

Development of Radar Active Jamming Recognition Technology

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Abstract: Active jamming identification technology in electronic countermeasures is one of the key points of military science and technology development. In this paper, aiming at the field of radar active jamming identification, firstly, the characteristics of current radar jamming technology are sorted out. Secondly, this paper summarizes the technical characteristics of active interference recognition, and introduces the feature extraction and feature classification module in detail. Finally, aiming at the existing problems of jamming identification, this paper puts forward the main research directions and difficult problems of radar active jamming identification technology in the future.

1. Introduction

As "the fourth dimension battlefield [1]", electronic warfare is a special and important means of modern warfare [2]. Since radar has been used in the military field, it has shown its irreplaceable role, and plays an increasingly significant role in modern warfare.

As a key component of electronic countermeasure, radar countermeasure is becoming increasingly fierce with the rapid development of electronic technology. Interference and anti-interference, like contradiction and shield, restrict and develop each other, and so on.

Interference identification technology is the prerequisite and key step of anti-interference, and also determines whether anti-interference measures are effective or not. In particular, modern war radar receives a large amount of data, and the traditional method of identifying jamming based on artificial experience has been unable to meet the requirements of battlefield environment. Therefore, radar is required to be able to identify all kinds of jamming automatically, quickly and efficiently. It has become one of the main directions of future electronic equipment development to master the battlefield dynamic information comprehensively and have the ability to survive and fight in the complex electromagnetic environment.

This paper reviews and introduces the current research status of active jamming identification technology in radar countermeasures. In view of the existing problems, some key problems to be solved in the future are put forward.

2. Development status of radar active jamming technology

In recent years, the development of radar jamming technology is becoming more and more mature. It is a serious threat to radar anti-jamming technology with the characteristics of complex, diverse, flexible and antagonistic jamming pattern.

Active deception jamming based on Digital Radio Frequency Memory [3] (as shown in "Fig. 1") is one of the hotspots of development. DRFM technology is based on high-speed sampling and digital storage technology. By storing, analyzing and duplicating digital radio frequency signals with a certain frequency and bandwidth, it can jam electronic equipment such as radar and missile fuze. Its advantages are: fast storage, retaining characteristic information, realizing multiple jamming control, generating deceptive signal coherent with radar target echo signal, generating new jamming modes such as frequency shift jamming, repeater jamming, dense false target jamming and compound jamming, so as to achieve ideal jamming effect with less power.

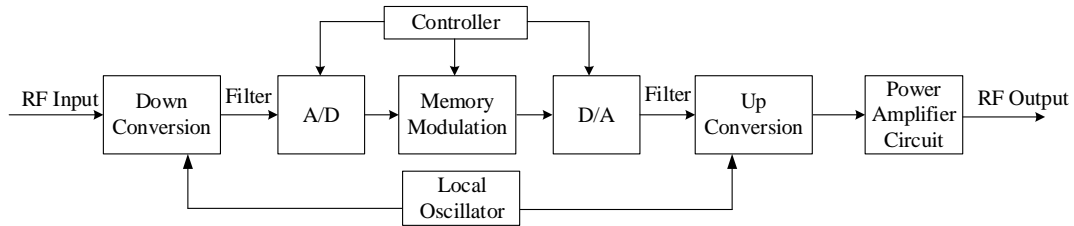


Figure 1. Schematic diagram of DRFM interference system

At present, DRFM technology has gradually developed towards systematization and practicality. The US fifth-generation stealth fighter F-35 can use DRFM technology to deceive enemy defense systems. In order to improve the air combat capability of the F-15, Japan has adopted EPAWSS (Passive/Active Alarm and Survival System) based on DRFM technology? Russia's L187AE new defense electronic system uses the DRFM core technology; from 2007, the US military began to upgrade the DRFM technology of the AN/ALQ-161 system equipped with the B-1 bomber, and represented the new development of deception jamming equipment. In addition, DRFM technology plays an important role in satellite communications, ultrasonic medical treatment, and destructive testing. Table 1 summarizes the technical characteristics of the four common types of interference. Therefore, the research of effective radar interference recognition technology has become one of the technical problems that cannot be solved urgently.

