Performance Analysis of High Resolution Range Profile

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Abstract:
In this Paper, we address the formation of Range profile i.e., RCS distribution of the target along the radial distance, by using Stepped Frequency Modulation(SFM) with less instantaneous bandwidth compared with the total bandwidth. Motion effects of the target are compensated by performing range migration correction and Doppler compensation. Extraction of the range profile from the received echo is done by performing IFFT. The quality of the range profile image depends on various factors. The effect of range ambiguities, target rotation, Doppler compensation error on range profile have been discussed in this paper.

Keywords— Doppler, SFM

I. INTRODUCTION

High resolution in radar is an area of research and development in most recent years. High Resolution Range profile(HRRP) is one of the important features used in Automatic Target Recognition (ATR). HRRP can be done in many methods[1], but each method has its own limitations. HRRP provides the one dimensional signature of the object. The range resolution is determined by the bandwidth of the transmitted signal by using the concept called pulse compression and the range resolution is inversely proportional to its bandwidth. So, by increasing the bandwidth correspondingly the radar's range resolution can be increased, but A/D sampling rate should support the implementation of high resolution.Wideband radar pulsescomplicate the design of transmitters and receivers and also, such receivers are prone to interference from other sources.

Stepped-frequency waveform (SFM) has the ability to achieve large bandwidth for high range resolution by sequentially changing carrier frequency over pulses. This results in lowering the A/D sampling rate and reduces the requirement on instantaneous bandwidth while maintaining a large bandwidth.

For ATR, the target's HRR profile is compared with a set of HRR profiles stored in the template library or HRRP Database. This library or database consists of many HRR profiles obtained from stationary targets. Therefore any distortion of the target's HRR profile will cause a significant deterioration in the identification performance. The robustness in the formation of HRRP has a major impact on the ATR. The distortion in the HRR profile of the target arises due to various factors. To generate a robustHRRP prior information about the target is necessary. The accuracy of the prior information decides the robustness ofthe HRRP. Radial velocity effect on HRRP has been discussed by Li Haiying Yang Ruliang[2]. The following aspects which are going to effect the HRRP is going to be presented in this paper with the supported simulations.

- Complex targets
- Range ambiguities
- Scattered SNR
- Doppler sensitivity
- Target rotation

The structure of the paper is as follows: Formation of Range profiling by SFM, Performance analysis of above mentioned parameters for S- band with the simulation results and finally conclusion along with references.

II. FORMATION OF RANGE PROFILE

HRRP is formed by using SFM. The carrier frequency in each pulse is increased with a step less than or equal to the instantaneous bandwidth of each pulse, The stepped-frequency waveform consists of a series of N pulses, whose carrier frequency is increased from pulse to pulse in step size of $\Delta f$with the pulse repetition interval (Tr). The carrier frequency of the nth transmitted pulse is given by

$$f_n = f_0 + n * \Delta f \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

wheref_0 is the nominal spot-frequency, $n = 0,1 \ldots\ldots (N-1)$,N is number of pulses, and Δf is step size of the frequency increment, so that the entire bandwidth of the radar can be covered as shown in fig(1)

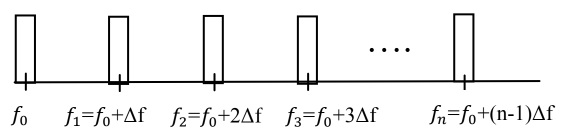

Fig. 1. Frequency change for HRRP pulses

The phase changes in the returned signal from pulse to pulse are caused by two factors i.e., the Doppler of the target and the carrier frequency change by a frequency step. The returned signal should be down converted in the radar receiver with the same transmitted carrier frequency. So always the pulse repetition frequency is chosen in such a way that the returned signal is first time around echo. So there is a compromise between the target range and the radar time to maintain coherency.

Supposing the target is stationary, when the frequency domain transmitted signal is converted to time domain using IFFT, the range profile of the target is formed. So the phase changes due to the Doppler of the target have to be removed. For this, the estimation of Doppler is required prior to the range profiling. A track on the target, in the radar data processing can provide the information of the Doppler.Motion of the target can cause the range migration, which is a shift in the range gates of the returned signal due to the high velocity of the target during the coherency time. By knowing the Doppler of the target from RDP, the shift in the range gates can be corrected. Matched filter is used to achieve the resolution of instantaneous bandwidth in each pulse individually by using linear frequency modulation. Then, across the pulses, for a particular coarse range gate IFFT is performed to extract the high resolution range profile. The process is shown in fig(2).

