Modified Position Correlation Method for High Resolution Radar Target Detection

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Abstract: Parameterized detection methods for high resolution radar target have the mathematical models mismatch problem**.** On the other hand, most parameterized range extended target detection algorithms are relatively complex and need a large amount of calculation. Thus these methods cannot satisfy the real-time processing requirements in engineering. In order to overcome the disadvantage of mathematical model mismatch and improve processing efficiency, this paper proposes a novel non-parametric double threshold detection method based on modified strong scattering point position information correlation. Measured data test shows that the algorithm can effectively detect the target and reduce the computational complexity.

Keywords: high resolution radar detection; position information; non-parametric method;

I. INTRODUCTION

High range resolution radars (HRRs) can obtain more abundant target information by transmitting wideband waveform. However, considering that range profile of target is composed of multiple physical scatters and these scatters are divided into different range cells [1][2], the target demonstrates the range extended target characteristic. Echo energy is dispersed and signal-to-noise ratio (SNR) within a single range cell is reduced. Adopting the traditional point target detector will lead to lower detection performance and even the complete failure of detection method [3].

Many scholars have extensively researched on range extended target detector for the different clutter background or model based on the existing narrowband point target detection technology. A variety of parameterized detectors have been used for range extended target detection, such as the GLRT-based adaptive detection algorithms [4], Model-based adaptive detection of range-spread targets [5]. These methods are all repeated under conditions in which relatively complex mathematical models or priori information are in need. When actual target or clutter do not match the models, the mismatch problem will appear [6]. The research concerned mismatch of range extended target detection have less progress so far [7]. In addition, complex mathematical data need massive calculations, which limits performance of real-time processing.

For these problems, this paper presents a modified non-parametric detection method based on modified strong scattering point information. Measured data of civilian aircraft target was used to verify the effectiveness.

II. MODIFIED POSITION CORRELATION DETECTOR

The profile extension length of isolated clutter is shorter compared with the real target. According to this characteristic, the reference [8] provided a detector based on position information. It can simulate visual redundancy feature of radar operator to eliminate isolated noise points and clutter cells form the real target echoes. Some problems, such as second threshold leak-detecting and pre-process, appeared in practical application of this method.

The method adopted the first threshold which were maximum amplitude value of echoes multiplied by the confidence factor. Because the amplitudes and numbers of target strong scattering points are apparently always in change, this first threshold approach may be unreasonable. In addition, complex vector superposition of the target echoes and windowing processing in pulse compression will lead to main-lobe widening of single scattering point. Main-lobe widening will cause high resolution cell exceeding the first threshold do not match with target real scattering points numbers. Thus, the choice of second threshold is difficult. According to the actual processing requirements, we proposed a modified method.

A. *First Threshold Detection*

Whereas amplitudes of strong scattering points are changing dynamically, corresponding cells around maximum amplitude position are adopted to estimate the average amplitudes T_L of target. The T_L can address the random fluctuation of clutter and noise. Then T_L multiplies by the corresponding confidence coefficient η as the first threshold Th_1.

The amplitude sequence of the radar echoes is

$$X = \{x_1, x_2, x_3, ..., x_{N-1}, x_N\} \tag{1}$$

The P denotes high resolution cell position.

$$P = \{1, 2, 3, ..., N-1, N\} \tag{2}$$

Search the maximum amplitude X_{max} of radar echo and the corresponding position $P_{X\text{-}max}$.

$$X_{max} = \max_{i=1}^{N}\{x_i\} \tag{3}$$

$$P_{X\text{-}max} = \arg_{\mathrm{P}}\{X_{max}\} \tag{4}$$

Here, we use L cells around P_{X-max} to estimate T_L. The value L can adjust according to the actual demand.

$$T_L = \frac{1}{L+1}\sum_{i=P_{X\text{-}max}-L/2}^{P_{X\text{-}max}+L/2} x_i \tag{5}$$

According to the T_L, the first threshold is represented as

$$Th_1 = \eta T_L \tag{6}$$

The η is confidence coefficient. The confidence coefficient can be larger, taking 0.7 ~ 1.0 generally.

