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Full Length Research Paper

High resolution range profile based extraction of radar target length

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Radar target identification using high resolution range profile (HRRP), the target length is an important feature due to that it can reduce the time of identification and mitigate noise redundancy. Traditional threshold methods with the different operators are highly sensitive to noise. In this paper, we proposed an adaptive difference operator for target length feature extraction from HRRP. Experimental results confirmed the proposed method effectively acquire the radial projection length of the target with high precision even in case of lower Signal-to-Noise Ratio (SNR).

Key words: Difference operator, target identification, HRRP, target length.

INTRODUCTION

Radar automatic target recognition (RATR) is to extract effective features of target from its radar echoed signatures and to identify the unknown target. A high resolution range profile (HRRP) is the amplitude of the coherent summations of the complex time returns from target scatterers in each range resolution cell, which represents the projection of the complex returned echoes form the target scattering centers onto the radar line of sight (Du et al., 2006). Among several kinds of wideband radar target signatures, HRRP is a promising signature and more easy to be acquired. Therefore, the identification based on HRRP has been subject to intense research in the field of RATR. The match method based on feature template of target is one of the most popular identification methods using HRRP (Du et al., 2006; Meng, 2005; Jacobs and O'sollivan, 2000; Yuan, 2006; Liu, 2007; Du et al., 1995) Because HRRP is highly sensitive to time-shift and target-aspect variation (Liu, 2007; Du et al., 1995), so how to extract robust and effective feature from the raw signal becomes a key problem. During past years, many experiments confirmed that some physical structure signatures contained in HRRP, such as central moment (Liu, 2007), the spectra (Du et al., 1995), and the scattering centers (Stanfill, 1999), etc., are beneficial to target recognition, and accordingly, a number of statistical methods have been proposed for feature extraction and dimensionality reduction (Fu et al., 2010).

Obviously, target length is a more visual target feature. A good example is the markers' distance in 3D face recognition (Mostayed et al., 2010). Effective extraction of the length feature can help the rough sort in terms of size and number of the target. Meanwhile, at the time of extracting the length feature, we can detect and intercept the real target echo information from the raw HRRP data so as to reduce redundant noise and improve both identification speed and performance. Although, a couple of literatures (He and Guo, 1992; Ma, 2001; Wang et al., 2006; Bai, 2006) have investigated into the target length identification, using a simple-threshold approach, the performance is seriously depressed by noise and interference, and thus this approach needs to be improved for practical utilization. Therefore, the study of a practical and effective algorithm extracting the target length feature is significant.

By analyzing the target length feature of the raw HRRP data, we propose an adaptive difference operator which

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Abbreviations: SNR, Signal-to-Noise Ratio; **HRRP,** high resolution range profile; **RATR,** radar automatic target recognition.

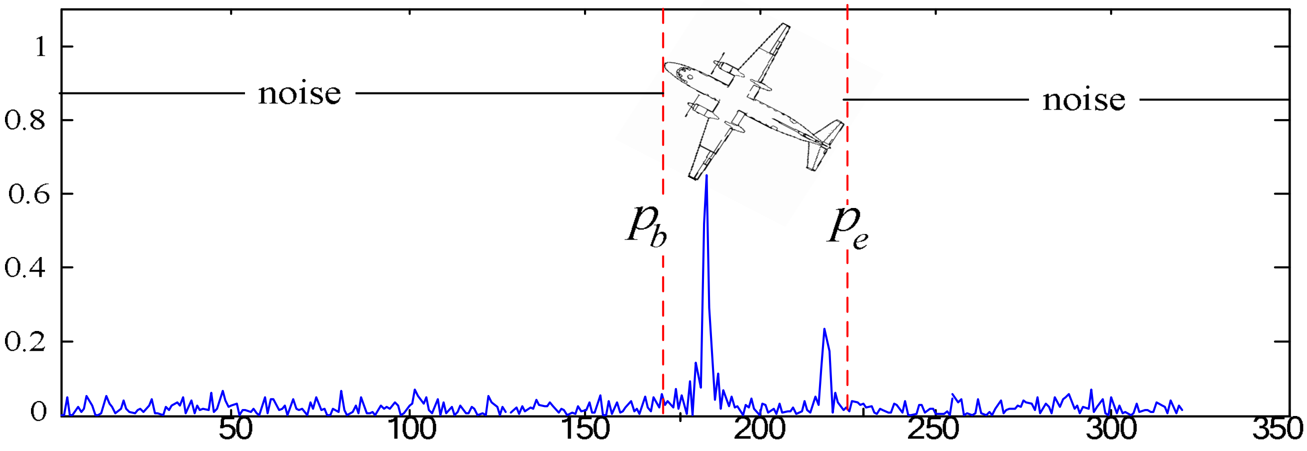


Figure 1. Target range profile.

