Research on Radar Automatic Target Recognition Based on High Resolution Range Profile

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Abstract. In the Cold War period, military management put forward more and more high requirements for the acquisition of information. The new research field of radar automatic target recognition (ATR) has emerged. The development of high-resolution radar provides a powerful technical support for the research of ATR. Because the radar high-resolution range profile can provide the target along the range direction. Geometric structure information, Because of its unique advantages of easy access and processing, ATR technology based on HRRP has attracted more and more attention. On the basis of previous work, this paper focuses on the theory of feature extraction and target classification of HRRP.

1. Introduction
With the rapid development of modern electronic information technology, material technology, aviation technology and many other disciplines, modern war has gradually developed into a war centered on high-tech information warfare and electronic warfare. The real-time monitoring and processing of battlefield dynamic information is an important factor related to the victory and defeat of war. Radar has been playing an important role in the military field since its birth. It cannot meet the needs of modern war. With the further detailed information of the target, the research field of automatic Target recognition has emerged. With the rapid development of signal processing and computer technology, the real-time processing required by ATR has become possible. Radar ATR technology can provide target categories, attributes, formation sorties, and even their weapons mount information for improving the level of command automation of the army has offensive and defensive capabilities. Anti-missile capability and strategic early warning capability of land air defense play an important role. ATR as an important development direction of modern radar technology will be an important technical component of the future weapon system.

2. Principle of Signal Processing in Radar System
The radar transmitting signal is modulated by the target to form the backward electromagnetic scattering signal. The radar target echo is the backward electromagnetic scattering signal (such as microwave, infrared ray, visible light, laser) of the target received by the radar. The modulation of radar signal by the target is determined by the geometric and physical structure of the target itself, and the characteristic information of the radar target is implied in the radar echo (complex number). The radar cross section and its fluctuation statistical model, angular scintillation and statistical characteristic parameters, and polarimetric scattering matrix of the target can be obtained by special waveform design and processing, analysis and transformation of echo amplitude and phase. Isoparametric distribution of multiple scattering centers of targets The theoretical and experimental results show that the characteristic
information relates to the shape of the target, the attitude of the target, the moving parameters of the target, the electromagnetic parameters of the surface material and the roughness of the surface. The type of power engine installed on the target is related to the way the engine works, and these characteristics reflect the attributes of the target from different aspects, the essence of radar ATR is to extract the information mark and stability feature of target from radar echo. Radar target recognition is the theory of pattern recognition in thunder. As the application, figure 1 shows a typical radar recognition system, including radar signal feature extraction, feature selection, establishment of target feature template library, judgment device and judgment direct. Key technology of radar target recognition is divided into two aspects: feature layer, it is a kind of objective physical difference according to other targets. It should be stable parameters which can characterize the target itself inherent characteristics. It should be able to reflect the characteristics of the target, and the dimension and the storage amount as low as possible, which is the research target feature layer problem, generalized including acquisition, pretreatment of radar signals.

![Figure 1. Principle Diagram of Radar Target Recognition System](image)

Target characteristic analysis and feature extraction is the most important link in radar target recognition system. Its quality directly affects the performance of target recognition system and the selection of classification and recognition methods. The early work of radar target recognition can be divided into the following categories: using the RCs undulation characteristics of moving targets and the periodic modulation spectrum characteristics of dynamic targets based on the target feature information contained in the radar time domain waveform sequence. Since aircraft types and formations are judged largely by the experience of the operator, they may be applicable to certain targets with regular echoes (such as helicopters, etc.). But for ordinary jet aircraft, it obviously has a lot of accidental components and lack of reliability. According to the characteristics of polarization of the target, it is generally possible to classify the targets in a rough way. For example, the target is divided into spherical object, vibrator like object and two-sided right-angle reflector according to the zero polarization or characteristic polarization defined by scattering matrix. The polarization feature is very sensitive to the attitude of complex target, which limits its application. Based on the recognition of target poles (i.e. natural resonance frequency), the distribution of poles is determined only by the inherent characteristics of the target and independent of the attitude of the target and the polarization mode of the radar, so the complexity of the recognition system is greatly reduced.

