Statistical Analysis of Target Detection using TRT-SGRFT

T Jagadeesh, B Sheela Rani

ABSTRACT: This paper proposes novel methodology for target detection and motion parameter estimation for a maneuvering target. Noise like interference may inculate few difficulties such as Range Migration (RM) and Doppler Frequency Migration (DFM). This paper proposes a novel method to overcome the issue. The method is to use Time Reversing Transform (TRT) and special generalized Radon Fourier transform (SGRFT), i.e., TRT-SGRFT. TRT separates the motion parameters and reduces the clutter. Then the SGRFT operation is employed to estimate part of the motion parameters. This method ensures a good tradeoff between the computational cost and estimation performance. Finally, simulations results are discussed to demonstrate the numerical results.

I. INTRODUCTION

As the technology develops in the field of moving target detection techniques, there is a need for new advanced techniques in radar signal processing. First, targets such as Missiles, Fighter Jets, Drones etc., have become high-speed targets and are becoming difficult to detect. Second, high-order motions of the target hinder imaging capability of the radar and it must be compensated. Third, long illumination time, used by radars for best possible detection, provides radar an inability to avoid acceleration and jerk. These factors compel development in the radar technology. The maneuvering targets are made up of low radar cross section, as the return radar signal maneuvering target is weak in turn it is arduous to make target detection and estimation. This can be overcome by the radar’s long coherent observation time. Motion parameter estimation such as speed, motions etc causes range migration and doppler frequency migration. Hence it is arduous to incorporate coherent integration method. So it is crucial to develop coherent integration method for providing better stability.

The analysis of available methods for migration correction and coherent integration are presented as follows: The coherent accumulation for a moving target with constant velocity using keystone transform (KT) and Radon Fourier transform (RFT) are the two methods. These novel techniques have widespread drawbacks. The other technique focuses on achieving the coherent integration for a target with constant acceleration motion. Fractional Fourier Transform based on axis rotation algorithm eliminates weak targets.

Fractional Fourier transform (FRFT) is done for eliminating the effects of jammer noise. FRFT is performed to nullify the effect of DFM. FRFT deals with eliminating the jammer noise in the presence of severe clutter environment. For this case, generalized Radon Fourier transform (GRFT) is used to obtain the motion parameter estimation. But GRFT has high computational costs. Alternatively, adjacent cross correlation function (ACCF) is used for lower computational cost. The ACCF based technology will have high impact on input SNR.

The analysis projects a conclusion that neither of available methods is reasonable for weak target detection. The analysis is done by detecting the targets in high order motions. A new method is proposed based on TRT-SGRFT to detect the motion parameters of severe clutter target. This method reduces the false targets and improves SNR and probability of false alarm. Moreover, it is superior in its detection ability compared to methods discussed in the analysis.

II. SIGNAL MODEL AND GRFT

Consider the linearly frequency modulated radar transmitted signal as

\[ S(f, t_m) = \text{rect}\left(\frac{t}{T_p}\right) \exp\left[j2\pi f_c(t + t \text{D})\right] \exp\left(j\pi f_c^2 t^2\right) \]

Where \( m \) is the total number of radar pulses, the slow time, \( M \) is the number of radar pulses and is assume to be even; \( \epsilon \) is the doppler time, \( T_p \) is pulse time and \( f_c \) is center frequency the pulse duration, FM rate and carrier frequency.

Consider a moving target in the an area and the instantaneous slant range between the radar and target be \( R(t, m) \). The slant range is modeled as polynomial function given by

\[ R(t_m) = a_0 + a_1 t_m + a_2 t_m^2 + \ldots + a_N t_m^N, \]

Let this be (2), where \( a_0 \) denotes the initial slant range, \( a_1, a_2, \ldots, a_N \) are the coefficients of target.

The received signal, after pulse compression is given by

\[ S(t, m) = A \text{rect}\left(\frac{t - 2n(t)}{\epsilon}\right) \exp\left(-\frac{4\pi n f_c R(t)}{c}\right) \]

\[ \exp\left(\frac{f_c t^2}{\epsilon}\right) \]

(3), where \( A \) is the amplitude of pulse compressed signal, and \( B \) is the signal bandwidth.

