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Moving Target Detection in Multichannel SAR Framework using Adaptive Neuro Fuzzy Decisive Technique

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Abstract: ***Precise and efficacious detection of moving targets is a prominent task in on-going synthetic aperture radar (SAR) technique. The perception of moving object allows quite significant data about the situation under observation for both surveillance and intelligence activities. The task of accurately locating moving targets against strong background clutter in minimum of time is of utmost interest in the current research area. Fractional Fourier Transform (FrFT) concentrates the energy of the required chirp signal so that it can be well separated from the chirp like noise. The proposed SAR Moving Target Detection (MTD) process is based on the combination of FrFT with the adaptive-neuro fuzzy decisive technique. The correlation among the received signal and the FrFT of the received signal are computed which maximizes the required signal energy and applied to the adaptive-neuro fuzzy decisive module that detects the target location adaptively using the fuzzy linguistic rules. The simulation is performed by changing the number of targets, different Pulse repetition intervals, antenna turn velocity, iterations and the analysis is carried out based on the metrics, like detection time, missed target rate, and Mean Square Error (MSE), proving that the proposed Adaptive-Neuro Fuzzy-based MTD process detected the object in 5.0237 secs with a minimum missed target rate of 0.1210 and MSE of 23377.48.***

Index Terms: ***Adaptive-Neuro Fuzzy MTD, multichannel SAR, FrFT, correlation, Ambiguity function***

I. INTRODUCTION

The use of multiple (concurrent) channels to generate information is used in the next generation of spaceborne SAR after centuries of achievement for the classic single-channel SAR working in different frequency bands [1]. Against a strong clutter background, the knowledge of the moving target gives quite important information of the scenario under observation for both monitoring and intelligence operations [2]. With the development of the Fractional Fourier Transform (FrFT) theoretical system, FrFT is widely used in quantum mechanics, photoelectric signal processing, artificial neural network, signal processing and so on [3-4]. It has better energy focusing ability than conventional Fourier Transform (FT) making it very suitable for processing non-stationary signals such as Chirp signal.

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The FrFT of chirp signals are more compact than that in the FT domain, which means that the sampling rate of chirp signals associated with the FrFT can be lower than that corresponding to the FT. The FrFT method yields the best refocusing capabilities [5] and computationally efficient [6] for SAR signals.

Compared to matching filter bank approach, applying FrFT to SAR signals is shown to be less biased and more robust[7] Accordingly, the fractional Fourier transform (FrFT) drags interest from the radar community that can be employed for MTD [8], beamforming [9], imaging [10], and waveform generation [11]. While concentrating on MTD, the echo of the moving target is considered as a chirp signal, and the energy of the signal is computed using FrFT in the Doppler Centroid (DC)-Doppler Frequency Rate (DFR) domain. The computation of the energy of the signal tends to locate the target in the stationary contribution.

Fuzzy Logic concept is able to manage uncertainties and ambiguities implicit in the SAR system. The fuzzy logic system takes care of the data from various remote sensors data and creates a user friendly interface by an adaptive control which predicts uncertainties for upcoming remote sensing systems [12]. The fuzzy logic approach to SAR data not only handles to deal with the ambiguity of the SAR signature but also reliable results can be obtained by training the data [13].

The paper is organized as:

Section I introduces multichannel SAR MTD method of different approaches. The mathematical processing of SAR signals is shown in section II. Section III proposes adaptive neuro fuzzy decisive approach for moving target detection. Section IV deliberates the metrics used and the results and discussion are presented in section V. Finally, section VI concludes the paper.