B. Scond Threshold Detection

Compare the radar echo data with the first threshold and record the positions of units whose amplitudes are greater than first threshold. I denotes the position according with the X_I. K denotes the total cell number of X_I.

$$X_I = \{X \geq Th_1\} \tag{7}$$

$$I = \{i_1, i_2, i_3, ..., i_K\} \subset P \tag{8}$$

Considering the main-lobe widening in high resolution processing, it is unreasonable that the K is taken the strong scattering point in detection windows. We search all the peaks in the X_I by seeking maximum value and put these peaks as scattering points. The peak position is S and peak number is J.

$$S = \arg_{Peak}\{X_I\} = \{s_1, s_2, ..., s_{J-1}, s_J\} \subset I \tag{9}$$

If the range resolution is ΔR, S can be transformed into position information of every peaks. Figure 1 shows the calculation relationship of $r(m, j)$.

$$r(m, j) = (s_j - s_m) \times \Delta R \qquad 1 \leq j \leq J \tag{10}$$

Take target maximum radial distance R as the reference window to start detection from the $r(1,1)$. When the strong scattering number N_t in detection window is greater than or equal to the real target strong scattering points, the target is detected. Here, the target strong scattering point number is the second threshold of detector. The second threshold can be estimated according to different targets. Generally, aviation aircraft or ship targets, 5-10 is quite reasonable.

When the $r(1, j)$ is greater than length of detection window, slide to next detection window, start from $r(j+1, j+2)$. Figure 2 shows the principle of double-threshold detection.

C. Detection Boundary Processing

When a target is in close proximity to another, tow targets have aliasing in profile. Because we use the correlation information of target scattering points as a basis of target detection, the scattering points locating in detection window boundary can be classified similarly. As shown in figure 3, in theory, $x_{s_{j+1}}$ belongs to detection window U_c. But we know that $r(j, j+1) > r(j+1, j+2)$, $x_{s_{j+1}}$ and $x_{s_{j+2}}$ can be classified to the same window U_{c+1}. On the contrary, $x_{s_{j+1}}$ and x_{s_j} can be classified to the same window U_c. Equation (11) and (12) give the judging criteria.

$$r(j, j+1) \leq r(j+1, j+2) \quad x_{s_j} \text{and}\, x_{s_{j+1}} \subset U_j \tag{11}$$

$$r(j, j+1) > r(j+1, j+2) \quad x_{s_{j+1}} \text{and}\, x_{s_{j+2}} \subset U_{j+1} \tag{12}$$

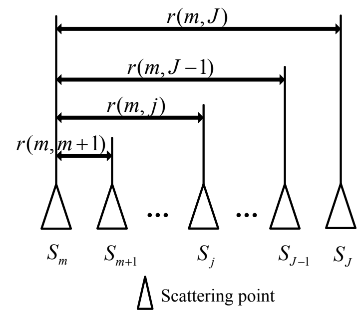

Fig. 1. Calculate $r(m, j)$

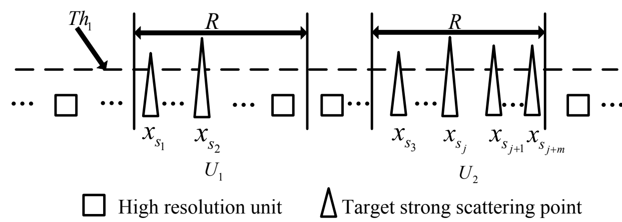

Fig. 2. Double-threshold detection

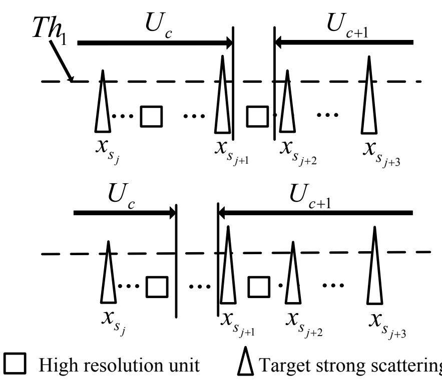

Fig. 3. Detection Boundary Processing

D. Pre-detection

To reduce the detection computation burden, this paper provided a pre-detection method in case of containing noise only. In noise environment, the cell number K exceeding the first threshold will be far more than target strong scattering point number N_t. When K is more than $K_{\max}$, 40% of all high resolution cell number, we abandon this frame detection directly.

E. Revised Algorithm Flow

Calculate the first threshold Th_1 from the radar echo and has the pre-detection. If there are targets, continue the detection flow. The next revised algorithm flow is shown in the figure 4. If $U_c \geq Th_2$, the c^{th} detection window has the target. Otherwise, the echo has no target.

