A FAST RFT METHOD BASED ON MULTIPLE FILTERING

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Abstract: A fast RFT method based on multiple filtering (MF-RFT) is proposed in this paper. The method on the basis of Radon Fourier Transform method, first of all, according to the target RCS and scenarios to determine or calculate the first decision threshold selection mode, the strong scattering points in the target echo are selected. Then, RFT and other traditional algorithms are used to achieve long-term coherent accumulation, which greatly reduces the calculation amount of the original method on the premise of ensuring the performance of parameter measurement and target detection. Then, the high efficiency and robustness of the proposed method in certain scenarios are proved by formula derivation and simulation.

1. introduction

Traditional moving target for a long time accumulation methods can be divided into two categories: the first category is a two-dimensional traversal search method based on speed/distance, speed/pole pitch, polar angle/distance, polar angle/pole pitch dimensions, when the search dimensions match the target, the corresponding parameters will be on the chart presents the bright spot, by setting different search interval to obtain different precision of accumulation results; The other method is based on the coupling and correlation between the echo signals, to calculate and eliminate the distance and Doppler deviation caused by the target movement\cite{1}.

Based on the traditional search method, the proposed method carries out pre-filtering processing in the fast/slow time dimension of echo data firstly, and selects the bright scattering points in the image. By pre-filtering, most of the noise points in the image are filtered out, while the target echo signal is retained effectively, thus the signal to noise ratio(SNR) of the signal is improved. In addition, the data dimension and complexity of subsequent processing are reduced by pre-filtering operation, the computation amount of the original accumulation method is greatly increased.

The work arrangement of this paper is as follows: In the section 2, the signal transmitting/receiving model of radar target is established. In the section 3, the concrete operation steps of MF-RFT method are given, and five typical ways of selecting strong scattering points are analyzed. In the section 4, the processing performance of MF-RFT method is analyzed from the aspects of operation steps and accumulation effect. The section 5 is the conclusion.

2. model of radar target signal

Linear frequency modulation (LFM) signal is adopted as the radar transmission signal, and its expression is as follows:
\[ x(t) = Ar \exp \left\{ j \pi K \left( t - \frac{R_s(t)}{c} - \frac{R_t(t)}{c} \right)^2 - j \frac{4 \pi R_s(t)}{\lambda} + w(t) \right\} \] (1)

Where \( Ar \) is signal amplitude, \( \tau \) represents the delay time, \( t \) represents the fast time, \( T_P \) is the signal single pulse period, \( f_0 \) is the transmitting signal carrier frequency, and \( K \) is the signal modulation frequency, \( R(t) \) is the distance between the target and the radar[2].

After pulse compression, equation (1) can be converted into:

\[ x(m, \tau) = Ar' \sin c \left\{ j \pi K \left( t - \frac{R_s(t)}{c} - \frac{R_t(t)}{c} \right)^2 - j \frac{2 \pi f_{dc}}{\lambda} \right\} + W(t) \] (2)

As the target movement brings about the change of the distance between the radar and the target and the change of the Doppler frequency:

\[ f_{dc} = \frac{-V}{\lambda} = \frac{2R_s(t)}{\lambda} \] (3)

When the change of the distance between the radar and the target is greater than a range unit, it is called the across-range unit (ARU) [3]:

\[ N_{ARU} = \frac{R_{CM}}{\rho_r} = \frac{2v(M-1)K}{c} T_P^2 \] (4)

Where, \( \rho_r \) is the range-direction resolution, \( M \) is the number of pulses, \( V \) is the target range-direction velocity, and \( R_{CM} \) is the range-direction movement length of the target.

Fig. 1 shows a two-dimensional diagram of the compressed target echo, from which the ARU phenomenon can be clearly seen.

3. multimedia figures – video and audio files
The selection of strong scattering points can effectively remove most of the noise in the echo, so it is difficult to make an effective contribution to the calculation of straight line detection and accumulation. On the contrary, the target signal has a relatively large number of strong scattering points in the whole echo, and most of the strong scattering points will still be retained after selection.

3.1 Fast time dimension
The strong scattering points are selected in the fast time dimension, that is, the strongest scattering point in each fast time dimension is selected.
Index$_m = \text{Index} (\max (x(m,1:N)))$

This method can select most of the target echo signals when the number of scattered points of distributed spread target is large or the scattering intensity is different greatly. If the echo signals of each target do not cross in the fast/slow time dimension, the scattering points of each target can be retained as much as possible.

3.2 Slow time dimension
Strong scattering points are selected in the slow time dimension, that is, the strongest scattering point on each slow time dimension (pulse) is selected.