From Eq. (3), the target’s complex motions \( (a_1, a_2, \ldots, a_N) \) will have serious impact on signal strength in terms of signal to noise ratio and clutter.
rejection ratio which has widespread impact on probability of false alarm and probability of detection. The GRFT is used to estimate the moving parameters,

$$S(\hat{t}, t_m) = A \operatorname{sinc} \left[ B \left( \hat{t} - \frac{2}{c} \right) \right] \sum_{p=0}^{N} a_p t_m^p \ast \exp \left( -j \frac{2 \pi f_c}{c} \right) \tag{4}$$

where \( b_0, b_1, ..., b_N \) denote the searching parameters. Substituting (3) into (4) and taking argument of resulting equation

$$(\hat{a}_0, \hat{a}_1, ..., \hat{a}_N) = \arg\max_{b_0, b_1, ..., b_N} |\operatorname{GRFT}(b_0, b_1, ..., b_N)| \tag{5}$$

Target motion parameters can be estimated based on coherent detection.

III. PARAMETERS ESTIMATION VIA TRT-SGRFT

First, the signal in (3) is fourier transformed with variable \( \hat{t} \) to \( S(f, t_m) \). Then a new signal is generated based on slow time, i.e.,

$$S(f, t_m) = A_2 \text{rect}(\frac{f}{B}) \exp \left[ -j \frac{2 \pi f}{c} + j \left( a_0 + a_1 \frac{M}{2} + ... + \frac{M}{2} \frac{T_r}{2} + a_0 \frac{M}{2} + ... + \frac{M}{2} \frac{T_r}{2} + \cdots \right) \right] \tag{6}$$

as where the symbol ← represents time reversing operation. On multiplying \( S(f, t_m) \) and (6), yields TRT. Taking TRT inverse fourier transform with variable \( f \) gives (7)

$$T(\hat{t}, t_m) = A_3 \operatorname{sinc} \left[ B \left( \hat{t} - \frac{4}{c} \sum_{p=0}^{P/2} a_p t_m^{2p} \right) \right] \times \exp \left( -j \frac{8 \pi f_c}{c} \sum_{p=0}^{P/2} a_p t_m^{2p} \right) \tag{7}$$

Compare (7) and the compressed signal (3), the motion parameters can be estimated with low computational complexity. The TRT Transformed signal is applied to SGRFT function and simplification yields (8)

$$\text{SGRFT}(b_0, b_1, ..., b_p) = \sum_{m=\text{-M}}^{M} A_3 \operatorname{sinc} \left[ B \left( \hat{t} - \frac{4}{c} \sum_{p=0}^{P/2} a_p t_m^{2p} \right) \right] \times \exp \left[ -j \frac{8 \pi f_c}{c} \sum_{p=0}^{P/2} (b_{2p} - a_{2p}) t_m^{2p} \right] \tag{8}$$

If the searching parameters match the target’s motion parameters, then output of SGRFT would be maximized. Thus, \( a_1, a_2, ..., a_p \) could be estimated by

$$(\hat{a}_1, \hat{a}_2, ..., \hat{a}_p) = \arg\max \text{SGRFT}(b_0, b_1, ..., b_p) \tag{9}$$

With the estimated parameters \( \hat{a}_1, \hat{a}_2, ..., \hat{a}_p \) the second SGRFT is performed on (3), i.e.,

$$\text{SGRFT}(b_0, b_1, ..., b_p) = \sum_{n=\text{-M}}^{M} \sum_{p=0}^{P/2} (b_{2p} - a_{2p}) t_m^{2p} + \sum_{p=0}^{Q-1/2} b_{2p+1} t_m^{2p+1} \tag{10}$$

Substituting (3) in (10), when the searching parameters are matched with target’s motion parameters, the residual motion parameters \( a_{2p}, a_{2p+1} \) can be estimated by

$$(\hat{a}_{2p}, \hat{a}_{2p+1}) = \arg\max \text{SGRFT}(b_0, b_1, ..., b_p) \tag{11}$$

From the above results, the computational complexity gets reduced. Therefore, the computational complexity of TRT-SGRFT can be reduced. The flowchart in fig. 1 gives the flowchart for target detection using TRT-SGRFT.