slides and operates on the HRRP. The data in the difference-window is divided into two sectors. Using the difference and ratio of energy between fore-sector and post-sector to detect the target echo's beginning and ending location, so as to extract the target's length. Experimental results based on three groups of airplane data show that the proposed algorithm has accuracy as high as 95%.

The target's length feature of harp

The target's HRRP characterizes the distribution of target scattering centers in the radar radial distance and describes the target's projection length in radial distance. Usually the raw HRRP data has a higher dimension, while the real target echo data accounts for a very small portion with a lot of data being noise redundancy at the two ends.

A HRRP is shown in Figure 1, the left and right dotted lines respectively correspond to the beginning position P_b and ending position P_c of echo data from the target scattering centers. The distance units' number of the target echo in the whole HRRP is $(P_c - P_b)$. The target radial projection length L on the current angle-of-sight (AOS) can be estimated as

$$L=(P_c-P_b)\times\Delta R,$$

Where ΔR is the radar range resolution. At the same time, the data segment $(P_b \sim P_e)$ can be intercepted as real target echo data.

Adaptive difference operator

The estimation of the target projection length L lies in the determination of the location of P_b and P_e. In signal detection theory, threshold based method is one of the general way to detect the location of target echo appearance and disappearance. However, its performance is very sensitive to noise level and the given threshold. In order to reduce the sensitivity, this paper adopts an adaptive difference operator to detect the appearance and disappearance position of the target echo.

Difference operator's definition and processing

Let $X=[x_1,x_2,\ldots,x_N]^T$ denote the normalized HRRP, where N denote the number of echo's sampling points. Now we define a difference operator with $2M$ width as;

$$W[k]=\begin{cases}-1, & -M \le k \le 0\\ 1, & 0 \le k \le M\\ 0, & others\end{cases}.$$

We make this difference operator slide on the inputting HRRP (*X*). At each step of sliding, the processing can be expressed as follows:

$$y_i=\begin{cases}(E_{i2}/E_{i1})\times(E_{i2}-E_{i1}) & , \quad E_i \ge 0\\ (E_{i1}/E_{i2})\times(E_{i1}-E_{i2}) & , \quad E_i < 0\end{cases},\ (i=1,2,\ldots,N-2M+1) \quad (3)$$

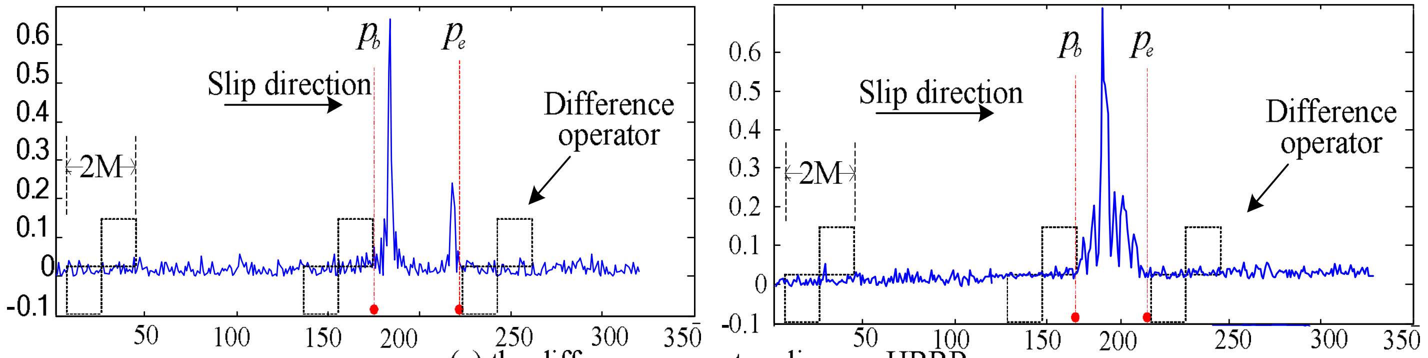
(1)