II. MATHEMATICAL PROCESSING OF SAR SIGNALS

Synthetic aperture radar employs the Linear Frequency Modulated (LFM) wave that is given as[14],

$$u_r(x,s) = rect(s|p).\exp(j\pi.\chi s^2).\exp[j2\pi f_c(x+s)] \quad (1)$$

where, r is the average pulse repetition interval, x denotes the slow time, p specifies the width of pulse, χ is the modulation rate, and f_c is the frequency of carrier. The fast or range time is denoted as, s in equation (1). The $rect(a)$ is the rectangular function is given as

$$rect(\ ) = \begin{cases} 1 & ; \quad |a| \le \frac{1}{2} \\ 0 & ; \quad Otherwise \end{cases} \quad (2)$$

The slow time is given as,

$$x = [m + \rho(m')]r \; ; (m = 0,1,\ldots, M) \quad (3)$$

where, M denotes the total number of coherent integrated pulses and $\rho(m')$ denotes the random sequence which lies in certain range of m' such that it satisfies $m' = \mathrm{mod}(m, N) + 1; N(N < M)$ and this corresponds to the length of the random sequence. The received base band signal is given as,

$$u(x,s) = \gamma C \sin c\left[\pi.\beta\left(s - 2K(x) \times \frac{1}{c}\right)\right].\exp\left[-j4\pi K(x) \times \frac{1}{\lambda}\right] \quad (4)$$

where, γ is the backscattering coefficient, C denotes the range compression gains, and the speed of the light is denoted as, c. The bandwidth of the signal is denoted as, β, wavelength, $\lambda = \frac{c}{f_c}$.

$$\sin c(a) = \frac{\sin(a)}{a} \quad (5)$$

The instantaneous slant range, which is denoted as $K(x)$, is given as,

$$K(x) = K_0 - u_0 . x - b_0 . \frac{x^2}{2} \quad (6)$$

Substituting equation (6) in equation (4) implies,

$$u(x,s) = \gamma C \sin c\left[\pi.\beta\left(s - 2\left(\left[K_0 - w_0 . x - b_0 . \frac{x^2}{2}\right]\right) \times \frac{1}{c}\right)\right].\exp\left[-j4\pi\left[K_0 - w_0 . x - b_0 . \frac{x^2}{2}\right] \times \frac{1}{\lambda}\right] \quad (7)$$

$$u(x,s) = \gamma C \sin c\left[\pi.\beta\left(s - 2\left(\left[K_0 - w_0 . [m + \rho(m')]r - b_0 . \frac{[[m + \rho(m')]r]^2}{2}\right]\right) \times \frac{1}{c}\right)\right]. \quad (8)$$

$$\exp\left[-j4\pi \frac{K_0}{\lambda}\right] \times \exp\left[\left(j4\pi . w_0 . mr + \frac{b_0 (mr)^2}{2}\right) \times \frac{1}{\lambda}\right] \times$$

$$\exp\left[j4\pi \times \left(u_0 \rho(m').r + b_0\left[2m\rho(m')r^2 + [\rho(m')r]^2 \times \frac{1}{2}\right]\right) \times \frac{1}{\lambda}\right]$$

From the above equation (8), due to the radial velocity and radial acceleration of the target and based on the slow time, the signal envelope changes. Also, when the range offset is greater than the range resolution, the Range Cell Migration (RCM) results and Doppler spectrum is the result of radial acceleration that occurs when the frequency offset becomes greater than the frequency spectrum. Moreover, there is an oscillation in the frequency that is decomposed as follows,

$$\psi_1 = \exp\left\{j4\pi\left(u_0 . mr + \frac{b_0 (mr)^2}{2}\right) \times \frac{1}{\lambda}\right\} \quad (9)$$

$$\psi_2 = \exp\left\{j4\pi\left[w_0 . \rho(m')r + b_o\left[\left[(2m\rho(m'))r^2 + (\rho(m')r)^2\right] \times \frac{1}{2}\right]\right] \times \frac{1}{\lambda}\right\} \quad (10)$$

In equation 10, change in mr feds to the changes in the phase of the signal. Also, the changes in PRI $\rho(m')r$ results in the jittering phase of the pulses. The moving object cannot be detected accurately with alterations in the phase of the signals practically.