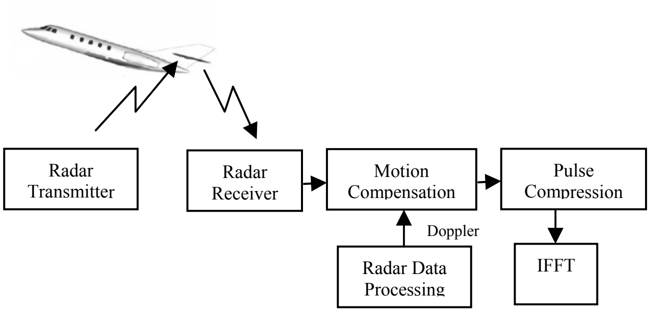

Fig. 2. Range Profile formation process

III. PERFORMANCE ANALYSIS OF RANGE PROFILE

The performance of the HRRP depends upon the design of HRRP i.e. internal design issues in the radar and the external issues with the target scenario and the environment. The internal design parameters

- Range ambiguities
- Doppler sensitivity

The external parameters of

- Complex target returns
- Target rotation
- Scatterer's SNR

are discussed in this paper.

i. Range ambiguities

In SFM the HRRP resolution is achieved by combining N pulses with frequencies of step$\triangle f$. The final range resolution achieved by HRRP is

$$\triangle R = \frac{c}{2 \triangle f(N-1)} \dots\dots\dots\dots\dots\dots\dots\dots (2)$$

Due to the sampling in the frequency domain at a rate of frequency step$\triangle f$, undesirable peaks arise at the intervals of $\triangle R_{am}$

$$\triangle R_{am} = \frac{c}{2 * \Delta f} \dots\dots\dots\dots\dots\dots. (3)$$

where c is the velocity of light and Δf is the frequency step. The targets which are in adjacent range gates with a higher SNR will appear in the range gate of interest as extra scatterers and may increase the length of the target as per HRRP. This will badly affect the performance of target recognition process

There are many ways to reduce the range ambiguity peaks. Andrew French has discussed about the Hybrid method to reduce the ambiguity peaks[3]. M R Walbridge, J Chadwick, DERA Malvern discussed with non-uniform frequency steps[4] for eliminating the range ambiguities, but above methods needs the design changes**.** A weighting function can be applied to reduce these ambiguities below the noise level to a greater extent.

ii. Doppler sensitivity

The accuracy of the Doppler used for motion compensation is very important aspect in the formation of HRRP. If the Doppler information which is used to compensate the phase changes is not the same of the physical Doppler of the target, there will be distortion in the Range profile. So it is very important to extract the exact Doppler from the target. A small error in the Doppler value will cause a shift in the range profile. But as the error increases the profile gets distorted. Though shift may not cause much performance degradation in the target recognition, distortion of the profile has to be avoided.

iii. Complex targets

A complex target is a target comprised of multiple scatterers at different ranges (i.e. more than range resolution). Since the resolution is more as compared to target length, it is no longer a point object. The target is assumed to have a strongscatterers, and multiple scatterers with low RCS spread along the targets radial length. In case of low SNR, the noise can develop local peaks competing with the true profile of the target. This will cause false scatters appearing in the profile.

iv. Target rotation

The relative motion between the target major scatterers with respect to Center Of Mass (COM) of the target will cause a small difference between the target's Doppler and the scatterers Doppler. This may not be estimated and compensated. When a target moves at a range rate of v towards the radar, and the forward scatterer was simulated as moving at a range rate of (v - Δv) whereas the rear scatterer was simulated at (v + Δv). This result in scatter's echoes moving towards each other, and the resolution gets compromised.

IV. SIMULATIONS AND DISCUSSION

The following radar parameters considered for the simulation

Carrier frequency	–3.2-3.5 GHz
Frequency step	– 5MHz
Total bandwidth	–300MHz
Instantaneous Bandwidth	– 10MHz
Number of pulses	– 60
PRF	– 2 kHz

i. Range Ambiguities

As per equation(2) and the radar parameters, the range resolution is 0.5m with 5MHz frequency step, but the range ambiguities occurs at every 30 m as shown in fig(3). The range ambiguities strength has been reduced by applying a window and can be observed the ambiguity peaks are very less as compare to the main peak.

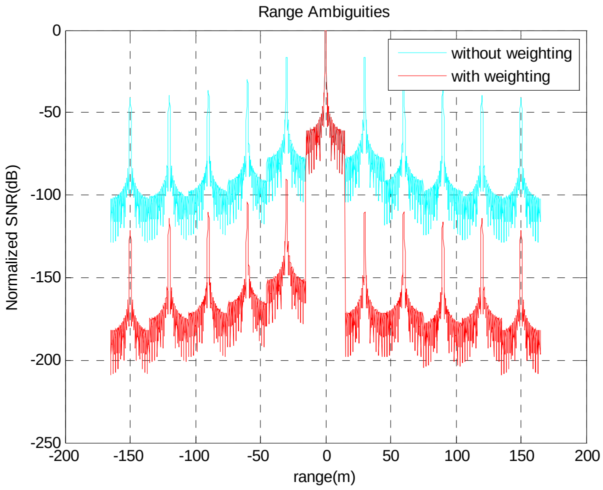

Fig. 3. Range ambiguities in the range profile

ii. Doppler sensitivity

The effect of the Doppler compensation error has been shown in fig(4). It can be noticed that as error increases the peak location is changing and the profile shape is distorting. The SNR of the target also reduces as the error increases. The same can be noticed from 0 m/s graph to 20 m/s graph.

iii. Complex targets

As per the simulation parameters the range profile resolution 0.5m, Here, we simulated Complex target with four scatterers of ranges as -2, 0, 0.5 ,5 meters. From fig(5), we can notice that the scatterers which are more than the resolution are able to develop the peaks and other scatterers merges.