Where;

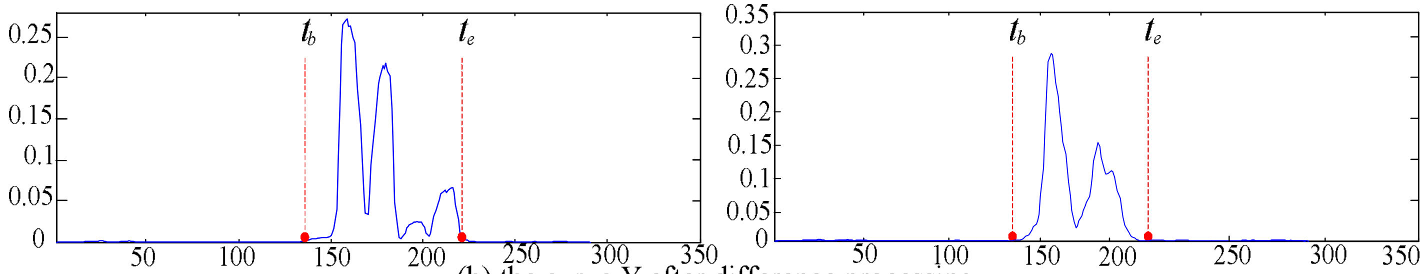
$$E_i=\left|\sum_{j=0}^{2M-1}\{x_{i+j}\times W[-M+j]\}\right|,$$

$$E_{i1}=\left|\sum_{j=0}^{M-1}x_{i+j}\right|,$$

$$E_{i2}=\left|\sum_{j=M}^{2M-1}x_{i+j}\right|.$$



(a) the difference operator slip on a HRRP



(b) the curve Y after difference processing

Figure 2. The "sliding" procedure and the output of the difference operator.

As show in (3), the $2M$ points in the difference-window is divided into two sectors, E_{i1} denote the power of fore-sector, E_{i2} denote the power of post-sector, the output y_i is the product of difference and ratio of E_{i1} and E_{i2}. After the process of the difference operator, the output is recorded as:

$$Y=[y_1,y_2,...,y_{N-2M+1}]^T.$$

This difference operator's processing and the results are shown in Figure 2. Figure 2a demonstrates the difference operator's sliding process on some HRRP. Figure 2b shows the result Y (after difference operator processing, where the abscissa standing for the sample subscript.

The difference operator has the following properties:

- When the difference operator is located entirely in the noise zone (shown as the left operator in Figure 2a), owing to the E_{i1} and E_{i2} is approximate, the output is approximately zero ($y_i \approx 0$);
- When the difference operator begins to enter the target echo (shown as the middle operator in Figure 2a), owing to the E_{i2} is bigger than E_{i1}, their difference and ratio both increase, the output begins to rise from zero;
- When the difference operator completely leaves the echo's data region (shown as the right operator in Figure 2a), owing to the E_{i1} is bigger than E_{i2}, their difference and ratio both decrease, the output returns to zero with a downward trend.

Based on the above characteristics, as shown in Figure 2b, in the changing curve Y, as long as we find the point t_b showing the first beginning of the upward and the point t_e showing the last ending of the downward trend, the corresponding starting position P_b and ending position P_e of the echo data of the scatters can be obtained. The conversation formula is:

(4)

$$\begin{cases} P_b = t_b + 2M - 1 \\ P_e = t_e \end{cases}. \qquad (5)$$

Construction of adaptive difference operator

Obviously, the difference operator plays the role of reducing the noise here. The operator's width (*M*) has a significant impact on the results. The following points should be considered when we choose the width:

- If M value is too small, then the data points entering the difference operator are few, statistical information is inaccurate, the difference output Y fluctuates too much, and the obtained target's length L would be larger than the true value.
- If M value is too large, exceeding the target echo's dimensions, the output Y fluctuates slowly, and the obtained target's length L would be less than the true value.
- If the SNR is low, M should take the larger value. If the

