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Time Frequency Analysis Using High Resolution Radar for Better Imaging of Maneuvering Targets

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Abstract: It is vital to image any given target with highest resolution so as to visualize the hotspots onboard and subsequently minimize the same to avoid any threat from the enemy, to visualize the given target better for suitable actions be it for agriculture, navigation, detection of different materials under the soil, etc. Imaging radar, like High Resolution Radar (HRR), offers a combatant the capability to perform long range surveillance with high quality imagery for positive target identification. To improve the time resolution, Time-Frequency Transform (TFT) methods of High Resolution Radar (HRR) imaging have been studied. Unlike traditional Fourier based processing time-frequency transform (TFT) allows variable time resolution of the entire event that falls within the HRR coherent integration period to be extracted as part of the imaging process. In this present work HRR imaging using time frequency transform to produce scattering or reflectivity centre's of maneuvering targets for different values of angular velocity and observation time, and it is observed that the cross range resolution has been improved.

Keywords: High Resolution Radar, Cross Range Resolution, Translational Motion, Rotational Motion.

I. INTRODUCTION

A radar target image is generated from the reflectivity or scattering data collected by a radar platform as the target is observed from a set of viewing angles. For Synthetic Aperture Radar (or SAR), the radar platform moves to give the imaging of remote targets which is observed at different target viewing angles, whereas High Resolution Radar (HRR) makes use of the target's angular rotations such as roll, pitch and yaw to collect the different target viewing angles for image generation. HRR imaging opens up the new possibility of using radar measurements to construct high quality images for target recognition purposes while the target (usually aircraft and ships) is moving and the radar platform remains essentially stationary. The classic two-dimensional High Resolution Radar image has the ability to display the hotspots that is scattering centers on the target.

II. RADAR TARGET IMAGING USING HRR

To construct a radar image from the reflectivity or scattering data, most HRR systems process the given information by performing a two dimensional Fast Fourier Transform (FFT). The first Fast Fourier Transform (FFT) generates the range profile of the target, and the second Fast Fourier Transform (FFT) extracts the Doppler information for each range cell. The resultant two-dimensional (2D) plot following this process would closely resemble an outline of the target, arising from the various reflectivity points around the target. The quality of the generated HRR image is directly related to the resolution imposed by the processing system. High range resolution can be achieved through pulse compression and Stepped Frequency Waveforms (SFW) is the most common methods used today. High cross-range resolution depends strongly on the variation in viewing angles which, in turn, increases with higher angular rate of target rotation and target dwell time.

However, a subtlety that affects the quality of the HRR image results from the requirement of minimum variation in the range over the different viewing angles between the radar platform and the target for cross-range synthesis.

The Range-Doppler algorithm is based on the assumption that the target is stationary and the reflected data are collected over a finite number of viewing angles. In real time, however, the target is usually in rotational motions (Pitch, Roll and Yaw motions) and therefore the unlike data can only be collected if the target's motion allows different viewing angles to the radar during the coherent integration time of the radar [2]. The radar usually sends frequency modulated pulse and stepped frequency continuous wave pulse waveforms to catch different viewing angles of the desired target. The movement of the target with respect to radar provides Doppler shift. After the radar receiver received the echo pulses from the target, the HRR image can only be formed in the two-dimensional Range-Doppler plot since the radar line of sight axis values in terms of angles with respect to target axis are unidentified to the radar [3].

III. TIME-FREQUENCY METHOD OF HRR IMAGING

Although Fourier Transform is very effective for demonstrating the content of a signal in frequency and it does not give the knowledge of variation in frequency over time. However, most of the real signals have time-frequency analysis content such as music and speech signals respectively. In almost these cases, the single-frequency sinusoidal bases are not suitable for the detailed time-frequency analysis of those signals. Therefore, Time-Frequency analysis methods were developed to represent these signals both in time and frequency to observe the frequency content as the time progresses [4].

There are many tools to image the time-domain or frequency-domain signal onto the Time-Frequency plane. Some of the most well-known Time-Frequency tools are the short-time Fourier transform, the Wigner–Ville distribution, the Choi-Willams distribution, the Cohen's

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class, and the time-frequency distribution series (TFDS). Among these, the most commonly used is the short-time Fourier transform or the spectrogram [4]. The STFT can easily display the variations in the frequency and phase content of local moments of a signal over time with sufficient resolution in most cases in terms of sinusoidal.

