

Statistical Analysis of Target Detection using TRT-SGRFT



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ABSTRACT: This paper proposes novel methodology for target detection and motion parameter estimation for a maneuvering target. Noise like interference may inculcate 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

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

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; \hat{t} 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

$$R(t_m) = a_0 + a_1 t_m + a_2 t_m^2 + \dots + a_N t_m^N,$$

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

The received signal, after pulse compression is given by $S(t, m) =$

$$A \text{rect}\left[\frac{\hat{t} - \frac{2R(t)}{c}}{T_p}\right] \exp\left(\frac{-j4\pi f_c R(t)}{c}\right) * \exp\left(\frac{j\pi\gamma}{c}\right)$$

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

From Eq. (3), the target's complex motions ($a_1, a_2 \dots a_N$)

Manuscript published on 30 September 2019

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will have serious impact on signal strength in terms of signal to noise ratio and clutter rejection ratio which has wide-spread impact on probability of false alarm and probability of detection.

The GRFT is used to estimate the moving parameters,

$$S(\hat{t}, t_m) = \tilde{A} \operatorname{sinc} \left[B \left(\hat{t} \frac{2}{c} \right) \sum_{p=0}^N a_p t_m^p \right] * \exp \left(\frac{-j4\pi f_c}{c} \right) \quad (4)$$

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

$$(\hat{a}_0, \hat{a}_1, \dots, \hat{a}_N) = \operatorname{argmax}_{b_0, b_1, \dots, b_N} |GRFT(b_0, b_1, \dots, b_N)|. \quad (5)$$

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,

$$\begin{aligned} \overleftarrow{S}(f, t_m) &= A_2 \operatorname{rect} \left(\frac{f}{B} \right) \exp \left\{ -j \frac{4\pi}{c} (f + f_c) \left[a_0 + a_1 \left(\frac{M}{2}, \dots, 1, 0, -1, \dots, -\frac{M}{2} \right) T_r + a_2 \left(\frac{M}{2}, \dots, 1, 0, -1, \dots, -\frac{M}{2} \right)^2 T_r^2 + a_3 \left(\frac{M}{2}, \dots, 1, 0, -1, \dots, -\frac{M}{2} \right)^3 T_r^3 + \dots + a_N \left(\frac{M}{2}, \dots, 1, 0, -1, \dots, -\frac{M}{2} \right)^N T_r^N \right] \right\}, \end{aligned} \quad (6)$$

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

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

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)

$$\begin{aligned} \operatorname{SGRFT}(b_0, b_1 \dots b_p) &= \sum_{m=-\frac{M}{2}}^{\frac{M}{2}} A_3 \operatorname{sinc} \left\{ B \left[\frac{4}{c} \sum_{p=0}^P (b_{2p} - a_{2p}) t_m^{2p} \right] \right\} \times \exp \left[j \frac{8\pi}{c} f_c \sum_{p=0}^{\frac{P}{2}} (b_{2p} - a_{2p}) t_m^{2p} \right]. \end{aligned}$$

If the searching parameters match the target's motion parameters, then output of SGRFT would be maximized. Thus, $a_1, a_2 \dots a_p$ could be estimated

$$(\hat{a}_0, \hat{a}_2, \dots, \hat{a}_p) = \operatorname{argmax}_{b_0, b_2, \dots, b_p} |\operatorname{SGRFT}(b_0, b_2, \dots, b_p)|. \quad \text{by(9)}$$

With the estimated parameters $\hat{a}_1, \hat{a}_2 \dots \hat{a}_p$ the second SGRFT is performed on (3), i.e.,(10)

$$\operatorname{SGRFT}(b_1, b_3, \dots, b_Q) = \sum_{m=-\frac{M}{2}}^{\frac{M}{2}} s \left(\frac{2}{c} \sum_{p=0}^{P/2} \hat{a}_{2p} t_m^{2p} + \frac{2}{c} \sum_{q=0}^{(Q-1)/2} b_{2q+1} t_m^{2q+1} \right) \times \exp \left[j \frac{4\pi f_c}{c} \left(\sum_{p=0}^{P/2} \hat{a}_{2p} t_m^{2p} + \sum_{q=0}^{(Q-1)/2} b_{2q+1} t_m^{2q+1} \right) \right]$$

Substituting (3) in (10), when the searching parameters are matched with target's motion parameters, the residual motion parameters $a_1, a_2 \dots a_Q$ can be estimated by

$$(\hat{a}_1, \hat{a}_3, \dots, \hat{a}_Q) = \operatorname{argmax}_{b_1, b_3, \dots, b_Q} |\operatorname{SGRFT}(b_1, b_3, \dots, b_Q)|. \quad (11)$$

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 apdative threshold based on CFAR detector.

$$\begin{matrix} H_1 \\ |C(\cdot)| \geq \eta \\ H_0 \end{matrix}$$

where, η is the CFAR threshold and $C(\cdot)$ 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.