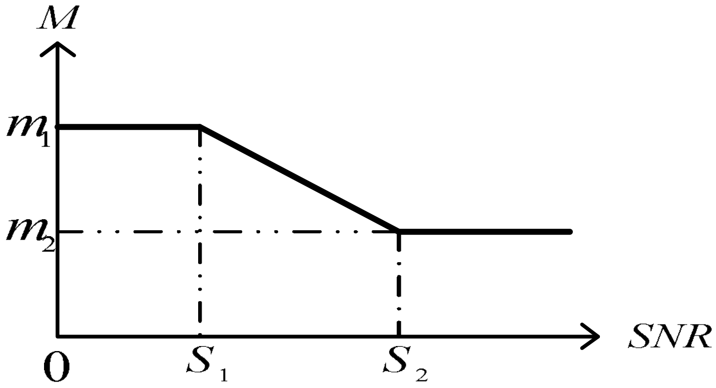


Figure 3. The relationship of difference length M and SNR.

Table 1. Parameters of planes and radar in the simulated experiments.

Radar parameter	**Center frequency**		5520 MHz
	Bandwidth		400 MHz
	Sampling frequency		1600 MHz
Planes	**Length (m)**	**Width (m)**	**Scale**
An26	23.80	29.21	1:1
Ah64	15.30	5.40	1:1
B1b	44.80	23.80	1:1

SNR is higher, M should take the smaller value.

Since the SNR is sensitive to the environment in practice, the operator's width M must be adaptively adjusted by SNR. Here, we propose a piecewise analytic function to calculate M, the relationship of M and SNR are shown in Figure 3. The M is calculated by formula,

$$\begin{cases} M = m_1, & SNR < S_1 \\ \dfrac{SNR - S_1}{S_2 - S_1} = \dfrac{M - m_1}{m_2 - m_1}, & S_1 \le SNR \le S_2 \\ M = m_2, & SNR > S_2 \end{cases}, \tag{6}$$

Where, the SNR is defined as;

$$SNR = 10 \times \log_{10} \left\{ \frac{[\max(x_i)_{i=1}^{N}]^2}{\frac{1}{N} \sum_{i=1}^{N} (x_i - \bar{x})^2} \right\} \quad where: \bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i. \tag{7}$$

By dealing with and validating a large number of measured data, the four parameters in (6) are set as: $S_1 = 10$, $m_1 = 15f/c$, $S_2 = 30$, $m_2 = 7f/c$, f is sample frequency, c is velocity of light.

The steps of extracting the target's length feature using the difference operator

Based on the discussion above, now we list several major steps of extract the target's length characteristic using the difference operator:

1) Normalize the energy of the HRRP.
2) Calculate the SNR of the current HRRP using (7).
3) Calculate the adaptive difference operator's width M using (6).
4) Make the difference operator slide in the HRRP and calculate the difference output Y using (3).
5) In Y, find the point t_b showing the first beginning of increasing trend and point t_e showing the last ending of decreasing trend.
6) Estimate the starting location P_b and ending location P_e of the echo data of the scatters using (5).
7) Obtain the target's radial projection length L of the current HRRP using (1).

EXPERIMENTAL

Experimental data

We simulate radar back-scattering data of three airplanes (An26, Ah64, B1b) by a program (Gorshkov et al., 2002; Shirman, 2002), and

