The Feature Description and Identification Method of Radar Signal Based on Kernel Density Estimation

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***Abstract*—Along with the development of modern radar technology, the radar signal system is more and more complicated. This makes the description way of the existing radar signal feature cannot effectively express and analysis it's characteristic. Therefore, in this kind of situation, a description method of radar emitter signal feature based on kernel density estimation is proposed. This method takes the probability density curve from kernel density estimation algorithm as radar emitter signal parameters characteristics stored into database, and on this basis a radar emitter signal recognition algorithm based on template matching is proposed.**

Keywords-kernel density estimation; radar emitter signal; basic paramete; template matching

I. INTRODUCTION

At the present stage, radar emitter pulse signal is mainly described through the characteristic parameters of the carrier frequency, pulse width, repetitive period, antenna scan period and intra-pulse characteristics. For conventional radar emitter source, the signal parameter is usually constant, the characteristic is easy to understand and store, the radar emitter source recognition method based on characteristic parameter matching is effective. But for complex system radar, such as the Falon radar designed by the United States ITT company it's repetitive period has three kinds mode: fixed, stagger and pulse group stagger, just using characteristic parameter data to express the signal feature will be complex. It is difficult to determine the tolerance effectively with making use of the characteristic parameter matching method to recognize. Due to the noise of the factors, there is always a certain error of the measurement parameter, such as the difference between the multiple frequency of frequency diversity radar is big, no matter how to choose the tolerance, certain parameter range contains a certain frequency and also excludes the other frequency value at the same time, which can lead to false recognition[1].

II. INTRODUCTIONTHE DESCRIPTION METHOD BASED ON THE KERNEL DENSITY ESTIMATION

$X_1, X_2, \cdots, X_n$ are independent same distribution samples drawn from one dimensional overall X , X has unknown density function $p(x)$, $x \in R$,and the kernel density estimation of $p(x)$ is[2][3]:

$$\hat{p}(x) = \frac{1}{nh}\sum_{i=1}^{n} K(\frac{x - X_i}{h}) \qquad (1)$$

In formula, n is the sample number of sample set ; $K(u)$ is kernel density estimation function, referred to as the kernel function; h is called window width, the kernel function has square window function, normal window function and exponential window function, etc. This paper takes the pulse repetitive period as an example, making use of kernel density estimation method, to describe the repetitive periods of the different working patterns. The pulse repetitive period work modes are: repetitive period fixed, repetitive period jitter, repetitive period stagger, repetitive period agility and subtle change.

The pulse repetitive period fixed means that the pulse repetitive period keep constant in a certain time. Making use of the kernel density estimation based on normal window function to estimate the probability density function whose repetitive period fixed is 50ms,the sample number N=200,the window width $h_N = 10$,the result is shown in figure1.The probability density curve of repetitive period has a obvious peak at 50ms from figure1.

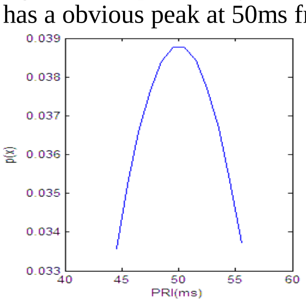

Figure1 The PDF curve of repetitive period fixed

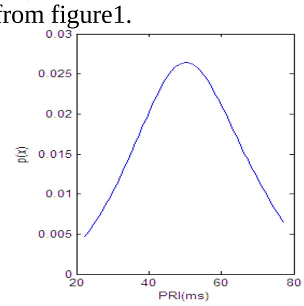

Figure2 The PDF curve of the repetitive period jitter

The pulse repetitive period jitter means that the pulse repetitive period changes fast and randomly in a very narrow range the range is usually less than 5% of the central value. Making use of the kernel density estimation based on the normal window function to estimate the probability density whose repetitive period jitter central value is 5% ,the sample number N=200,the window width $h_N = 10$,the result is shown in figure2.In figure 2,the probability density curve estimated by the normal window function is similar to the fixed pattern, but the variance is bigger, it indicates that the parameter transformation range of the jitter is larger than the fixed pattern.

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The repetitive period stagger means that the PRI of adjacent pulses change according to certain regular, the change is cyclical, such as level 2 stagger and level 3 stagger, etc, more than level 8 stagger signals are very rare. Using kernel density estimation method based on normal window function to estimate the probability density of three staggers repetitive period (values are: 50 ms, 150 ms, 250 ms) , the sample number N = 200, the window width $h_N = 10$, the result is shown in figure 3. From figure 3, the probability density curve of repetitive period has obvious peak at 50 ms, 150 ms and 250 ms. It indicate that repetitive period value can be 50 ms, 150 ms and 250 ms.