Index$_n = \text{Index} (\max (x(1:M,n)))$

This method has a good selection effect when the number of strong scattering points of the target is small or the intensity is similar, and the strongest scattering point on each pulse can be selected. By selecting and filtering the echo signal, the target echo can be retained relatively completely.

3.3 Fast/Slow time dimension
The strong scattering points are selected in the fast/slow time dimension, that is, the whole two-dimensional echo data is processed, and a certain number of the strongest points are selected. Here, it is assumed that the selected number is M, namely the number of pulses.

Index$_m = \text{Index} (\max_{1\ldots M} (x(1:M,1:N)))$

Where, max$_{1\ldots M}$ represents selecting the largest M points in a matrix. When the noise intensity in the echo data is high, the method ensures the proportion of target signal in the selected point as much as possible.

3.4 Selection of 1×P region
Selection of 1×P region represents the selection of strong scattering region with a size of 1×P on each slow time dimension, that is, the sum of each adjacent P scattering points on the slow time dimension is carried out and the maximum value is selected.

\[
\text{Index}_m = \text{Index} (\max (x(m-1:m+1,1:N)), m = (P-1)/2 : M - (P-1)/2)
\]

This method is similar to the single scattering point selection method in the slow time dimension, and has better noise suppression effect, and the effect will more obvious in the case of large noise energy and fluctuation, but the calculation amount of this method will increase with the increase of P.

3.5 Slow time dimension
The selection of P×P region represents the selection of strong scattering region of P×P size from the fast and slow time dimensions. The sum of each adjacent P scattering points is carried out, and the largest part of the region is selected, which is set as M-P.

\[
\text{Index}_n = \text{Index} (\max (x(m-1:m+1,n-1:n+1)), m = (P-1)/2 : M - (P-1)/2, n = (P-1)/2 : N - (P-1)/2)
\]

This method is similar to the method for selecting single scatters in fast and slow time dimensions. It has a significant effect when the target scatters are less or the intensity is similar, and the noise suppression effect is obvious. Similarly, the calculation amount of this method will also increase with the increase of P.

3.6 Comparison of several methods
Several selection methods of strong scattering points were analyzed in the previous section. Single scattering point, 1×P scattering region and P×P scattering region were selected from three dimensions of fast time, slow time and fast/slow time respectively. Different selection and combination were carried out according to different environments and requirements.
In order to verify the effect and difference of each group selection method, a series of comparative simulation experiments are carried out in this section. The main parameters affecting the selection method include the number of target scatters, the relative intensity between scatters, noise energy and variance, target velocity, etc. Therefore, the parameters given in the table are the reference parameters of the experiment. The influence of each parameter on different selection methods and the differences among different selection methods are analyzed through the control variable method.

Table 1. Parameter setting of simulation experiment

| Variable          | Symbol | Value  |
|-------------------|--------|--------|
| Peak Power        | $P_t$  | 100kW  |
| Antenna Gain      | $G$    | 24dBi  |
| Bandwidth         | $B$    | 200MHz |
| Frequency         | $f_c$  | 1.5GHz |
| Pulse Duration    | $T$    | 50μs   |
| Pulse Repetition Period | PRF | 1000  |
| Time-bandwidth Product | $D$ | 400   |
| Noise Coefficient | $F_n$  | 3dB    |
| System Loss       | $L$    | 15dB   |
| Target Velocity   | $V$    | 50km/s |
| Target RCS        | $\sigma$ | 0.5   |

The experimental results are shown in the figure below:

![Fig. 2. Results under different selection methods. (a)Compressed echo. (b)Fast time dimension. (c)Slow time dimension. (d)Fast/Slow time dimension. (e)Slow time dimension--1×3 region. (f)Slow time dimension--3×3 region.](image)

As shown in Fig. 2, the original echo and the results of the five selection methods are respectively presented from Fig. (a) to Fig. (e). Fig. (a) is the amplitude diagram of the original compressed echo signal in the fast/slow time dimension; Fig. (b) shows the selection of strong scattering points in the fast time dimension. It can be seen that in the fast time region where there is target echo, the echo of strong scattering points of the target is well preserved, but a large number of false scattering points will appear...
in other regions. Fig. (c) shows strong scattering points selected in the slow time dimension. Compared with the fast time dimension, the filtering effect of strong noise points is improved. In fig. (d), strong scattering points are selected in the fast/slow time dimension. It can be clearly seen that strong noise points are effectively filtered and the target echo trajectory is obvious under this method. Fig. (e) shows the selection of 1×3 strong scattering region in the slow time dimension. It is obvious that under the treatment of this method, most of the noise is filtered out and the target echo is retained completely. In fig. (f), the selected area is changed to 3×3 on the basis of fig. (e), and the noise filtering processing effect in this mode is improved again.