3. Range profile study

The traditional low-resolution radar has insufficient ability to measure the target characteristic signal, which cannot accomplish the task of target stability recognition in complex battlefield environment. The rise of modern high-resolution radar provides a new way for target recognition. With the development of large scale integrated, circuit technology and high performance electronic device technology, high range resolution radar technology had developed. The techniques of synthetic Aperture Radar (SAR) and inverse synthetic Aperture Radar (ISAR) can be used to analyze the target echo signal in high resolution time domain, which greatly reduces the target scattering model with attitude. The complexity of factors such as frequency and polarization changes by targeting One-dimensional or two-dimensional electromagnetic scattering imaging. It makes the target become an extended target, so that the fine
structure information of the target can be obtained, which provides powerful technical support for the development of radar ATR technology, and makes this field gradually become international in recent years. It has turned to be a research hot spot in China.

3.1. Study on Translation Sensitivity of Distance Profile
In practical applications, the target is generally in mobile motion and is a non-cooperative target. The location of the range image in the range window is uncertain. The range profile can be represented by a segment of vector, which contains the target and has a certain degree of redundancy, which is extracted from the radar echo data by the range window because of the existence of the redundancy. Even if there is a small translation, the range image vector is obviously different, which is called the translation sensitivity of the high-resolution range profile based on the recognition of the range profile. The impact of distance translation must be considered. There are three approaches to this problem.

In the training stage, it is for a frame of range image in the basic angle of view of the same target. Since the approximation is considered to be a one-dimensional search for the translation of random vector pairs from the same scattering point model, it can be expected that the range units corresponding to the peaks of each range profile can be “aligned” one by one. The range profile and the template in the database may be range profiles corresponding to different scattering point models or even different types of targets, and the waveforms are very different, so it is impossible to expect to be fully aligned with the range unit. However, it is still possible to make a one-dimensional search on translation under certain criteria, which is usually called translation registration. Radar target recognition methods based on high resolution range profile in the State key Laboratory of Radar signal processing. The in-class alignment of range profile in training process and the translation registration between range profile and template in testing process are essentially the optimal matching of range profile after translation compensation under certain measure criteria, and the most representative is the sliding maximum correlation method. By calculating the maximum correlation coefficient for translation compensation, even if the fast sliding correlation method based on FFT or Hilbert transform is used. Figure 2 shows two adjacent range images of aircraft echo measured by radar. The scattering intensity of the reflected target is similar in shape along the radar line of sight, but the two range images have been shifted on the range gate. Figure. 2 / b is the result of the alignment of the two range images with the maximum sliding correlation method. You can see that the translation has been compensated.

![Figure 2 Two Adjacent Distance Profiles](image-url)

Figure. 2 Two Adjacent Distance Profiles
The other one is the absolute alignment of range profile, which is mostly studied in zero phase absolute alignment and zero linear phase absolute alignment. Compared with sliding correlation classifier, absolute alignment calculation is simple, but the alignment accuracy is low.

The third one is to extract the translation invariant feature and recognize the target in the feature domain. The translational invariant feature can be directly processed, which not only greatly reduces the computation, but also is easy to use in many classifiers.

3.2. Intensity Sensitivity of Range Profile and Pretreatment Method
Because of the different radar parameters (such as radar operating range, radar antenna gain and radar receiver gain, etc.), different targets, the range profile of different radars has different yardsticks in terms of amplitude. It is difficult to convert the output of different radars to the same conditions as when the template was created. Only intensity information is discarded and only shape information is used. There is still the problem of how to deal with the strength. The method of dealing with the intensity sensitivity is to deal with concave or search the best intensity registration factor under certain measure criterion.

The results show that the nonlinear pretreatment of range profile can obviously improve the recognition rate, and the representative method is power transformation. The theoretical basis of power transformation is that the power transformation can be applied to the random process with a certain probability distribution, which is closer to Gauss distribution. Therefore, the classical classifier based on Gauss distribution can be used for recognition.