III. PROPOSED METHOD OF MOVING TARGET DETECTION USING THE ADAPTIVE NEURO FUZZY DECISIVE APPROACH

The main intention of the paper is to detect the moving objects using the FrFT based fuzzy decisive approach for Synthetic aperture radar signals. Radar transmits a sequence of pulses towards the objects to be detected and receiver receives the pulses in sequence. The location of the target is detected by knowing the delay in the received pulse from the transmitted pulse. Due to presence of noise, clutter etc., the radar signals changes their originality which requires processing of signals to detect the moving object location accurately within minimum time.

Here, to tackle signals with noise, Fractional FT of the received signal and then AF is applied. To obtain maximum energy of signal, correlation between FrFT signal and original signal is computed. Similarly the AF of MF output signal is correlated with original signal. Thus, two outputs are from matched filter and FrFT are fused using the adaptive neuro fuzzy decision approach. The fuzzy decision approach employs the fuzzy rules to disclose the moving target in the search space. Fig 1 shows the schematic diagram of the proposed method of MTD.

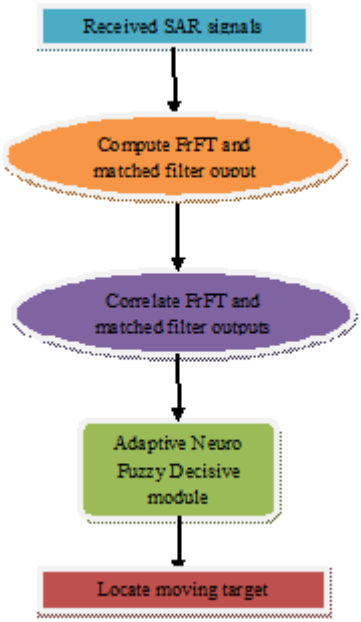


Fig 1. Flowchart for implementation of proposed Moving target detection (MTD)

A. Received SAR Signal processing using FrFT

Moving target detection in search space can be accurately located by applying FrFT to SAR signals which are chirp like signals. Chirp detection and chirp like noise suppression is one of the FrFT's most significant apps.

Consider the received continuous time signal, denoted as, $f(x)$ and the FrFT of $f(x)$ is denoted as, $T_\sigma(v)$. The received signal $f(x)$ undergoes sampling to form $f(x_m)$ such that it satisfies the following equation as,

$$f(x_m) = f(x). \sum_{m=-\infty}^{\infty} \partial(x - x_m) \quad (11)$$

On applying FrFT to $f(x_m)$, a sampled version of FrFT is obtained and is given as,

$$T_\sigma[f(x_m)](g) = \sum_{m=-\infty}^{\infty} X_\sigma(g, x_m) f(x_m) \quad (12)$$

$$X_\sigma(g,x_m)=\begin{cases} B_\sigma.\exp\left\{jx_m^2.\cot\frac{\sigma}{2}-jgx_m.\operatorname{cosc}\sigma+jg^2.\cot\frac{\sigma}{2}\right\} & ; \quad \sigma\neq \ell\pi \\ \partial(x_m-g) & ; \quad \sigma=2\ell\pi \\ \partial(x_m+g) & ; \quad \sigma+\pi=2\ell\pi \end{cases} \tag{13}$$

$$B_\sigma=\sqrt{\frac{(1-j\cot\sigma)}{2\pi}}\,;\ \sigma=\frac{n\pi}{2} \tag{14}$$

where, σ is the fractional angle and n specifies the fractional order. The received signal $f(x)$ with the uniform interval $x_m=m.r_w$ is written as,

$$T_\sigma[f(x_m)](g)=\frac{1}{r_w}.e^{j\frac{w^2}{2}.\cot\sigma}\left\{T_\sigma(g).e^{-j\frac{g^2}{2}\cot\sigma}*\sum_{m=-\infty}^{\infty}\partial\left(g-m\frac{2\pi.\sin\sigma}{r_w}\right)\right\} \tag{15}$$