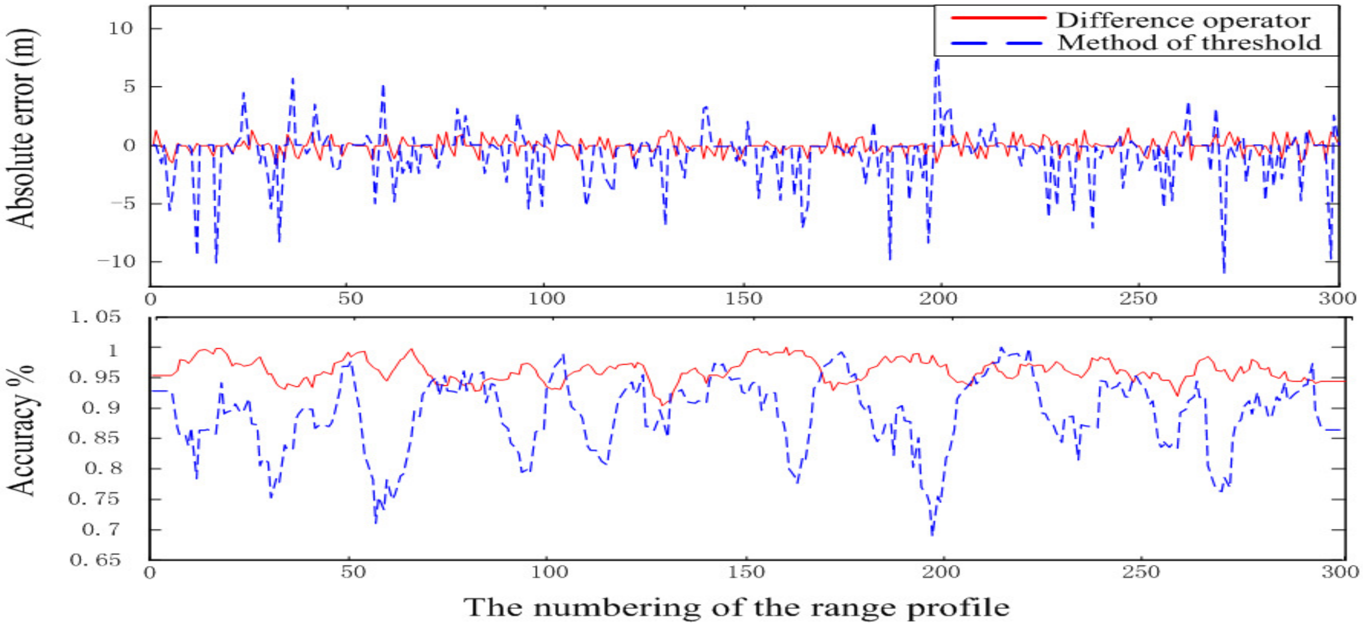


Figure 4. An26 : the error of the extracting length.

the parameters of targets and radar are listed in Table 1. These three airplanes are all set as flight mode with the same initial state (speed of flight is 700 m/s , altitude is 8000 m, radar radial distance is 150 km, initial azimuth of plane is 120°, initial elevation angle is 3°, the time of flight is 15 s, number of HRRP is 20 pre second, SNR is 20 dB). Accordingly, there are 300 HRRP of each planes to be processed.

Experimental methods

We deal with each HRRP as follows: 1) Determine the radial projection length L_{r_i} of the target as the reference value using manual identification, where i is the number of the HRRP ($i = 1, 2, ..., 300$).

2) Extract the target's radial projection length (Ld_i) using the difference operator presented in the paper, and calculate the below three parameters:

The absolute error of length L : $R_i = Ld_i - Lr_i \ (m)$.

The relative error: $E_i = |R_i| / Lr_i \times 100\%$.

The accuracy: $C_i = 1 - E_i$.

3) As compared with our difference operator method, using the common threshold detection method to obtain the target's radial projection length (the determined threshold is set as: $th = [\max(x_i) - \min(x_i)]/20$, also calculating the length's absolute error R_i , relative error E_i , and accuracy C_i of single profile.

EXPERIMENTAL RESULTS AND ANALYSIS

Figures 4-6 shows the absolute error (R_i) and accuracy(C_i) obtained after extracting the length information by using the difference operator method and the threshold method respectively to process the 300 HRRP of each planes(An26, Ah64, B1b). Dotted line stands for the threshold method, and solid line stands for the difference operator method. Abscissa is the 300 HRRP' numbering.

Table 2 is the final statistical result. Among the table, average accuracy is defined as the average of the 300 range profiles' length characteristic's accuracy, it can be represented as $\bar{C} = \sum_{i=1}^{300} C_i / 300 \times 100\%$.

Compared threshold method with our difference method, the corresponding accuracy differences are shown in Figure 4~6 and Table 2. Firstly, in Figures 4-6, we can see that the three planes' accuracy curves all fluctuate very much due to the high aspect sensitivity of HRRP, while the difference method are more stable and robust than the threshold method. Secondly, in Table 2, we can see that the relative error of threshold method is up to 35% and its average accuracy is 82%, while the relative error of difference method is 11% and its average accuracy is up to 95%. Obviously, the performance of difference method is apparently superior to the threshold method.