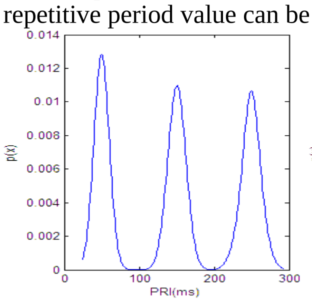

Figure3 The PDF curve of repetitive period three staggers

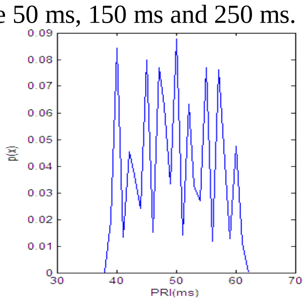

Figure4 The PDF curve of repetitive period agility or subtle change

The repetitive period agility means that the PRI of signals can be a random one of present multiple parameters and it change range is usually between 10% and 20% of the central value. repetitive period subtle change means that the PRI of signal change rapidly in a larger range according to a certain rule, such as sine change rule, sawtooth wave change rule and so on, and their variation ranges are usually between 10% and 20% of the central value. Using kernel density estimation method based on normal window function to estimate the probability density of repetitive period agility or subtle change (values are: 40 ms, 42.5 ms, 45 ms, 47.5 ms, 50 ms, 52.5 ms, 55 ms, 57.5 ms, 60 ms) , the sample number N = 200, the window width $h_N = 0.5$, the results is shown in figure 4. In figure 4, the probability density curve estimated by the normal window function changes from 40 ms to 60 ms interval with 50 ms as the center and peaks are corresponding to the nine values of the repetitive period.

If the repetitive period has a variety of work modes at the same time, such as fixed mode and three stagger mode, using kernel density estimation method based on normal window function to estimate the probability density of the repetitive period, the sample number N = 200, window width $h_N = 10$, the results is shown in figure 5. In figure 5, this parameter has two work modes, the parameter is 300 ms in fixed mode, the parameters are 50 ms, 100 ms, 150 ms in stagger mode. Therefore, making use of kernel density estimation method to analysis the radar signal parameters which have a variety of work modes is also effectively.

It can be seen that the probability density curves of radar signal carrier frequency, pulse width, repetitive period can be got as long as setting out the right window width and making use of kernel density estimation method, then store three probability density diagrams of the radar emitter signals into database, and can identify rapidly making use of image processing at last, from the above the simulation results.

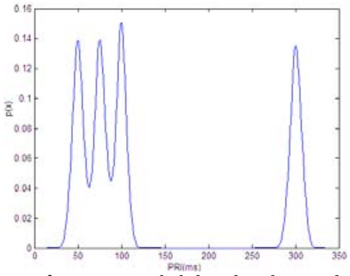

Figure5 The carrier frequency probability distribution diagrams in two work modes

III. THE IDENTIFICATION BASED ON KERNEL DENSITY ESTIMATION

After getting the probability density curve spectrum diagram of radar emitter signal parameters through using the kernel density estimation method, the radar emitter processing method is shown in figure 6. Concretely speaking, the processing identification based on kernel density estimation can take three schemes, the first kind of plan is to rapidly screen, identify and process the diluted radar signal directly, and this scheme does not need the signal full separation, and is mainly suitable for rapid processing of the important targets. The second scheme is to identify the separated radar signal, this scheme do not need to extract features compared with traditional radar signal identification. The third way combines the kernel probability estimation and histogram to extract features, this scheme can solve the problem that the group number of histogram is difficult to determine compared with traditional radar signal identification.