Table.1. Technical characteristics of new active jamming

Jamming Types	Conception	Characteristic
Compound jamming	A new type of jamming combining non-coherent suppressive jamming with deceptive jamming	It can reduce the detection probability of real echo and increase the ambiguity of jam signal.
Smart noise jamming	Convolution of noise modulated signal and intercepted signal	It solves the problem of non-coherent jamming signal and can produce double jamming of covering and deception.
High fidelity false target jamming	False target generated by DRFM jammer has high fidelity	It is highly realistic with the echo signal, and the jamming has been extended to multiple domains such as time, frequency and space.
Multiple false target jamming	Multiple false targets generated by interception signal of jammer	It has realistic effect, both suppressing jamming effect and deceiving effect.

3. Development Status of Radar Active Jamming Recognition Technology

As far as the traditional radar electronic system is concerned, operators often need to judge the radar jamming situation according to the radar display picture and their own experience, and implement the corresponding anti-jamming strategy through related operations [9]. But in such a fierce electronic countermeasures, it is difficult for the technicians who control radar to distinguish the jamming types in real time and accurately.

With the development of radar anti-jamming technology, a multi-level and multi-angle anti-jamming mode has been formed. Based on the difference of suppression method and operation time, radar anti-jamming measures can be divided into two categories: one is to weaken and eliminate the jamming signal before the receiver receives it, and to improve the signal-to-noise ratio as much as possible. The main ways are [10-11]: Antenna anti-jamming technology, transmitter anti-jamming technology, receiver anti-jamming technology, etc. The other is after the radar receiver receives the jamming signal. Whether it is suppressive jamming or deceptive jamming signal, there will be differences between radar echo signal and suppressive jamming signal. And this difference will be reflected in the time domain, frequency domain, time-frequency domain, and other transform domain of the signal. People usually use the difference of signal characteristics to realize the recognition of interference signal. At the same time, some scholars have proposed interference recognition algorithm based on maximum likelihood criterion [12]. Specifically, the mathematical model of radar jamming is established first, and then the statistical hypothesis test theory is used to achieve the purpose of classification and discrimination of radar jamming [13].

In view of the difference of signal characteristics, active jamming recognition is regarded as a pattern recognition problem at home and abroad. The database based on the prior information of radar signal is introduced into the field of data mining. The system flow and technical route are shown in “Fig. 2”. Compared with the traditional artificial judgment, great progress has been made.

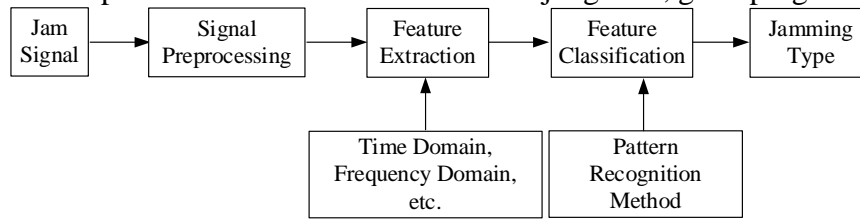


Figure 2. Radar Jamming Recognition Process

Pre-processing is the first step of system processing. Its main purpose is to reduce noise and multipath effects, and to suppress interference factors. Appropriate algorithm denoising algorithm can judge the dynamic characteristics of the signal, eliminate the influence of the noise signal to the greatest extent, enhance the stability of the system, and improve the final recognition accuracy of the system.

Feature extraction is equivalent to a kind of non-linear transformation [14]. Samples are represented in low-dimensional space by mapping method. Generally speaking, the size of the dry-to-noise ratio has a great impact on the feature extraction process. When the dry-to-noise ratio is too low, the noise will completely cover up the interference signal, and it becomes very difficult to extract the characteristics of the signal.

Feature classification mainly uses statistical method to classify the identified objects into a certain class in feature space through the design of classifier, so as to achieve the purpose of classification and recognition. Common classifiers are Decision Tree (DT) [7], Support Vector Machine (SVM) [8], Artificial Neural Network (ANN) [6], etc. Next, we will summarize the technical process of feature extraction and classification.

3.1 Feature Extraction

Feature extraction is a key link in signal recognition, and also a process of mining the essential information of signals. Because the size of the dry-to-noise ratio has a great influence on feature extraction. Therefore, we expect that the extracted feature parameters have good robustness to noise [15], and have obvious distinguishability among different interference types.