The short-time Fourier transform transforms the signal onto two-dimensional time-frequency analysis plane via the following equation:

$$STFT\{g(t)\} \triangleq G(t,f) = \int_{-\infty}^{\infty} g(\tau).w(\tau-t)e^{-j2\pi f\tau}\,d\tau \qquad (1)$$

This formula is nothing but the spectrogram version of the Fourier transform operation.

It is obvious that spectrogram will produce different signal outputs for different windows duration and this windows duration affects the resolution Time-Frequency domain and at the frequency domain the resolution becomes poor. This is fact that the duration of time and frequency bandwidth of a given signal is inversely proportional to each other. Similarly a good resolution in the frequency domain will be obtained for a long duration time signal. Similarly if we consider resolution in time domain will be poor. Therefore a compromise for the duration of the window in time domain which is able to view to view both time and frequency domains with good resolutions.

The window function with shape that has an effect with the resolutions and with sharp ends is chosen and their side lobes are strong in other domain. The waveform type windows which are smooth are usually used to obtain better resolved images.

IV. THEORY OF MOVING TARGET IMAGING IN HRR

A. HRR Geometry and its Relationship with the Returned Signal

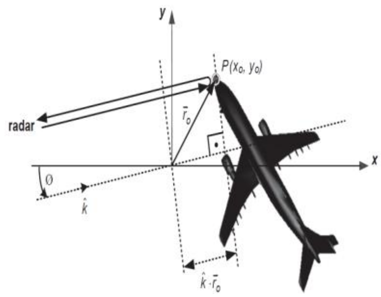

Fig 1. Geometry for HRR imaging in two-dimensional space.

The effect of the target's motion to the phase of the reflected wave and/or to the HRR image is examined based on the geometry illustrated in Figure 1. In the general case, the target may have both translational and rotational motion during the integration period of radar. For this reason, the point scatterer at $P(X_0, Y_0)$ on the target is assumed to have both translational and rotational motion components. According to the practical convention of high resolution radar imaging, the phase information is selected in the middle of the target and is assumed to be the origin [5].The algorithm for two-dimensional HRR imaging is provided. Let us start with the algorithm such that a point scatterer $P(X_0, Y_0)$ is assumed to be situated on the target as illustrated in Figure 1. Taking the origin as the phase center of the geometry, the distant-field reflected field from the point scatterer at an azimuth angle $\emptyset$ can be given as

$$E^s(K,\emptyset) = A_0.e^{-j2k\cos\emptyset.x_0}e^{-j2k\sin\emptyset.y_0} \qquad (2)$$

The High Resolution Radar image of the target can be found by taking the two-dimensional inverse Fourier integral of the two-dimensional reflected data as

$$HRR(x,y) = \int\int_{-\infty}^{\infty}\{E^s(K,\emptyset)\}.e^{j2\pi\left(\frac{2f}{c}\right)x}\,e^{j2\pi\left(\frac{k_c\emptyset}{\pi}\right)y}\,d\left(\frac{2f}{c}\right)d\left(\frac{k_c\emptyset}{\pi}\right) \qquad (3)$$

Assuming that the reflected signal can be represented by a total hotspot centers, the time-frequency analysis of High Resolution Radar image can then be approximated as

$$HRR(x,y) = \int\int_{-\infty}^{\infty}\sum_{i=1}^{M} A_i\,e^{-j2\vec{k}\vec{r}_1}e^{j2\pi\left(\frac{2f}{c}\right)x}e^{j2\pi\left(\frac{k_c\emptyset}{\pi}\right)y}\,d\left(\frac{2f}{c}\right)d\left(\frac{k_c\emptyset}{\pi}\right)$$

$$= \sum_{i=1}^{M} A_i\int\int_{-\infty}^{\infty} e^{-j2\vec{k}\vec{r}_1}e^{j2\pi\left(\frac{2f}{c}\right)x}e^{j2\pi\left(\frac{k_c\emptyset}{\pi}\right)y}\,d\left(\frac{2f}{c}\right)d\left(\frac{k_c\emptyset}{\pi}\right)$$

$$= \sum_{i=1}^{M} A_i\int\int_{-\infty}^{\infty} e^{j2\pi\left(\frac{2f}{c}\right)(x-x_i)}e^{j2\pi\left(\frac{k_c\emptyset}{\pi}\right)(y-y_i)}\,d\left(\frac{2f}{c}\right)d\left(\frac{k_c\emptyset}{\pi}\right)$$

$$= \sum_{i=1}^{M} A_i\,\delta(x-x_i, y-y_i).$$

Therefore, the resultant time-frequency analysis HRR image is composed of nothing but the sum of M reflecting centers with their reflectivity coefficients.