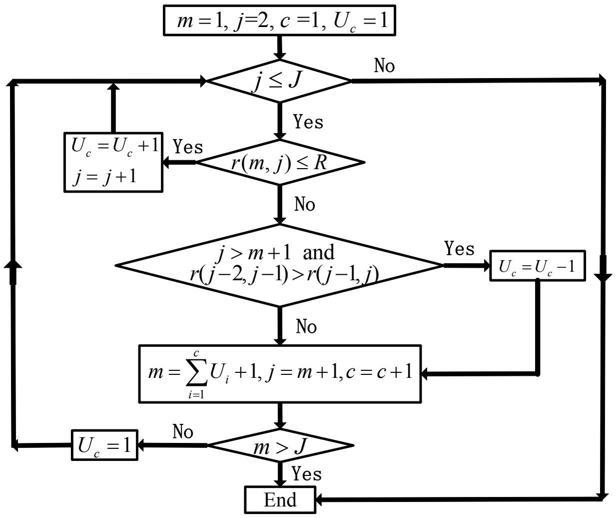

Fig. 4. Algorithm Flow

III. MEASURED DATA TEST AND RESULT

We use the LFM stepped-frequency signal to verify the method detection result. Signal bandwidth is 512MHz and range resolution ΔR is 0.2930m. Figure 5 shows the high resolution radar profile (HRRP) of a civil aircraft. Estimating from the HRRP, the size of target is about 40m, which is consistent with the actual size of large civil aircraft.

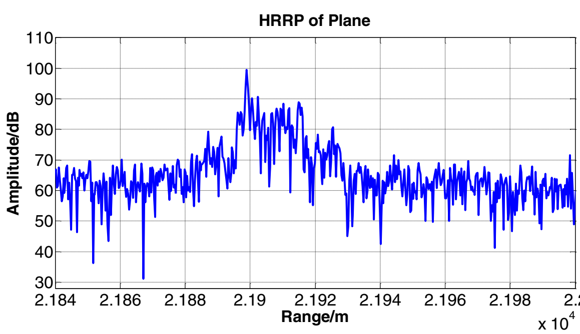

Fig. 5. HPPR of civil aircraft

Figure 6 demonstrates the first threshold detection output using the different method. Only one strong scattering point satisfies the first threshold adopting previous method in reference [8]. If Th_2 is 5, the target will be undetected. When η is 0.6, the strong scattering point occupied three high resolution cells. When η is 0.4, the strong scattering point occupied four high resolution cells. If we set the Th_2 as 3, despite target can be detected, it has no practical significance of the second threshold. On the other side, quite a number of target scattering points are not included in detection window, which means a part of target information has been lost. Obviously, the first threshold method in this paper is more reasonable and applicable.

Take the L as the real size of target shown in equation (13). The L is 137 via computing. Here, we set the Th_2 as 6. Figure 7 shows the pre-detection result containing noise only. This group HRRP has the 10240 units. The K is 4562, 44.5% of total numbers. Figure 8 shows the detection result of 100th frame data. High resolution cell number exceeding first threshold is 50 and the strong scattering point number is 15 by extracting the peaks.