Figure 7 shows the length of three planes in the radar radial distance, which is obtained by using the difference operator method. As shown in Figure 7, we find that the radial length of B1b-plane is about 16 meter, and the others planes' is below 14 m, consequently, we can distinguish between B1b-plane and the others by using14 m as a dividing line for every HRRP. Furthermore, the radial length of An26-plane and Ah64-plane is near, so we can not distinguish between An26-plane and Ah64-

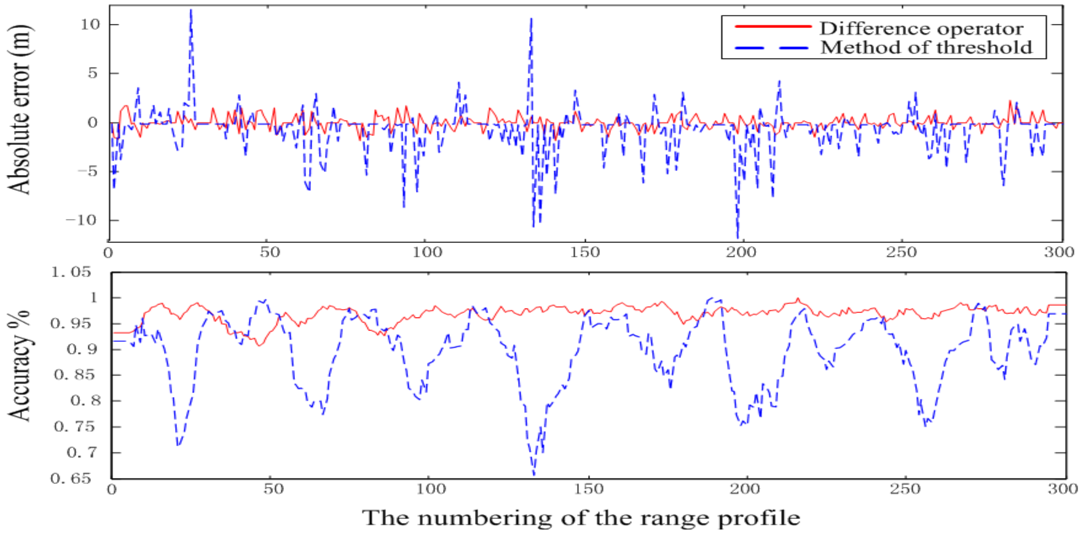


Figure 5. Ah64: the error of the extracting length.

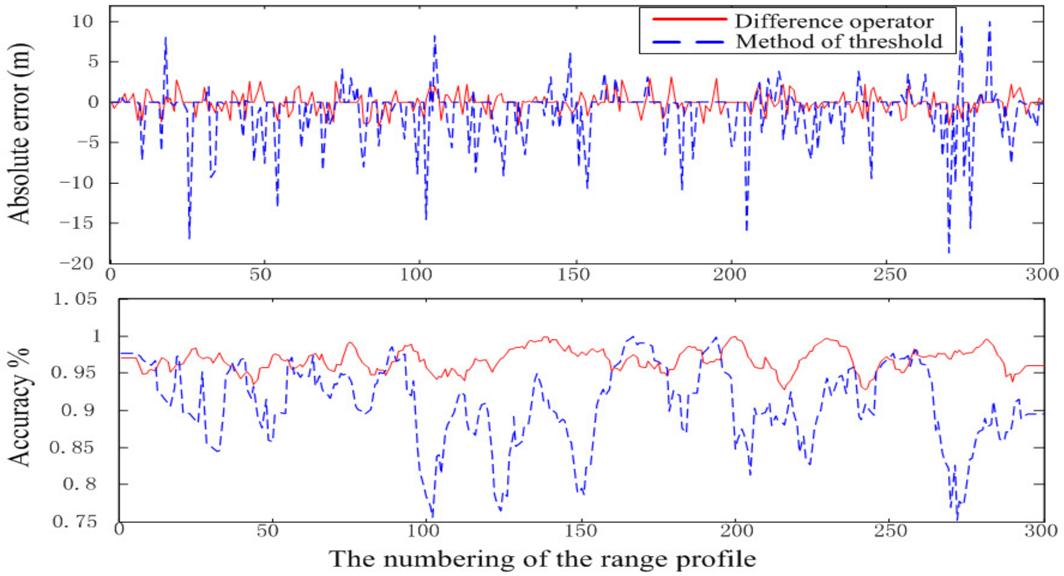


Figure 6. B1b : the error of the extracting length.

Table 2. The error of the extracting target length.