where, r_w denotes the sampling interval and $*$ specify the complex conjugate operator. Equation (15) explains the relation between the continuous signal of FrFT and the uniformly sample signals of FrFT. The sampling points are sub-divided as l sample groups and the sum of the FrFT of the l uniform samples forms the FrFT of the non-uniform signal. Thus, according to equation (15), FrFT of the lth uniform sub-sample is given as,

$$T_\sigma[\overline{w_l}](g)=\frac{1}{Lr}e^{j.\frac{g^2}{2}.\cot\sigma}.\left\{T_\sigma[f(x+x_l)].(g).e^{-j\frac{g^2}{2}.\cot\sigma}*\sum_{m=-\infty}^{\infty}\partial\left[g-m\frac{2\pi.\sin\sigma}{Lr}\right]\right\} \tag{16}$$

Using the FrFT property, $T_\sigma[f(x+x_l)](g)$ is expressed as,

$$T_\sigma[f(x+x_l)](g)=T_\sigma[f(x)],(g+x_l.\cos\sigma)e^{j\left[\frac{1}{2}(x_l^2.\sin\sigma.\cos\sigma+g\,x_l\,\sin\sigma)\right]} \tag{17}$$

Using the equations (16) and (17), the FrFT of the uniform samples is given as,

$$T_\sigma[w](g)=\frac{1}{Lr}\sum_{m=-\infty}^{\infty}\sum_{n=0}^{N-1}R_\sigma\left[g-m\frac{2\pi\sin\sigma}{Lr}-p_l.r\cos\sigma\right]\times$$
$$e^{j.\frac{1}{2}r^2.p_l^2.\sin\sigma\cos\sigma}.e^{j\frac{2\pi m}{Lr}\cos\sigma\left(g-\frac{\pi m\sin\sigma}{Lr}\right)}.e^{-jp_l r.\sin\sigma\left(g-\frac{2\pi m\sin\sigma}{Lr}\right)}.e^{-\frac{j2\pi ml}{L}} \tag{18}$$

where, L denotes the non-uniform sampling points lying in the individual time period x_l. The average sampling period is denoted as r and the sampling time offset is $p_l\,r$. AF [15] is applied to the FrFT signal of the original time signal $f(x)$, and is given as,

$$F(s,f)=\frac{1}{|F(0,0)|}\int_{-\infty}^{\infty}T_\sigma[w](g)T_\sigma^*[w](g)e^{j2\pi fx}\,dx \tag{19}$$

$$F(0,0)=\int_{-\infty}^{\infty}T_\sigma[w](g)^2\,dx \tag{20}$$

where, $T_\sigma[w](g)$ is the FrFT signal of the received signal $f(x)$, $T_\sigma^*[w](g)$ is the complex conjugate of the FrFT signal with a time shift, and $F(0,0)$ denotes the normalization factor.

The maximum energy of the signal is obtained by computing the AF of the received signal and the FrFT of the received signal. The correlation processing is stated as,

$$Cor(s,f)=\frac{1}{|Cor(0,0)|}\int_{-\infty}^{\infty}f(x).f^*(x+s).e^{j2\pi f(x+s)}\,dx \tag{21}$$

$$Cor(s,f)=e^{j2\pi fs}\frac{1}{|Cor(0,0)|}\int_{-\infty}^{\infty}f(x).f^*(x+s).e^{j2\pi fx}\,dx \tag{22}$$

$$Cor(s,f)=e^{j2\pi fx}\frac{1}{A(0,0)}\int_{-\infty}^{\infty}f(x).f^*(x+s).e^{j2\pi fx}\,dx \tag{23}$$

$$Cor(s,f)=e^{j2\pi fx}A(s,f) \tag{24}$$

$$A(s,f)=e^{-j2\pi fx}.Cor(s,f) \tag{25}$$

$$|A(s,f)|=|Cor(s,f)| \tag{26}$$

where, $Cor(s,f)$ is the correlation function. The original signal and the time shift in the original signal (received signal) are notated as, $f(x)$ and $f^*(x+s)e^{j2\pi fx}$. $A(s,f)$ refers to the AF of the original signal, and $|Cor(s,f)|$ specifies the maximum energy of the original signal.