A target comprised of two scatterers with 2m apart and with 3dB difference is simulated against noise at several scenarios of SNR level is shown in the fig(6). As the SNR decreases the noise forms local peaks competing with dominant peaks. For a better HRRP higher SNR is demanded.

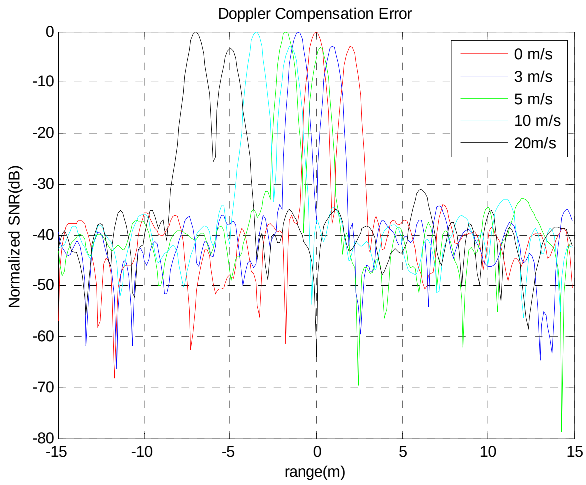

Fig. 4. Doppler Compensation error effect

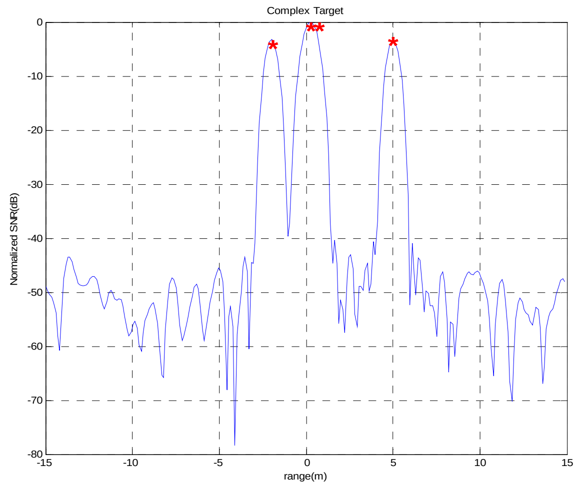

Fig. 5. Complex targets HRRP

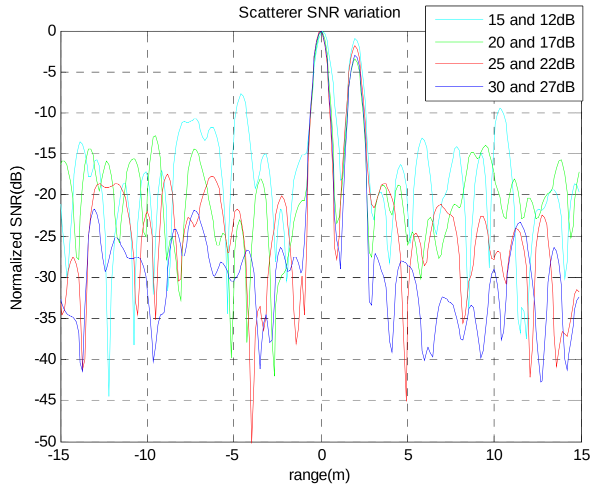

Fig. 6. Effect of SNR

iv. Target Rotation

The effect of target rotation on HRRP has shown with two dominant scatterers of distance 2m for various relative velocities. It can be observed that as the relative velocity increases the profile distorts and look like a different profile and the resolution changes as shown in fig(7).

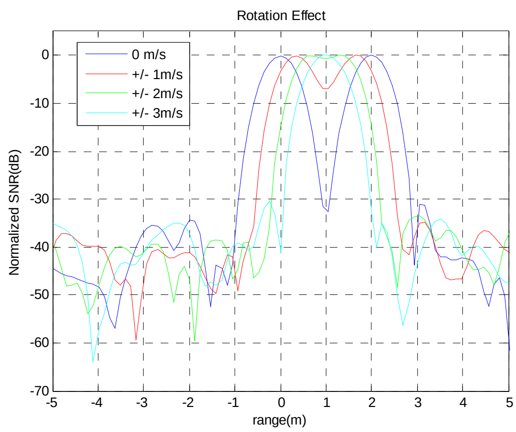

Fig. 7. Target rotation effect

V. CONCLUSION

In this paper, the formation of High Resolution Range Profile from the Radar signals is discussed. The performance of range profile under various aspects is discussed with simulation results for S-band radar. While using range profile as the feature vector for Automatic Target Recognition, these issues may degrade the performance and have to be attended for more accurate recognition.

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