- The time domain characteristics of interference signals are based on the time domain space of signals, and the waveform characteristics are characterized. By synthesizing a large number of literatures, the commonly used time-domain characteristic parameters are summarized. Reference [13] discusses the mathematical modeling of the composite jamming signal, extracts the features of its samples in time domain and analyses the features. Random forest algorithm and soft Max classification algorithm are used to identify and classify the two classifiers respectively. The classification and recognition ability of the two classifiers for Radar Composite jamming is verified, and the Monte Carlo method is used to evaluate the classification and recognition ability of the two classifiers. Reference [18-20] based on signal processing, has carried on the detailed characteristic analysis to each kind of interference signal in the time domain, has extracted many characteristic parameters, and has quantitatively studied their distribution along with JNR. According to the difference between these characteristic parameters, carries on the organic combination, may provide the basis for the active interference type recognition. Reference [21-23] considers that the normalized instantaneous maximum amplitude feature can be used to distinguish signals containing amplitude fluctuation information from signals without amplitude fluctuation information.

- In addition to time domain characteristics, frequency domain transformation is also a basic transformation of signals. The spectrum or power spectrum of signals can be obtained by Fast Fourier Transform (FFT) transformation. Frequency domain analysis makes up for the shortage of time domain analysis to a certain extent, and further improves the comprehensive perception ability

of interference signals. Two kinds of features extracted from deception jamming signal in reference [25] are: convexity in bispectrum domain and stationarity in frequency domain. By constructing two-dimensional feature space of deception jamming signal and optimizing the initial value of BP neural network by genetic algorithm, a GA-BP neural network classifier is designed to avoid falling into local optimum. The simulation results show that the model is feasible. The average recognition accuracy is 91.2%. Reference [26] proposes that in frequency domain, based on wavelet decomposition, the approximate and detailed similarity coefficients of the energy distribution of interference signal and echo signal at different scales are extracted as the multi-scale similarity coefficients of interference signal. Finally, three classifiers, K-nearest neighbor, least squares support vector machine and BP neural network, are used for interference recognition, and good results are obtained.

- Compared with the single time-frequency domain, the time-frequency domain has more intuitive physical significance. In the process of radar jamming signal recognition, it plays an increasingly important role. Wavelet transform [23] divides the frequency band into several levels, which can depict the interference signal more carefully, and make up for the shortcoming of low resolution in high frequency band. Reference [28] analyzed the technical characteristics of DRFM jammer, studied the identification method based on the type of pull deception jamming, and proposed a wavelet decomposition method for normalized echo signal of a coherent processing period to realize interference recognition. Reference [29] Aiming at the recognition of interference types in communication field, a method of interference recognition based on wavelet packet energy and fractal box dimension is proposed. By designing BT-SVM classifier, the classification and recognition of interference signals are completed, and the recognition results are better than those of traditional methods. Wigner-Ville distribution [33] was first proposed by Wigner in the field of quantum mechanics. In the case of single component, the Wigner-Ville distribution of LFM signal has ideal time-frequency aggregation, so the field of free interference recognition has been widely concerned. In reference [34], aiming at the time-frequency signal characteristics of spectrum dispersion interference, Wigner-Ville transform is proposed to transform the interference signal into time-frequency plane, and the spectrum dispersion interference is identified by extracting the energy characteristic parameters of the signal, and a certain recognition effect is achieved. In reference [36], it is found that the Wigner-Ville distribution can produce cross-terms for the signals with non-linear frequency variation and multiple components, and the cross-terms will affect the time-frequency analysis results to a certain extent. Reference [42] proves that there is no Wigner-Ville distribution without cross-terms through theoretical analysis. Therefore, based on the purpose of suppressing cross-terms, some improved algorithms are proposed. In reference [35], SPWVD time-frequency image is obtained by time-frequency transformation for active deceptive towing jamming. The third-order Renyi entropy and time-frequency domain separability are used as feature parameters, and the deceptive jamming type is identified according to the feature parameters. Reference [37] analyzed the characteristic differences of five typical jamming signals. Choi-Williams transform was used to obtain the time-frequency two-dimensional distribution image based on jamming signals. Finally, according to the characteristics of the extracted characteristic parameters, a support vector machine classifier was designed to recognize the jamming signals, which provided a priori information for subsequent radar anti-jamming. Short-time Fourier transform (STFT) [38], whose basic idea is to multiply a window function with limited time before the Fourier transform of the signal, so as to realize the localization of the signal in the time domain. Compared with Wigner-Ville distribution, STFT is a linear time-frequency transformation, so there is no cross-term. Reference [40] introduces the short-time Fourier transform time-frequency analysis method to realize the comprehensive perception of LFM interference signal based on digital radio frequency memory replication.