The processing of correlation between the FrFT of SAR signal and its time shifted signal is depicted in the equations (27) to (32). The location of the target is ensured by the relation between these two signals. The FrFT of SAR signals ensure that the targets can be perfectly located even with noisy signals.

$$Cor^F(s,f)=\frac{1}{|Cor^F(0,0)|}\int_{-\infty}^{\infty}T_\sigma[u](g)T_\sigma^*[u](g).e^{j2\pi f(x+s)}\,dx \tag{27}$$

$$Cor^F(s,f)=e^{j2\pi fx}\frac{1}{|Cor^F(0,0)|}\int_{-\infty}^{\infty}T_\sigma[u](g)T_\sigma^*[u](g).e^{j2\pi fx}\,dx \tag{28}$$

$$Cor^F(s,f)=e^{j2\pi fx}\frac{1}{|F(0,0)|}\int_{-\infty}^{\infty}T_\sigma[u](g)T_\sigma^*[u](g).e^{j2\pi fx}\,dx \tag{29}$$

$$Cor^F(s,f)=e^{j2\pi fx}F(s,f) \tag{30}$$

$$F(s,f)=e^{-j2\pi fx}.Cor^F(s,f) \tag{31}$$

$$|F(s,f)|=|Cor^F(s,f)| \tag{32}$$

The amplitude of the ambiguity function equals to the amplitude of the correlation function that is computed between the signals $T_\sigma[u](g)$ and $T_\sigma^*[u](g)e^{j2\pi f(x+s)}$. $|Cor^F(s,f)|$ is the maximum energy of FrFT signal.

B. Processing of the received SAR signal using Matched filter (MF)

The time response of the matched filter is AF and it corresponds to the received energy signal. It is a two-dimensional function that relates the delay signal and the Doppler frequency so that the correlation between the original received signal and the distorted Doppler time signal is measured. AF is applied to the original time domain signal and the equation is stated as,

$$A(s,f)=\frac{1}{|A(0,0)|}\int_{-\infty}^{\infty}f(x).f^*(x+s).e^{j2\pi fx}\,dx \tag{21}$$

$$A(0,0)=\int_{-\infty}^{\infty}|f(x)|^2\,dx \tag{22}$$

Where, $A(0,0)$ is the normalization factor, $f(x)$ is the received signal and the time shift of the received energy signal is denoted as, $f^*(x+s).e^{j2\pi f(x+s)}$

C. Estimating the peak energy based on the correlation output

The equation (26) gives the correlation among the original signal $f(x)$ and the time delay signal $f^*(x+s).e^{j2\pi f(x+s)}$ which determines the maximum energy of the original signal that is essentially required to locate the target. Similarly, the equation (32) gives the correlation between the FrFT signal $T_\sigma[u](g)$ and the time time-shift signal $T_\sigma^*[u](g).e^{j2\pi f(x+s)}$ that pictures the peak energy of the signal for finalizing the position of the target. The target located using the maximal energy of the signals $f(x)$ and $T_\sigma[u](g)$ is denoted as, $T_{original}$ and T_{FRFT}, respectively.

D. Adaptively Fusing the decision of FrFT and matched filter

This section deliberates the fuzzy decisive approach of detecting the moving target in the search space.

Fig 2. Block diagram of ANFIS model

Fig 2 summarizes the block diagram of the Adaptive neuro fuzzy inference system (ANFIS), which is a hybrid intelligent system that integrates the best features of Fuzzy Systems and Artificial Neural Networks (ANN). ANFIS first derives a fuzzy model together with its input variables using the laws obtained from the system's input output information. Next, the ANN adaptively fine tunes the fuzzy model's laws to generate the system's output.

The target is located based on the maximum energy, which is the input to the fuzzy decision system. The fuzzification block is applied with two inputs $T_{original}$ and T_{FRFT} that maps the inputs in terms of the fuzzy membership function which is formulated using the fuzzy rules to detect the target in the search space. The adaptive capabilities of ANN ameliorate the performance of the system. The defuzzifier converts the output variables into the crisp values for the reference. The required moving target detected using the fuzzy decisive approach is denoted as T_{target}. The proposed ANFIS based MTD is able to disclose the dynamically moving targets and capable of locating multiple targets effectively and accurately.

