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PRC-CW Radar Target Recognition Based on Chaotic Dynamics and Artificial Neuron Network

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Abstract: To the nonlinear and time variation of Pseudo-Random Coded Continuous Wave (PRC-CW) radar backscattering spectrum, this paper adopts chaotic approach to analyze the characteristics of PRC-CW radar moving target's echoes. Based on analysis and calculation of Lyapunov spectrum, correlation dimension and Kolmogorov entropy to different kinds of moving target, it can be concluded that PRC-CW radar backscatter possesses some chaotic natures. Moreover, a classifier based on Adaptive Resonance Theory (ART) Artificial Neuron Network (ANN) is derived to achieve a satisfied recognition result and overcome the unstablity of different kinds of targets' features.

1. Introduction

Pseudo-Random Coded Continuous Wave (PRC-CW) Radar has low intercept probability, excellent Electronic Counter Countermeasure (ECCM) performances superior to the conventional puls e radar [1]. With the rapid development of modern microwave solid apparatus, PRC-CW radar has achieved wide applications on transport management, control, surveillance, reconnaissance, guidance and tracing. It is known that radar with continuous waveform has good resolution in frequency domain, and radial velocity of target can be easily acquired by the measurement of Doppler shift. But continuous wave radar without modulated waveform has no discriminating capability in time domain, so frequency modulation or phase modulation is often adopted to improve range resolution. PRC-CW radar takes the latter, and the modulated function includes many kinds of coding with excellent time correlative performance, such as M series. Unfortunately the length of these kinds of coding are normally finite, and it is inevitable to bring about range ambiguity with the guarantee of range measurement precision in large area use.

The processing flowchart of PRC-CW radar is illustrated as following: The carrier wave produced by mic rowave vibrator modulated by Pseudo-Random coding is transmitted through antenna, and the backscattering after mixing and amplifying can provide both range and velocity information by decoding and narrow-band filtering. But to cover certain large area in real use, the range resolution of PRC-CW radar is always not high enough, normally tens of meters. It is obvious that target scattering structure acquired by PRC-CW radar is comparatively limited due to above resolution So it becomes demanding to develop new methods to discriminate targets with same radial velocity but different scattering characteristic in PRC-CW radar.

In the recent years, Chaotic in the radar signal processing application has drawn more and more attention. H Leung [6] proved that the backscatter from sea surface possess the chaotic nature firstly based on real data. Moreover, Lo T and H Leung [7] reconstructed the dynamic of sea clutter based on neuron network predictor (RBF network) according to correlative dimension. And excellent detecting performance to weak target on sea surface was achieved with above predictor, which is more effective than many conventional methods. S.haykins[8] and his colleagues further researched the sea clutter characteristics and detection methods in X-band radar in detail. Dong and et al [2] have proved that backscatter from sea surface in High Frequency (HF) band is chaotic based on real data. In the radar target recognition, Xian and et al [3] have introduced chaotic and Multi-fractral to the explanation and recognition of High Resolution Range echoes of different flying targets, and make effort to disclose the complicated nonlinear dynamics of radar echoes. This paper discusses chaotic in the application of PRC-CW radar moving target analysis and recognition based on above researches.

2. Chaotic Dynamic and its Invariants

Chaos is a kind of complex behavior of a low-order dynamical system that is both nonlinear and deterministic, and the output of system exhibits sensitivity with respect to initial conditions. Consider a nonlinear dissipative dynamic system whose state space or phase space is described by the differential equations

$$\frac{d}{dt}x(t) = f(x(t)) \qquad (1)$$

Where $x(t)$ is the state vector at time t and $f(\ )$ is a continuously differential function, and dimension of $x(t)$ is m . For the computational purpose we can get the difference equations by discretization on t, which form a projection from R^m to itself.

$$x(n+1) = f(x(n)) \quad n = 0,1,2, \ldots.. \tag{2}$$

The signal generated by system reflects the dynamics characteristics of system. At first we define an attractor as a subset of the m dimensional state space of the system towards which all sufficiently close trajectories converge asymptotically. To chaotic system, three principle invariants, namely, correlation dimension, Lyapunov spectrum, and Kolmogorov entropy can be naturally served as invariants or features for target recognition.

2.1 Lyapunov Spectrum

Lyapunov exponents describe the action of dynamic by defining the evolution of attractor's trajectories, and they measure the exponential rate of growth or shrinkage of principle axes of evolving ellipsoid. For a state space of dimension m, there will be an array of m Lyapunov exponents ordered by value as $\lambda_1 \geq \lambda_2 .... \geq \lambda_m$. This array is called Lyapunov spectrum. In non-chaotic dynamic system, The growth rate of principle axes is negative or approaching infinite. So we can different attractor by maximum Lyapunov exponent. The maximum Lyapunov exponent is positive in chaotic system, which assures system evolution sensitive to initial conditions.