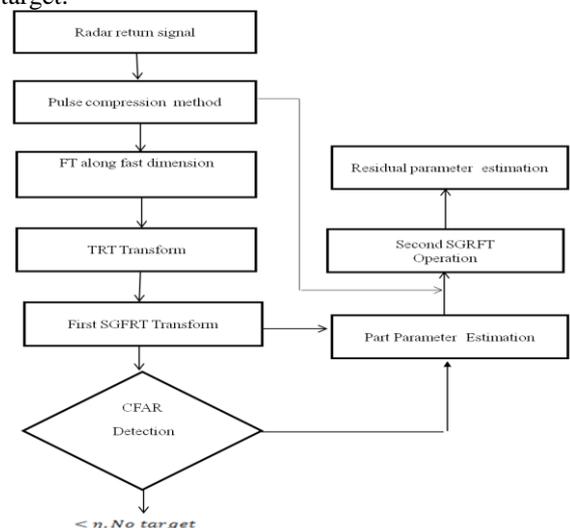


Fig.1. Flowchart of the detection procedure using TRT-SGRFT



Remark 1.

In this paper, we assume that there is no target fluctuation. This algorithm works well for non-fluctuating target.

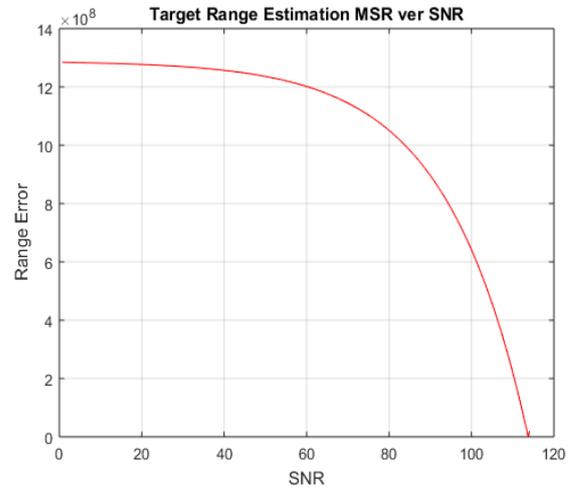
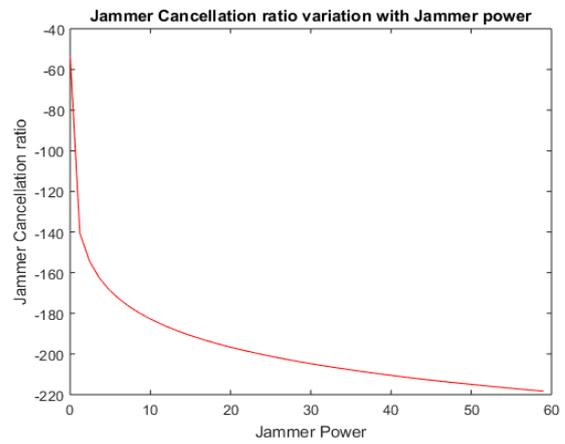
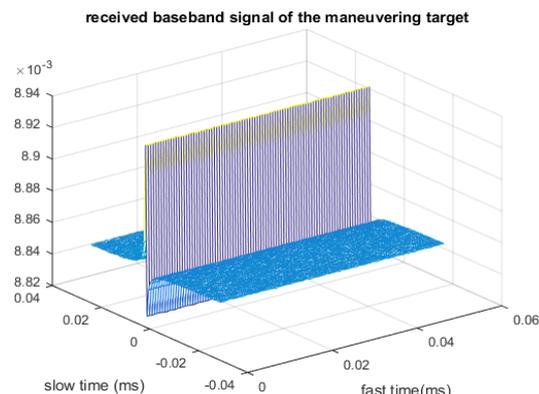
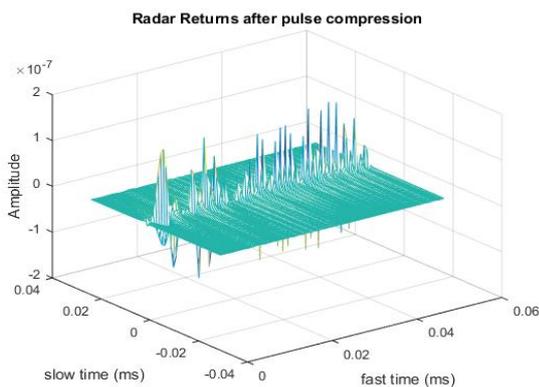
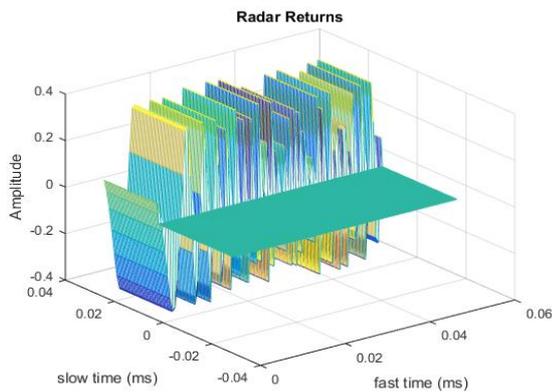
Remark 2

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.



S No	Parameters	Existing System	Proposed System
1.	Initial SNR (dB)	-939.2168	-755.5412
2.	SNR after Clutter Suppression (dB)	-181.6161	-69.0371
3.	SNR after Sidelobe Blanking (dB)	-172.0032	-59.4296
4.	SNR after Sidelobe Cancellation (dB)	-82.5464	26.42
5.	Estimated Target Parameters	[4500000 10000000 700000 70000]	[4500000 10000000 700000 70000]
6.	Probability of False Alarm	1.24e-09	6.2465e-06
7.	Jammer Cancellation Ratio	1.077e04	1.5743e6
8.	Peak Sidelobe Levels for Stationary Target	3.699	3.699

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.

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