It can be seen from the above series of experiments that the noise filtering effect will improve with the expansion of the selected area. In most cases, when the intensity of the target strong scattering point is similar, the processing effect in the fast/slow time dimension is better than that in the slow time dimension, and it is also better than that in the fast time dimension.

4. coherent accumulation and target detection

4.1 Subsequent processing after filtering

Based on the strong scattering points selected in Step 1, the RFT method was used to realize coherent accumulation. Xu et al. gave the expression of RFT in reference [4]:

\[
G_n(r,v) = A \sum_{m=0}^{M-1} x \left( mT_p, \tau + \frac{mT_p v}{c} \right) H_\tau (\tau)
\]

In the distance/polar angle dimension, the following expression is given:

\[
G_n(r,\theta) = A \sum_{m=0}^{M-1} x \left( mT_p, \tau + mT_p \tan \theta \right) H_\theta (\tau)
\]

By selecting strong scattering points and RFT, the target echoes are well accumulated. At this time, the target can be extracted through detection methods such as CFAR, and the fast/slow time information of the target can be obtained. After calculation, the speed and position information of the target can be obtained.

4.2 Simulation experiment

The steps and basic principles of MF-RFT method were analyzed above. In order to evaluate the performance of MF-RFT method more comprehensively and objectively, RFT was performed on the resulting image based on the pre-filtering experiment. The simulation parameters were the same as that in Table 1, and the results were as follows:
Fig. 3. Results under different selection methods. (a) Compressed echo. (b) Fast time dimension. (c) Slow time dimension. (d) Fast/Slow time dimension. (e) Slow time dimension--1×3 region. (f) Slow time dimension--3×3 region.

As can be seen from fig. 3, fig. (a) to fig. (f) respectively show the result graphs under the original compressed echo and five pre-filtering methods. Then, through the subsequent processing of detection methods such as CFAR, parameters such as target velocity and position can be obtained. Intuitively, all the above six methods can clearly see the target, but there are obvious differences in the accumulation effect of each target. In order to evaluate the performance of each method in a more specific and objective way, image signal-noise is defined as follows [5]:

\[
\text{SNR} = 10 \log_{10} \left( \frac{A_P^2}{MSE} \right)
\]  

(12)

Where, \( A_P \) is the amplitude of the peak point in the two-dimensional image, and \( MSE \) is the image noise energy:

\[
MSE = \frac{1}{MN} \sum_{m=1}^{M} \sum_{n=1}^{N} \left| G_{nm} - \bar{G}_{nm} \right|^2
\]  

(13)

According to Equation (12), the processing results after the five filtering methods are calculated:

| Selection method          | SNR\(_{\text{max}}\) | Average SNR |
|---------------------------|-----------------------|-------------|
| RFT                       | 36.6552               | 36.2222     |
| Fast Time                 | 38.8080               | 35.9744     |
| Slow Time                 | 37.4245               | 36.4564     |
| Fast/Slow Time            | 40.0088               | 38.9927     |
| 1×3 Region                | 42.2666               | 41.1463     |
| 3×3 Region                | 39.8480               | 39.4055     |

As can be seen from Table 2 and the experimental results of the two groups, several methods have their advantages and disadvantages in different scenarios. Although the original RFT method can also have a good accumulation effect, it can be seen from the data in the table that RFT after pre-filtering can effectively improve the SNR of the image. Among the five pre-treatment methods, the effect of region selection is better than that of scattering point selection. Two-dimensional selection is better than one-dimensional selection; Only judge the selection effect, the larger the area, the better the selection effect.

In addition, there are two special cases:

1) The average accumulation effect of the fast time selection method is worse than that of other methods, but it has a good effect on the accumulation of the strongest scattering points, which indicates that the signal filtering from the fast time dimension can effectively retain the strong scattering points in the target.

2) Large-area filtering method has the best effect in filtering noise, but is not as good as monopulse region selection method in terms of accumulation. This is because the signals between different pulses do not consider the problems of range walking and frequency offset during region summation, which results in partial performance loss during accumulation.
5. conclusions
After pre-filtering, the noise in the target echo data is effectively removed. After RFT, the SNR of the image is significantly improved. The robustness of the proposed method is also proved by experiments. However, it can also be seen from the experiment that different filtering methods have different effects under different target intensity and target number. Therefore, finding the optimal filtering method and expanding the universality of the pre-filtering method are still the focus of the next research.

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