IV. PERFORMANCE MEASURE OF PROPOSED METHOD

Fig 3 shows the simulation results using MATLAB. The SAR signals are transmitted from the transmitter and pulses are received by the receiver. The distance of the object is obtained by the time taken for the radar signal to transmit and to receive to from the center. The objects detected in the first round, 50 rounds, 100 rounds, and 200 rounds are depicted in figs 3a), 3b), 3c), and 3d), respectively.

A. Simulation Results

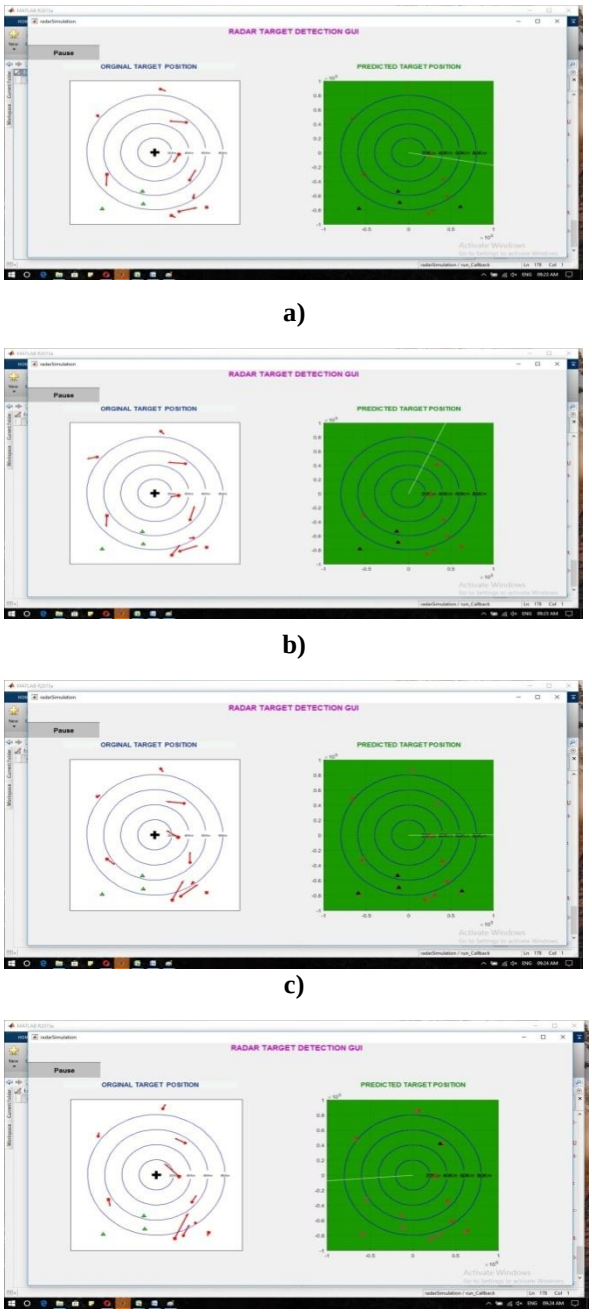


Fig 3. Simulation results of moving object detection a) At the initial round b) after 50 rounds c) after 100 rounds d) after 200 rounds

B. Implementation parameters for comparison

The following are the performance parameters worked out for dissecting the efficacy of the suggested method.

- ***MSE:*** The accuracy of the proposed method in locating the moving target is determined by the Mean Square Error (MSE). It is the difference between the actual location of the moving target and the location detected using the proposed method. A less MSE value should be offered by the efficient technique.
- ***Missed Target rate:*** The missed target rate adjudicates, how many targets are missed out during the detection technique employed. The rate of the missed target should be less for accurate method

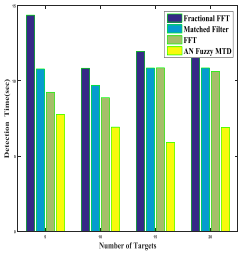
- ***Detection time:*** The average time taken to detect all the targets in a search space is given by detection time. For accurate and efficient method of detection, it should be less.