Target	An26 (%)	Ah64 (%)	B1b (%)
Threshold based method			
Maximum relative error of single profile: $\max(E_i)$	31	35	25
Average accuracy of 300 range profiles: $\overline{C}$	85	82	86
Difference operator based method			
Maximum relative error of single profile: $\max(E_i)$	10	11	7
Average accuracy of 300 range profiles: $\overline{C}$	96	95	97

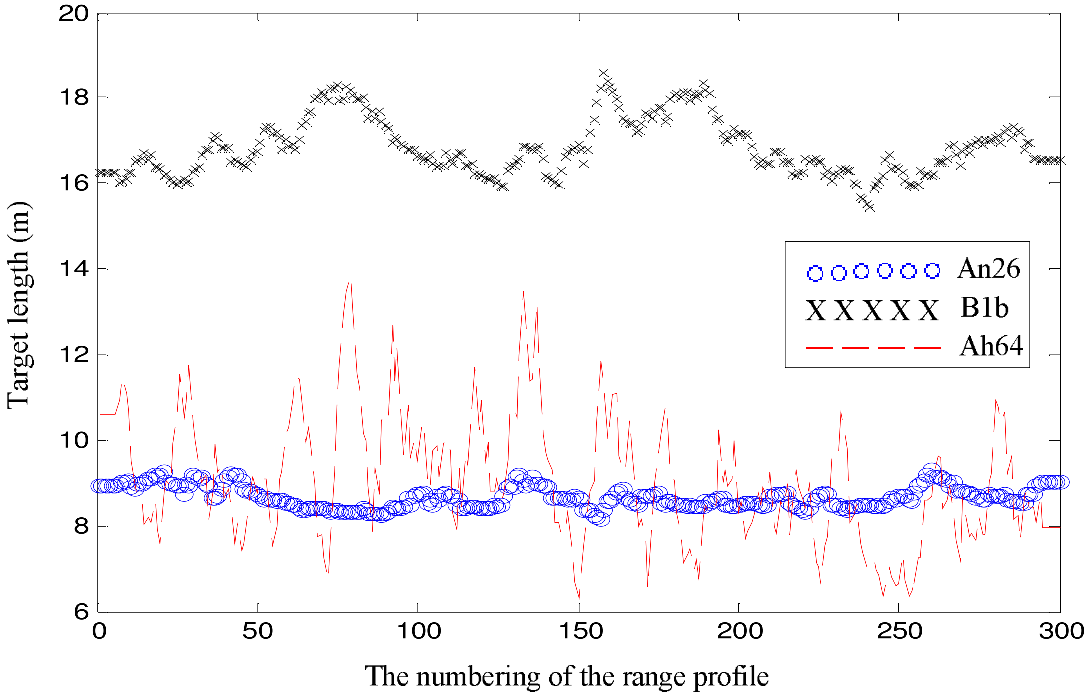


Figure 7. The target length of three planes which is extracted using threshold method.

plane by using the length of a single HRRP, however, there is airscrew on Ah64-plane, the airscrew will modulate the radar echo while the plane flight, therefore, the radial lengths which are obtained from adjacent HRRPs will fluctuate acutely, the fluctuation is obvious in Figure 7. As described above, we can distinguish between An26-plane and Ah64-plane using the characteristic of fluctuation, this fluctuation can be estimated using the variance of adjacent radial lengths.

Conclusion

In order to extract the length information of radar target from HRRP, in this paper, we proposed a self-adaptive difference operator to estimate the begin point and the end point of target echo, and then we obtain the target's length. Compared the traditional simple-threshold approach with the difference operator approach, the former is highly sensitive to noise, the latter use a difference window to slide and operate on a HRRP, the essence of this process is noise reduction. Contrast Figure 2a with Figure 2b, we can see that the SNR is seriously improved by the difference process; therefore, the extracted target length is more exact. As an applied example, these experimental results also reveal the high effectiveness of the difference operator proposed in this paper. It is worth pointing out that the target radial length is a very visual target physical feature nevertheless it seldom appears in radar HRRP recognition. In this paper, we extract the length and apply it in radar HRRP rough recognition and obtain an obvious effect. However, rough recognition is just the primary stage in radar target recognition. Obviously, future work should be focused on the study of combining length feature with other target features for practical radar HRRP recognition.

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