4. Research on recognition method of high-score range profile
The target is stimulated by the electromagnetic wave emitted by the radar and forms the electromagnetic scattering source of the electromagnetic wave. Some of the energy of the target is returned back to the radar station, which constitutes the physical basis for radar detection and recognition of the target. The range resolution of the conventional narrowband radar is very low. The resolution unit is usually much larger than the general target, so the radar regards the observed target (such as aircraft, vehicle, etc.) as a "point target". Although the radar echo also contains certain target information, the range resolution of radar can be greatly improved. The length of range resolution unit can be as small as sub-meter level, then the radar of general target can be used. The echo signal is presented as a one-dimensional range knife distributed along the distance. Under the irradiation of high resolution radar signal, the scattering characteristics of the target can be approximately expressed by a simplified scattering point model. The scattering point model uses the backscattering approximation of a series of scattering points located on a curved surface instead of the target dimension range profile. In fact, it is the distribution map of the scattering intensity of each distance element of the target and contains the radial structure information of the target. Therefore, it is very valuable for target recognition and classification.

High resolution radar operates in the optical region, the wavelength of the radar emission signal is far less than the target size, the total electromagnetic scattering of the target can be considered as the synthesis of electromagnetic scattering from some local positions. These local scattering sources are often referred to as equivalent multi-scattering points. Radar signals are modulated by the delay and amplitude of each scattering point to form scattering point echoes. The target echo is the vector sum of the echo of each scattering point. The scattering point model is a commonly used model in the radar signal processing of wideband radar signal. It can describe the scattering characteristics of the target in the radar optical region. Its effectiveness has also been well tested in the field of radar imaging and radar target recognition. With the development of radar technology, large bandwidth signal (such as linear frequency modulation signal, step frequency signal, etc.) can be used to obtain the high resolution of target scattering point in radial distance by pulse compression technology. Thus, the one-dimensional high-resolution range imaging of the scattering point of the target can be realized.

Assuming that the radar transmitted signal is a linear frequency modulation signal, the target frequency response can be expressed as the sum of the frequency response of each scattering point.

\[ X_f = \sum_{k=1}^{K} a_k e^{j\frac{2\pi f_r t_k}{\lambda}} \]  

(1)
Formula (1) is the scattering point model of high resolution radar target in frequency domain, where \( K \) is the number of scattering points on the target azimuth timing target, and \( \alpha_K \) is the complex scattering intensity of the \( k \) scattering point. The radial distance from the \( k \)-th scattering point to the radar indicates that the frequency \( c \) is the speed of light.

In practice, we can only get a finite number of sampling values of \( X_F \), let the sampling width of frequency be \( f \), and obtain the corresponding discrete frequency form.

\[
X(n) = \sum_{k=1}^{K} \sigma_k e^{j2\pi nf r_k^2}, \quad n = 0,1,2,\ldots,N-1
\]  

(2)

The scattering center parameters \( \{K, r_k, \sigma_k\}, k=1,2,\ldots, K \) in radar echo data indicate the number of scattering points, the position of scattering points and the echo intensity, and reflect the one-dimensional distribution of scattering points along radar line of sight in a given attitude. The radial structure information of the target is provided. When the bandwidth of the radar transmitting signal is constant, the parameters of the scattering center can be extracted by different parameter estimation methods for the radar echo data obtained, and the one-dimensional range profile with different resolution can be obtained.

5. Conclusion

The technology of radar target recognition has been developed for nearly 60 years. The technology of target recognition based on high resolution range profile is developed only after the development of high resolution radar technology. However, there are still many basic problems that have not been solved, and there is still a distance from practical use.

The most important problem in target recognition in this paper is feature extraction. Based on the scattering point model, the acquisition method of high resolution range profile is briefly described. The characteristics of range profile and several key problems that need to be considered in recognition are discussed in detail. It has a direct impact on the final recognition performance. Exploring a new feature extraction method of radar high resolution range profile is a problem that needs further research. Because range profile has the physical feature of wavelet, and wavelet technique Gabor replacement, support vector machine has the characteristic of signal analysis localization. We can do this by selecting the appropriate kernel method. To achieve feature extraction, translational sensitivity makes the computation of distance recognition very large, which limits the use of complex classifiers, and extracts effective translation invariant features.

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