The identification technology of two schemes above can use the thought based on template matching, the method is to use kernel density estimation algorithm to estimate the probability density curve of three parameters such as diluent pulse signal carrier frequency, pulse width and repetitive period, then take these three images as the original images and three probability density curve stored in the database as template images, make use of template matching thoughts to match three pictures, and fuse three matching results to judge whether there is important targets. Template matching process is as follows:

(1)The pixel points whose gray scale of the image is not zero are expressed as $P(x, y, s)$, (x, y) are line marks and column marks of the pixels; s is the slope between this pixel and the pixel whose gray scale is not zero ;

(2)Looking for first matching pixel and intercepted a sub image whose size is equal to the template image;

(3)With H lines to approximate the continuous curve of template image and sub image and to transform H lines into the points $MP_h(x_h, y_h, W_h, S_h)$ with weight and the direction, calculation method is[4]:

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$$\begin{cases} W_h = J_h - J_{h-1} \\ X_h = \dfrac{1}{J_h - J_{h-1}} \sum_{i=J_{h-1}}^{J_h} x_i \\ y_h = \dfrac{1}{J_h - J_{h-1}} \sum_{i=J_{h-1}}^{J_h} y_i \\ S_h = \dfrac{1}{J_h - J_{h-1}} \sum_{i=J_{h-1}}^{J_h} s_i = s_h \quad (h \in \{J_{h-1}, j_h\}) \end{cases} \tag{2}$$

J_h is the location index of the endpoint in the curve of the first h side. Therefore, template images and sub images can use sequence TSM and SSM to express:

$$\begin{aligned} \text{TSM} &= \{TMP_0, TMP_1, \cdots, TMP_H\} \\ \text{SSM} &= \{SMP_0, SMP_1, \cdots, SMP_H\} \end{aligned} \tag{3}$$

(4)Calculate the similarity between sequence TSM and SSM, when the similarity is greater than the preset threshold, then templates and sub images are considered matching; Otherwise, look for the next matching pixel and intercept sub image's size the same as template image, then return to step (3).

The basic idea of combining kernel density estimation and histogram algorithm in the third scheme is: in the condition of proper number of group, the histogram shape should be able to reflect the probability density distribution of parameters[5]. Therefore, in the case of unknown probability density function of parameter, if the kernel density estimation method is used to estimate the probability density function of the sample, the probability density function estimated by the kernel density estimate algorithm and the top profile function of the histogram after normalized processing should be as the closer the better, specific steps are as follows:

(1)The probability density function $\hat{p}(x)$ estimated by the kernel density estimate algorithm;

(2)Let the number of group N=5, make and normalize the histogram, $f_i' = f_i / N$, f_i is the number of the first i histogram's frequency, $f(x)$ is the top profile function of the histogram after normalized processing;

(3)Calculate the close degree between $f(x)$ and $\hat{p}(x)$, if the close degree is less than the preset threshold, let N=N+2 and return to step(2); otherwise, the group number N is the optimal group and execute step (4);

(4)To analysis and extract the parameters of the histogram according to the optimal grouping, the algorithm is end.

IV. CONCLUSION

Using kernel density estimation to get probability density curve can describe the complex system radar signal and provide basis for the analysis and identification of the complex system radar signal. Combining with kernel density estimation algorithm on the basis of the traditional identification method can improve the analysis and processing capacity of complex system radar signal feature . Of course, this paper just to provide a new thought to research the feature expression methods of radar signal and also need for further study on how to set the window width to obtain accurate probability density curve and realize fast template matching etc.

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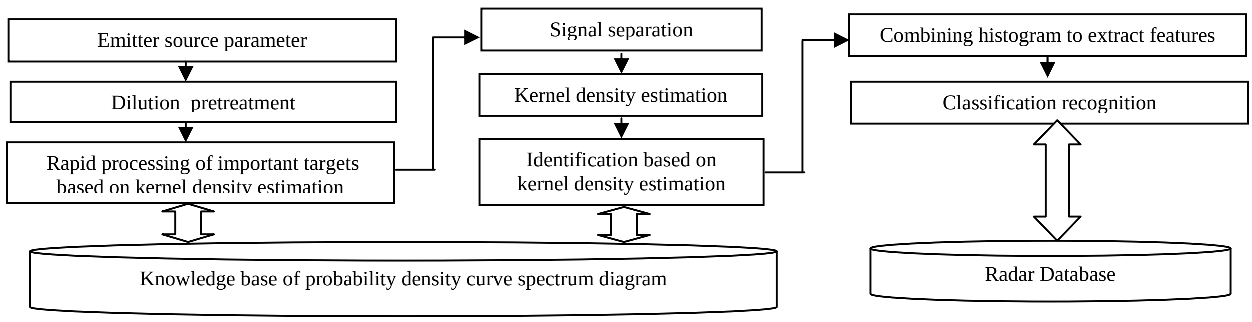

Figure6 The model of radar emitter identification based on kernel density estimation

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