- With the deepening of signal analysis in the field of recognition, a lot of research has been done on the interference recognition algorithm based on feature extraction at home and abroad, and some parameter features in other domains can also effectively identify the interference signal. Bispectral

transform [45-46] is a further representation of power spectrum, because power spectrum contains only amplitude information. The bispectrum has phase information and amplitude information. It can also suppress the influence of Gauss colored noise on non-Gauss signal and non-Gauss colored noise. Therefore, bispectrum transform is also a widely used signal analysis method [47]. References [48-49] proposed a bispectrum feature extraction method for range-velocity Gate Pull off (RGPO), Velocity Gate Pull off (VGPO) and velocity-distance Pull Off (R-VGPO), which can effectively combat deception jamming. Reference [50] a method of interference recognition based on pseudo-Zernike moments and bispectrum analysis is proposed for spectrum dispersion interference (SMSP) and slice combination interference (C&I). Compared with other methods, it has better recognition rate, stability and superiority in low dry-noise ratio. Fractal theory uses the mathematical tool of fractal dimension to describe and study objective things. Fractal can effectively depict similar signal waveforms. The box dimension can reflect the geometric scale of the fractal set, and the information dimension can reflect the fractal set's partial information [51]. In reference [52], fractal theory is applied to the spectrum of interference signal and target echo signal, and support vector machine (SVM) is selected as classifier to carry out interference recognition experiment. This method overcomes the drawback of low recognition efficiency of traditional methods. Reference [16] By analyzing the mechanism of smart noise jamming, three features are extracted, including box dimension feature, envelope fluctuation parameter feature and phase threshold probability feature, to characterize the difference between target and jamming signal in waveform, phase and scale information. The simulation results show that the method is effective and feasible in identifying smart noise jamming. With the further development of active interference identification technology, Specific Emitter Identification (SEI) technology emerges as the times require. Fingerprint feature [55], which is an unintentional modulation, is a parasitic modulation caused by the circuit system of radar system itself. This feature characterizes the inherent properties of each radar. DRFM has a natural advantage in generating deceptive jamming with high fidelity [32]. However, in the process of signal generation inside the jammer, it is unavoidable to produce non-linear distortion fingerprint features such as harmonics and spurious factors. Reference [41] uses Auto-Regressive and Moving Average (ARMA) model to characterize the phase noise generated by the transmitter's local oscillator, and extracts characteristic parameters based on ARMA model to realize the recognition of interference types. In reference [43-44], considering the phase quantization error of DRFM, the mathematical models based on distance-dragged interference and real echo signal are established respectively.