V. ANALYSIS OF COMPARISON AND DISCUSSION

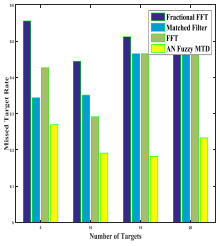
To substantiate the efficacy of the proposed method of detection, existing methods like fractional FFT [3], matched filter [3], and FFT [16] are compared with the proposed Adaptive Neuro Fuzzy-MTD. Also, the comparison has been done by changing the number of targets, antenna turn velocity, different PRIs and number of iterations with respect to detection time, missed target rate and MSE.

A. Result analysis

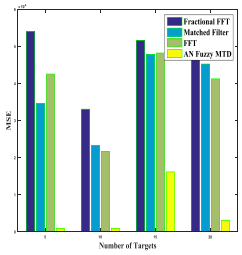
The analysis of detection time missed target rate and MSE versus number of targets is illustrated in figs 4a), 4b), 4c) respectively by considering 5, 10, 15, and 20 targets in the search space. It has been observed that even with more number of targets, proposed method offers less time for target detection, less missed target rate and less MSE in comparison with existing methods



a)

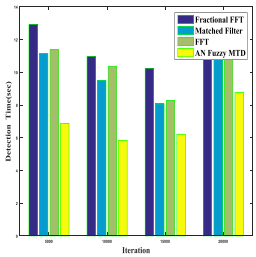


b)

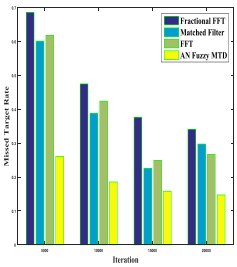


c)

Fig 4. Analysis based on the number of targets a) detection time b) missed target rate c) MSE



a)



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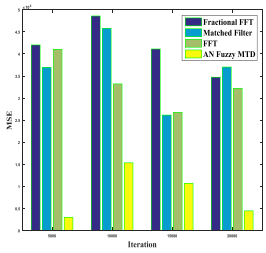
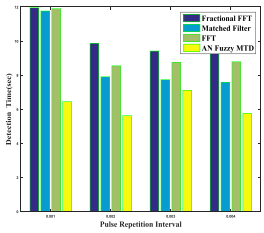


c)

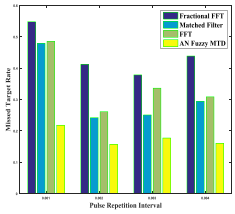
Fig 5. Analysis based on the number of iterations a) detection time b) missed target rate c) MSE

The comparative analysis of detection time, missed target rate and MSE versus the number of iterations for Fractional FFT, matched filter, FFT, and proposed Adaptive neuro Fuzzy-MTD is illustrated in figS 5 a), 5 b), 5c) respectively by considering 5000, 10000, 15000, and 20000 iterations. From the plots, it has been noticed that the proposed method takes very less detection time, missed target rate and MSE when compared with the existing methods.

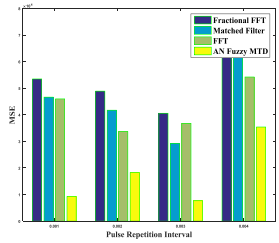
Figs 6 a), 6 b), 6 c) illustrates the comparative analysis of detection time, missed target rate and MSE versus the pulse repetition interval of 0.001s, 0.002s, 0.003s, for the MTDs Fractional FFT, matched filter, FFT, and proposed Adaptive neuro Fuzzy-MTD. It is assured that for various PRIs, the proposed MTD detects target in less time, precise in detecting targets with less MSE compared to current techniques.



a)



