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Fuzzy logic classifier design for air targets recognition based on HRRP

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ABSTRACT

The paper describes a fuzzy logic classifier (FLC) to achieve the recognition for air targets. We first acquire the high range resolution profiles (HRRP) of three types of air targets from the measurements. We extract two typical features, namely, the length of the air targets and the difference between adjacent two HRRP based on HRRP from the measurements. Then we design the FLC to synthesize the two characters and identify the type of air targets. Simulation results show that our FLC can achieve the function of target recognition with a high ratio of recognition and also show a robust performance to some extent.

1. Introduction and background

The non-cooperative target recognition based on the wideband radar systems has been studied extensively for decades. Among these research studies, the high range resolution profile (HRRP) is a promising approach. An HRRP is the phasor sum of the time sequence returns from individual scatterers on the target located within a resolution cell of the wideband radar. Each of scatterer corresponds to typical structure signatures of the target such as the target length, the radar dish, the engines, the main and tail wing roots and pylons on the wings [1,2]. The amount of data corresponding to the one-dimensional profile is relatively small, which shows the computational tractability compared with 2-D or 3-D images. Thus, it is a practical approach to achieve the high speed real-time signal processing. Therefore, HRRP-based radar target recognition has captured intensive attention from the radar automatic target recognition (RATR) community.

Recent works mainly concentrate on the processing methods on feature extractions and classifying algorithms. The aim is to constitute a more robust way for target recognition with a high accurate ratio [3–6]. With regard to the spectrum method, a classical high-order spectrum method is proposed by Du et al. [3]. And the corresponding template matching method based on the high-order spectrum has been used to investigate the radar-aspect sensitivity. A differential power spectrum (DPS) and the product spectrum raised by Guo and Li [4] will be viewed as the translation invariant. These two methods focus on the spectrum method and computational tractability; however some information contained in the frequency is inevitably lost through the processing procedure. Liu et al. [5] suggested the absolute difference between the Euclidean lengths of the amplitude spectrums of two neighboring HRRPs as a novel feature to distinguish propeller-driven airplanes from turbine-driven airplanes. It shows an idea to describe the change of HRRPs; nevertheless it requires the data of high quality that can make sure to get good results from its feature extraction. Zhou et al. [6] designed a transform to maximize the between-class distance while preserving the within-class structure, which is a method that comes from pattern recognition. However, the between-class

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distance still will be influenced by the structure of the class. If it goes bad the performance becomes worse.

Though successful to some extent, above methods have their limitations. Because these methods are mainly designed to preserve the discriminant features or structures of HRRPs. The HRRPs are determined by original sample data. The worse the sample data goes, the lower the recognition ratio they get. Therefore, a proper design for the combination of the various methods will be capable of increasing the target recognition ratio. It will take more situations into consideration than single one, which shows its robustness in the real environment. To some extent, it is fuzzy to achieve perfect intelligent combinations of several methods for target recognition in the real world.

In this paper, we propose a fuzzy logic classifier to show the well-performed weighted combination of the typical features and achieve a better recognition performance. The fuzzy logic classifier is based on the theory and design of Type-1 fuzzy logic system [7]. Thus it is a combination and a synthesis of the traditional detection and recognition methods and the powerful mathematical tool. The novelty and contributions of this paper are twofolds.

(1) It is an innovative attempt to apply the theory of Type-1 fuzzy logic system into the field of air target recognition. We exhibit a new direction of exploring and advancing the methods and performance of the means of exploiting HRRP.

(2) All the simulations are based on the real measurements which show the reliability of the final results. We also further show the evolvements of the recognition ratio based on the change of two principle factors in target detection.

The outline of this paper is as follows. In Section 2, we derive and illustrate the process of HRRP generation and feature extraction which we will adopt in this paper. In Section 3, we design the model of FLC and specify the requirements of each component. Based on simulation results, Section 4 shows the performance of target recognition of the FLC and the variations of the recognition ratio on specified conditions. Finally, some concluding remarks are given in Section 5.

2. Generation of HRRP and feature extraction

A widely used and effective approach of pulse compression is linear frequency modulation (LFM) which is also called a chirp' waveform, and this technique is adopted in generating the HRRP in our work. One of the most attractive characteristics is that LFM can solve the dilemma between range resolution and the range of radar detection. This difficulty is used to be a difficulty in the radar signal processing field [8].

The LFM waveform adopted in this work can be expressed as follows:

$$s[n] = \exp\{j2\pi[f_c n + 0.5\mu n^2]\} \quad n = 1, 2, \ldots \tag{1}$$

where $\mu = \frac{\beta}{\tau}$. Here f_c is the carrier frequency of the radar, β stands for the bandwidth of the waveform and τ the pulsewidth. The LFM waveform is regarded as the transmitted signal of the wideband radar.

To suppress the sidelobe, a window $w[n]$ is applied to solve it. Thus the LFM waveform can be expressed as

$$s_1[n] = s[n] \times w[n]. \tag{2}$$

A matched filter is used to accomplish the pulse compression. The steps are as follows. First we do zero padding here, i.e.,

$$h[n] = \begin{cases} s_1[n], & n = 1, \ldots, K \\ 0, & n = K + 1, \ldots, M' \end{cases} \tag{3}$$

where M' is the power of 2 and M' must be greater than or equal to M. Then we do a fast Fourier transform (FFT) to $h[n]$, and then we acquire the conjugate result after we do the FFT, i.e. $H(K) = FFT\{h[n]\}^*$

The measurements are the time sequences of reflection of the wideband radar. They are regarded as the radar echoes. Clutters are not involved in the data and purely noise in it. The aspect angle of adjacent two HRRPs is 0.1° and the targets have an elevation of 3°. We expressed these signals as $x[n]$, and we also do the fast Fourier transform of the signals, i.e., $X[K] = FFT(x[n])$. Thus the output of the matched filter is obtained by taking the inverse fast Fourier transform of the multiplication of $X[K]$ and $H[K]$,

$$y[n] = IFFT[X(K)H(K)] \tag{4}$$

where $y[n]$ is the HRRP that we obtain. The three air targets that we will use in this paper are F-15, Tu-16 and AH-64. Typical normalized HRRPs of the three air targets are shown in Fig. 1.

The length and the type of engine are two features that are adopted for the target recognition in our work. They will be introduced in the following two parts.

2.1. Length

First of all, we need to preprocess the HRRPs. We cancel the ones of low SNR in order to select the HRRPs of good quality. The relationship between length and the equivalent bandwidth is $L = N \times \frac{c}{2B}$. Here we use the sampling frequency to supplant the equivalent bandwidth, i.e., $L = N \times \frac{c}{2f}$, where N is the number of range units in the HRRP. We have known from the fact that the length of target is less than a prerequisite window length W. We can construct a sampling window with window length W to choose the target region. We adopt the following steps.

(1) Find the maximum value of the amplitude in each HRRP (we defined as Smax) and the corresponding position in the sequence which Pmax lies in (we defined as Pmax).

(2) View Pmax as the centroid, if Pmax is localized in the middle of the sequence, we set up a sampling window with a range of [Pmax$-W$, Pmax$+W$]. The part which lies in the sampling window is regarded as the signal and noise and the part which is out of the sampling window is purely noise. If Pmax is not localized in the middle, shift Pmax to the middle.

(3) We defined the maximum signal-to-noise ratio as follows:

$$\mathrm{SNR} = 10 \times \log_{10} \frac{{S_{max}}^2}{E^2 + \sigma^2} \tag{5}$$