3.2 Data Compression and Feature Classification

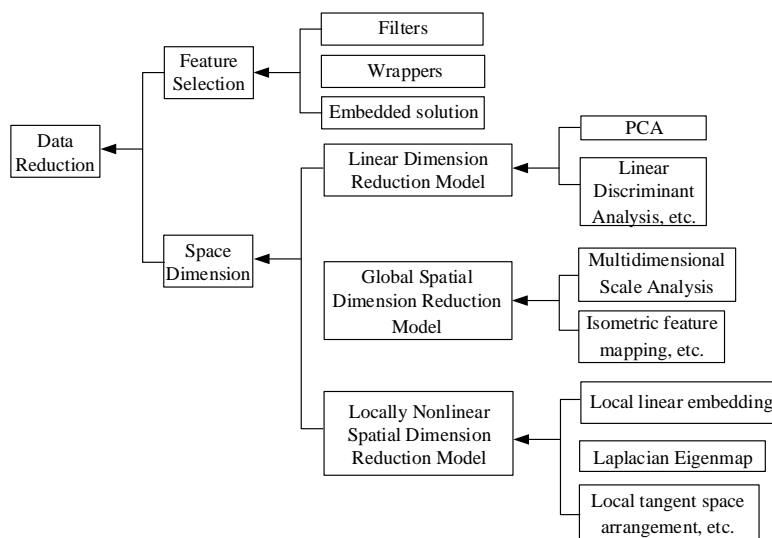


Figure 3. Main Methods of Data Dimension Reduction

The effect of pattern recognition is often related to the size of the data. However, large-scale data often contain redundant information, which will significantly increase the time of data processing,

not only is not conducive to improving the classification effect, but also falls into the "dimension disaster". Therefore, before feature classification, the effective dimensionality reduction of data is often considered before entering the classifier for recognition and judgment.

Data dimensionality reduction can be considered from two aspects: one is to select a suitable subset from the variable set according to some evaluation criteria by feature selection; the other is to study how high-dimensional data can be better represented in low-dimensional space by spatial dimensionality reduction, so as not to lose or lose necessary data information as much as possible. The main research methods of two dimension reduction methods are shown in Figure 3.

Feature classification is based on the extracted signal feature attributes, and the extracted feature vectors are classified into different categories according to a certain criterion. With the development of machine learning theory, the types of classifiers are increasing. Table 2 summarizes the performance characteristics of four common classifiers.

Table.2. Performance comparison of various classifiers

Classifier	Advantage	Shortcoming	Recognition performance
Decision tree	Suitable for high-dimensional data, able to process large amounts of data in a short time	Under the condition of high threshold value and low JNR, recognition is limited.	The JNR is greater than 5dB and the recognition probability is greater than 70% [14, 17, 28]
SVM	Without setting threshold value, it can handle high-dimensional data well and has strong generalization ability.	It is difficult to implement large-scale training samples, and it is important to select the kernel function.	The JNR is greater than -3dB and the recognition probability is greater than 85% [18, 61]
BP Neural Network	It can realize non-linear mapping, has fault-tolerant ability, and has high learning ability.	Slow convergence and possible local extremum	The JNR is greater than 5dB and the recognition probability is greater than 90% [15, 18, 20]
Convolutional Neural Network	It can automatically extract feature [31]. It has strong robustness and high recognition rate.	Long training time and high hardware requirement	The JNR is greater than -10dB and the recognition probability is greater than 90% [31]

4. Summary and Prospect

Facing the increasingly complex battlefield environment, the development of active jamming recognition technology has made some achievements. However, human interference identification can no longer meet the needs of the battlefield, so it needs to be improved and perfected from the following aspects:

- More and more complex electromagnetic environment puts forward higher requirements for active interference identification technology. As far as the current research is concerned, how to extract signal features and achieve high recognition rate under the condition of low interference-to-noise ratio will also be one of the research directions.

- It is difficult to recognize new active jamming, such as high-fidelity false target jamming, effectively based on the characteristic parameters of a single domain. Therefore, the method based on joint extraction of

- Multi-domain feature parameters is currently an effective means of recognition. With the increasing types of interference, the difficulty of identification of interference is also increasing. We need to further expand the feature field to reflect the essential characteristics of different interference signals from multiple perspectives.

- The existing classifier algorithms generally have the shortcomings of imperfect classification rules, long training time and a large number of prior sample knowledge. We need to find a classifier

with better classification effect and more suitable for engineering implementation, so as to maximize the difference of extracted features.

- With the increasing types and methods of interference, the amount of signal data processing will become more and huger. Therefore, we need to study how to reduce the dimension of data effectively under the condition of ensuring the recognition rate, so as to reduce the amount of calculation and improve the efficiency of operation.

- Machine learning, as an important research of artificial intelligence applications, has been widely used in image recognition, speech recognition, data mining and other fields. At present, there are still some problems in interference recognition technology, such as weak intelligence and autonomy and poor generalization. We need to integrate machine learning into the field of radar active jamming recognition better, reduce the impact of human factors on the recognition results, and promote the development of radar countermeasures technology to the direction of intelligence and autonomy.

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