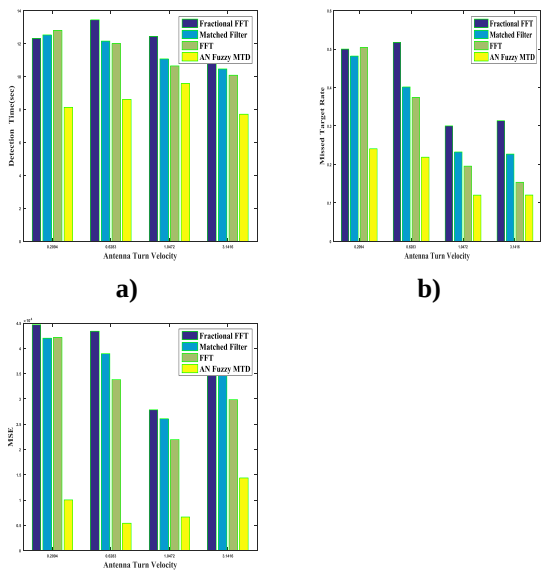
b)



c)

Fig 6. Analysis based on the pulse repetition interval a) detection time b) missed target rate c) MSE

Figs 7a),7b), 7c) shows the illustrates the comparative analysis of detection time, missed target rate and MSE versus the antenna turn velocity by considering 0.2094, 0.6283, 1.0472, and 3.1416 for Fractional FFT, matched filter, FFT, and proposed Adaptive neuro Fuzzy-MTD. The analysis ensures that when compared to the existing methods, the proposed method is extremely precise in detecting targets in the search space.



a) b)

c)

Fig 7. Analysis based on the antenna turn velocity a) detection time b) missed target rate c) MSE

B. Discussion of Results

Based on the MATLAB experimentation, tables I to IV shows that the utmost performance is accomplished by proposed method compared to existing methods of MTD for N=20 targets, 5000 iterations, 0.003s PRI and antenna turn velocity of 0.2094m/s.

Table I. Comparative analysis of the MTD methods for N=20 targets

	FrFT	MF	FFT	Proposed method
DT (s)	11.80	10.86	10.63	6.91
MTR	0.573	0.488	0.476	0.233
MSE	49721.6	45215.2	41225.0	3077.5

Table II. Comparative analysis of the MTD methods for 5000 iterations.

	FrFT	MF	FFT	Proposed method
DT (s)	12.91	11.14	11.37	6.88
MTR	0.685	0.601	0.617	0.260
MSE	42043.7	36938.7	41047.7	2972.8

Table III. Comparative analysis of the MTD methods for 0.003s PRI

	FrFT	MF	FFT	Proposed method
DT (s)	9.564	7.573	8.778	5.74
MTR	0.438	0.293	0.308	0.160
MSE	70383.6	62303.6	54217.5	35401.5

Table IV. Comparative analysis of the MTD methods for 0.2094m/s antenna turn velocity.

	FrFT	MF	FFT	Proposed method
DT (s)	12.30	12.52	12.79	8.13
MTR	0.500	0.481	0.503	0.240
MSE	44683.4	42021.2	42167.8	10021.9

VI. CONCLUSION

In this paper, Adaptive neuro Fuzzy MTD is proposed. The proposed method employed the FrFT based fuzzy decisive approach for Synthetic aperture radar signals to detect the moving objects in the search space. Fractional Fourier Transform (FrFT) easily separates the required chirp signal from noise. To locate the object accurately, maximum energy is computed by applying correlation FrFT signal. The efficacy of proposed method is enhanced by applying original and FrFT signals to ANFIS model, where fuzzy rules are used adaptively to get accurate output. The simulation is performed using MATLAB upto 20 moving targets, by changing antenna turn velocity, PRIs, number of iterations. Detection time, missed target rate, and MSE are the implementation parameters to measure the performance of proposed and existing methods. Comparative analysis shown in tables 1 to 4 substantiates that the proposed Adaptive neuro Fuzzy MTD detect the targets accurately with least amount of time.

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