Step1: Apply pulse compression operation on received signal.
Step2: Apply doppler filtering on the pulse compressed signal.
Step3: Perform time reversing operation and estimate the parameters.
Step4: Compare the vaules with adaptive threshold based on CFAR detector.

$$\text{CFAR Detection}$$

where, \( \eta \) is the CFAR threshold and \( C(.) \) denotes the output of first SGRFT.

Step5: If the test results are larger than threshold, target detection is working properly. Then perform second TRT-SGRFT.
Step6: If the results are smaller than threshold, then there is no target.

Fig. 1. Flowchart of the detection procedure using TRT-SGRFT.
Remark 1.
In this paper, we assume that there is no target fluctuation. This algorithm works well for non-fluctuating target.

Remark 2
This algorithm works well for high input SNR and has better trade-off in computational complexity. Therefore, we may need to select the coherent integration method according to the real application situation.

IV. NUMERICAL RESULTS
The proposed algorithm (i.e., TRT-SGRFT) is computed for severe clutter environment. It could be seen that serious RM (range walk and range curvature) occurs. By applying TRT and SGRFT, the SNR gets improved and false alarms got reduced. The reason, why methods discussed in the analysis failed because, higher order motions were not considered. In other words, they are all mismatched for the target with complex motions. It is concluded that the target’s SNR is having two peaks in the output.

<table>
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<tr>
<th>Parameters</th>
<th>Existing System</th>
<th>Proposed System</th>
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<tr>
<td>Initial SNR (dB)</td>
<td>-939.2168</td>
<td>-755.5412</td>
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<tr>
<td>SNR after Clutter Suppression (dB)</td>
<td>-181.6161</td>
<td>-69.0371</td>
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<td>SNR after Sidelobe Blanking (dB)</td>
<td>-172.0032</td>
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<tr>
<td>SNR after Sidelobe Cancellation (dB)</td>
<td>-82.5464</td>
<td>26.42</td>
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<td>Estimated Target Parameters</td>
<td>[4500000 1000000 70000 70000]</td>
<td>[4500000 1000000 70000 70000]</td>
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<tr>
<td>Probability of False Alarm</td>
<td>1.24e-09</td>
<td>6.2465e-06</td>
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<td>Jammer Cancellation Ratio</td>
<td>1.077e04</td>
<td>1.5743e6</td>
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<td>Peak Sidelobe Levels for Stationary Target</td>
<td>3.699</td>
<td>2.889</td>
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V. CONCLUSIONS

A novel algorithm for moving target detection and parameter estimation is presented. This algorithm can make compromise between computational complexity and motion parameter estimation.

REFERENCES


AUTHORS PROFILE

Mr. Jagadesh T is a research scholar at Sathyabama Institute of Science and Technology. He has done M.E VLSI Design in Kongu Engineering College and B.E ECE in Jeppiaar Engineering College. He is currently pursuing his research in Radar Signal Processing. His areas of interest are VLSI Signal Processing, ASIC Design and CAD for VLSI Circuits. He has published 16 papers in various scopus indexed journal, 7 papers in IEEE International Conference. He has conducted 2 workshops using MATLAB. He worked as Assistant Professor in Jeppiaar Engineering College from 2014 to 2018 and joined in KPR Institute of Engineering and Technology in June 2018.

Dr. B. Sheela Rani was born on November 21, 1966 in Chennai. With a passion towards teaching, she started her career in 1989 as a lecturer and has been with the Institution for over twenty-five years in various academic and leadership positions as Professor, Faculty Head and as Dean (Research). With a strong technical expertise, she acquired M.S (By Research) and Ph.D degree from Anna University, College of Engineering Chennai, in 2001. By virtue of working for a considerable number of years in the academic and research arena, she reached the position of the Vice Chancellor of SATHYABAMA and assumed office in April 2011.