hat{R}_p(k)/\Xi(k)$

Step 4. Calculate the inverse Fourier transform of $\tilde{R}_d(k)$, then the image is constructed.

The calculation amount of RSA is $(2M+1)N\log_2 N+MN^2$, $N=\lceil \lambda r_0 PRF/DV\rceil$ is the burst numbers and *M* is the pulse numbers within one burst, *D* is the antenna length and *V* is radar's motion velocity. From Eq (3) and (4) we can deduce that the azimuth resolution by RSA is V/PRF,while the azimuth resolution by the traditional RDA is $D\lambda'/(2\lambda)$, λ is the carrier wavelength.

3. SIMULATION RESULTS

The radar parameters are shown in table 1. Suppose a virtual stationary 3.6*m*×9.4*m* tank exists in the simulation scenario, and the imaging scene is a 20*m*×20*m* square zone which is 4500*m* away from the radar. Figure 2 shows the imaging result by the traditional RDA, the azimuth resolution is 16.7*m*, while figure 3 shows the imaging results by RSA, by which the azimuth resolution is 0.35*m*. It shows that the RSA algorithm can get finer azimuth resolution than the traditional RDA algorithm.

Table 1. Simulation Radar Parameters

Carrier Frequency f_c	10GHz
Stepped Frequency Δf	120KHz
Stepped Frequency Number M	250
Pulse Width τ_p	20us
Radar Antenna Length D	1m
Radar Moving Velocity V	70m/s
Burst PRF	200Hz

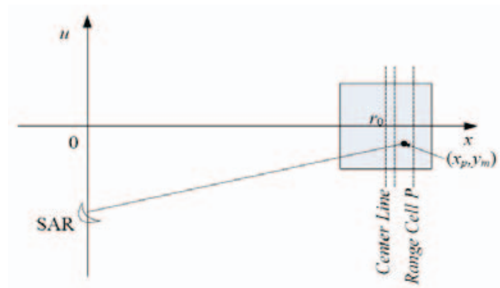

Figure 1. Imaging Geometry

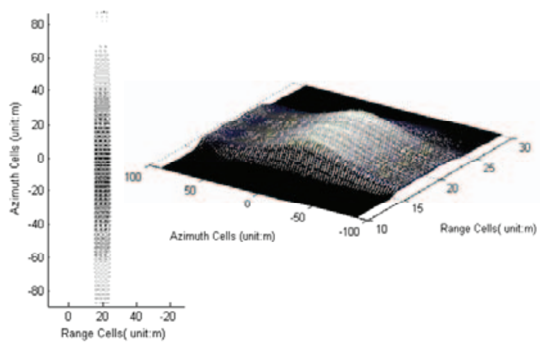

Figure 2. Traditional RDA Imaging Result

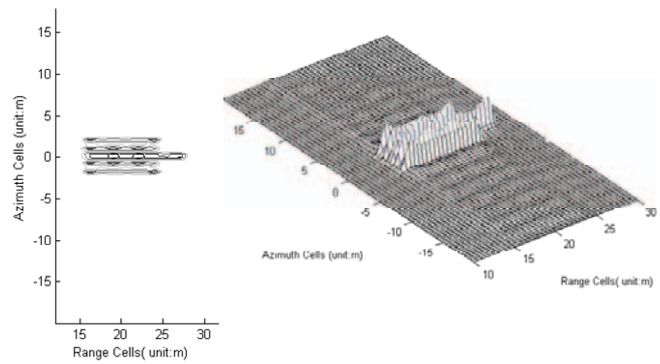

Figure 3. RSA Imaging Result

Figure 4 gives the correlation coefficient between the standard tank image and the tank imaging results with different velocities from -20m/s to 20m/s by RSA, it shows that RSA is almost insensitive to the motion status of targets. Figure 5 gives the correlation coefficient between the standard tank image and the tank imaging results by RSA when the receiver's SNR varies from -40dB to 20 dB, it shows that the target can be recognized when the SNR is more than 10dB.

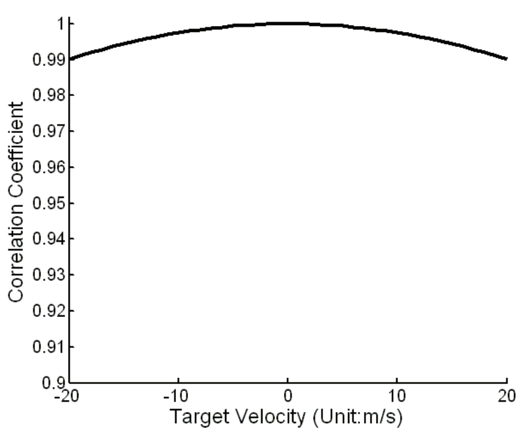

Figure 4. Correlation Coefficient Under Different Target Motion Velocity

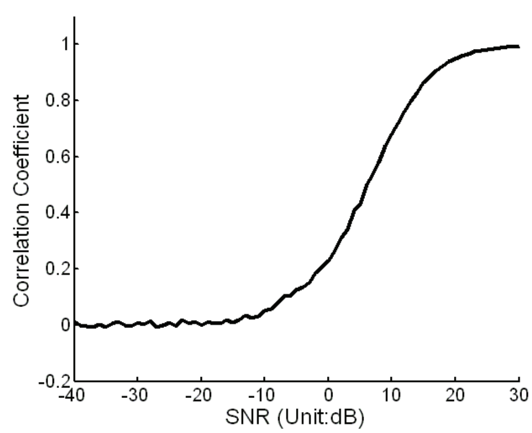

Figure 5. Correlation Coefficient Under Different SNR Of The Receiver

4. REFERENCES

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