$$L = \text{round}\{\frac{R}{\Delta R}\} \tag{13}$$

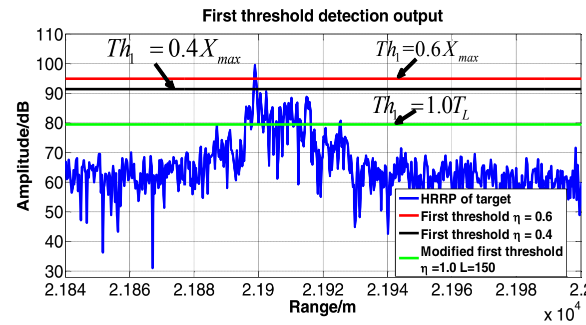

Fig. 6. First threshold detection output

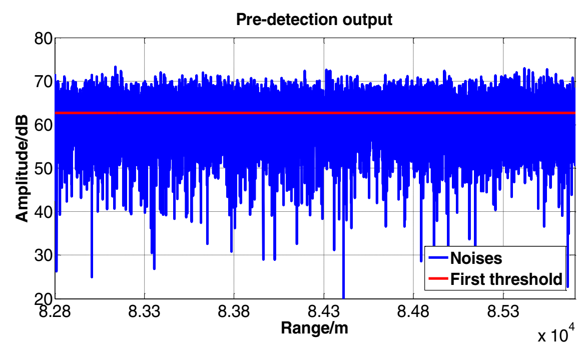

Fig. 7. Pre-detection output

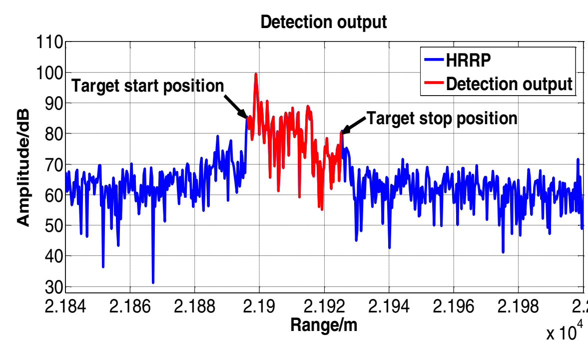

Fig. 8. Frame 100th detection output

Figure 9 shows two different methods, double threshold method in reference [9] and the method in this paper, detection results. Two methods adopt the same detection window length (about 60m) and the false alarm probability is 10-6. These results proved that detector we proposed can get more accurate strong scattering points information of target in the detection window. 5000 frames measured data operation test verified the method we proposed saved the 40% computing time compared with the method in reference [9]. And this modified novel detector also has no complicated parameterized calculations.

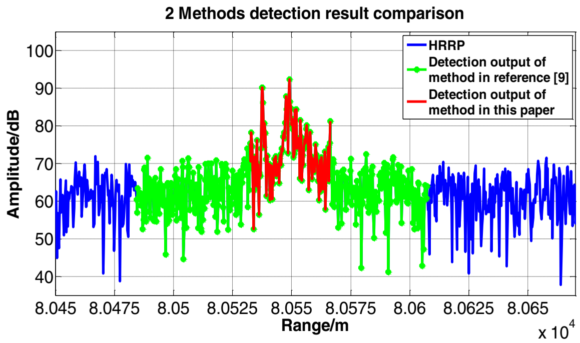

Fig. 9. Frame 5900th detection output

IV. Detection Parameter Analysis

Since the η and T_L affects the selection of the first threshold. As shown in the TABLE I, the proportion of T_L / X_{max} is lower, the T_L is closer to actual noise power. Figure 10 shows number of strong scattering point exceeding first threshold under different η and L. When L is 120 and η is 1.0, number of strong scattering point is around 10. It has a linear relationship with reference L after 60.

TABLE I. Proportional Relationship of X_{max} and T_L

	Relationship of X_{max} and T_L					
L	20	40	60	80	100	120
T_L / X_{max}	0.3236	0.2181	0.1749	1.6155	0.1477	0.1354

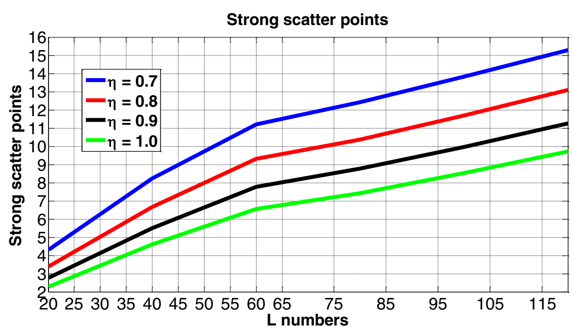

Fig. 10. Strong scatter number

V. Conclusion

To address mathematical model mismatch and poor real-time processing performance of parameterized methods, this paper proposed the modified strong scattering point position information correlation detection method and adopted wideband civilian aircraft data to verify the effectiveness. The selection strategy of corresponding detection parameter was also analyzed.

The results show that the method we proposed can detect the complex range extended target effectively. The first threshold parameter is more reasonable, which can avoid the leak-detection caused by randomness phase and amplitudes fluctuation of target echoes. By extracting maximum value from cells which satisfy the first threshold, the second threshold is more according with the actual distribution of target strong scattering point. At the same time, the computational complexity of algorithm is lower compared with the conventional parameterized detection method. Thus it enables very high value in real-time processing. Of course, combined with track association technology, the method can achieve better performance.

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