V. RESULTS

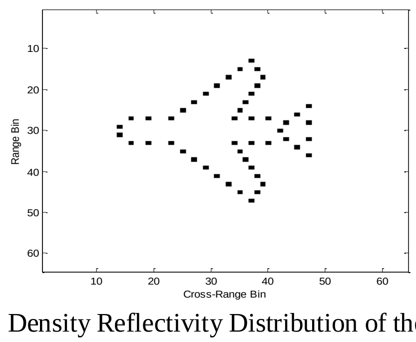

Fig 2. Density Reflectivity Distribution of the Target Scattering Points

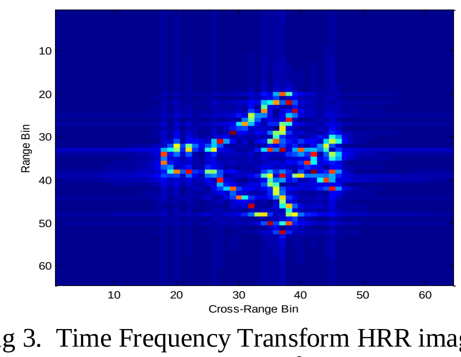

Fig 3. Time Frequency Transform HRR image at an angle 0^0

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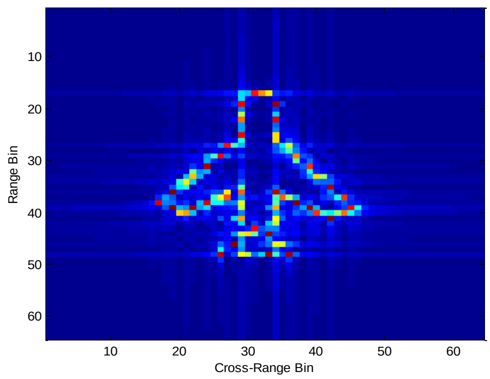

Fig 4. Time Frequency Transform HRR image at an angle 90^0

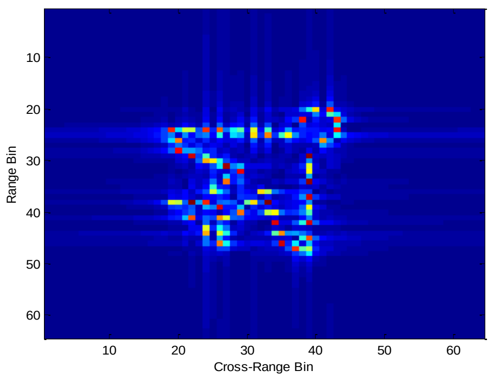

Fig 5. Time Frequency Transform HRR image at an angle 135^0

Density distribution function and including Image obtained of the target under study are obtained using software code developed on MATLAB platform and are shown in figures 2,3,4 and 5.

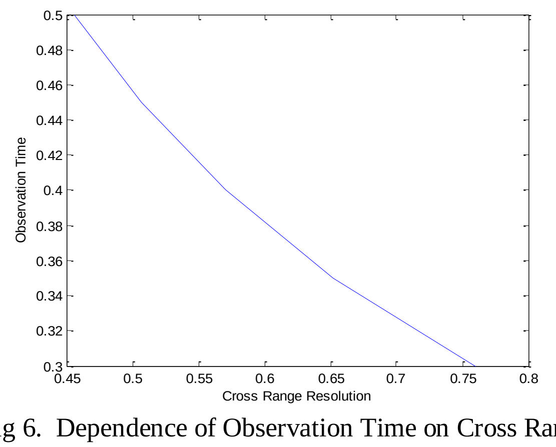

Fig 6. Dependence of Observation Time on Cross Range Resolution

Variation of observation time with cross range resolution has been computed on MATLAB platform using the formulation developed in [9], and is shown in figure 6. As expected, it is observed that the observation of integration time almost has inverse relationship with cross range resolution.

VI. CONCLUSION

The significant advantage of High Resolution Radar as opposed to other types of sensors is its ability to produce high resolution target images at greater surveillance ranges than optical systems. However, most High Resolution Radar images are generally static in nature and require relatively long processing periods to construct. The feature of the image is often fixed to the processing time and the prior conditions associated with the processing. The primary of these conditions is the assumption that the received radar signal is reflected from a target with only constant angular velocity components (an assumption that is used to map the Doppler variation of the respective scattering points caused by the angular rotation to the cross-range position of the scattering points). Variation of cross range resolution has been tried by varying parameters like angular velocity, observation time and the results are found to be satisfactory. Variation of synthesis time with cross range resolution is observed. However further improvement in cross range resolution needs to be explored.

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