2.2 Correlation Dimension

Whereas Lyapunov exponents describe the dynamics, the correlation dimension characterizes the distribution of the points in the state space of the attractor. The correlation dimension is obtained from the correlation between randomly selected points set $\{x(n)\}_{n=1}^N$ on the attractor. The spatial correlation between pairs of points $(x(n), x(k))$ with $n \neq k$ is measured by the correlation integral $C(r, N)$, which is defined

$$C(r,N) = \frac{1}{N}\sum_{i=1}^{N}\frac{1}{N-1}\sum_{j=1}^{N-1}H(r - \|x(i) - x(j)\|) \tag{3}$$

where $H(\cdot)$ is Heaviside function, $\|x(i) - x(j)\|$ is defined Eucildean distance between $x(n)$ and $x(k)$. For a sphere of small radius r the correlation integral $C(r, N)$ grows in accordance with a power low. Thus we can get correlation dimension according to the following formula.

$$D_2 = \lim_{\substack{r \to 0 \\ N \to \infty}} \frac{\log C(r, N)}{\log(r)} \tag{4}$$

And (4) can be solved by least square error method, the slope of the approaching line is D_2. The correlation dimension of chaotic process may be a non-integer, which provides a lower bound on the embedding dimension m.

2.3 Kolmogrov Entropy

Kolmogrov entropy (K entropy) can be considered as a measurement of the disorder content of system and a generalization of Shannon entropy. The different kinds of K entropy correspond to different dynamic systems

i) $K = 0$: Regular system;
ii) $K > 0$: Chaotic system;
iii) $k = \infty$: Stochastic system

So we can give the basic description of system according to different value of K entropy.

3. PRC-CW Radar Echoes Dynamics Analysis and Invariants Extraction

In the research of moving target echoes from PRC-CW radar, we find their spectrums possess characteristics of nonlinear and time variation. The typical spectrum of a running tractor is illustrated as Fig.1. During 0.5 second both Doppler peak and structure changed obviously.

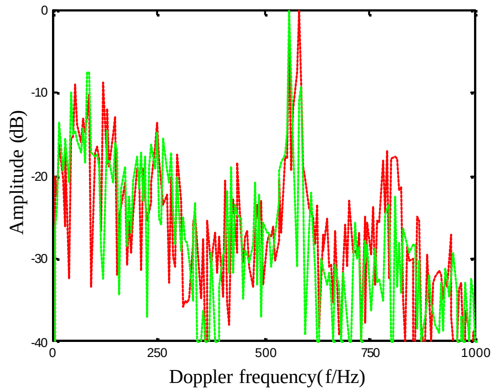

Fig.1. Doppler Spectrum of moving target

We have designed a complete flowchart for extraction of different invariants of one-dimension chaotic time series, and it is illustrate as fig.2. The detailed definition and processing of every step can be found in [5].

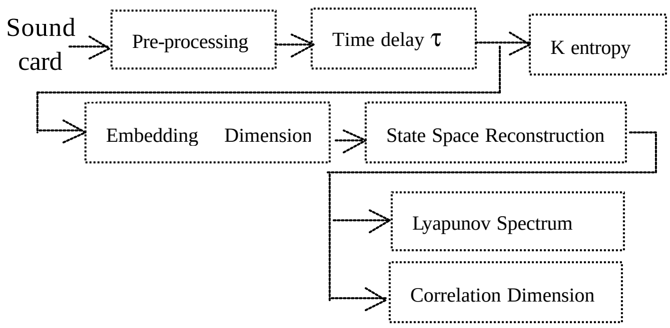

Fig.2 Flowchart of PRC-CW chaotic analysis

To reduce the complexity of system, we designed a processing system by out-of-shelf sound card to experimental PRC-CW radar that is designed for reconnaissance. And target detection and parameter estimation are realized by operator's interception with ear. This PRC-CW radar adopts M-series coding for match filtering. And the range resolution is about 50m, which corresponds to 3MHz processing bandwidth. According to Nyquist sampling principle, the sampling frequency should be set more than 6MHz to avoid spectrum overlap. To satisfy this condition we should design corresponding processor and software, which is actually not a too difficult task. But for the portability consideration, we designed a simple system based on an integrated portable Personal Computer (PC). The sampling frequency of general sound card is 22.05KHz, which cover the Doppler shift of most moving targets illuminated by X-band radar. On the other words, we will realize target recognition with these special echoes that contain total Doppler information and distorted range information due to under-sampling. To this kind of time series we perform the chaotic dynamics analysis according to above flowchart.

Three kinds of targets are selected in our experiments, single walking man, three walking men and moving tractor. They were all repeatedly illuminated in more than several hundreds meter away and out of vision. A typical sampled echo of moving tractor is displayed as Fig.3. Because the system SNR is not high enough, we adopt Haar wavelet as an effective pre-processing filter to eliminate noise. Time-delay estimating by temporal correlation is given as Fig.4, and it can be found that the first minimum located about 8th points, so we set $\tau = 8$. Consequently we determine the embedding dimension according to Cao's method. With τ and m we can reconstruct state space as Fig.6. Moreover, The statistics of maximum Lyapunov exponent λ_1, Correlation dimension D_2 and Kolmogrov entropy K_2 are calculated and illustrated as Table.1.

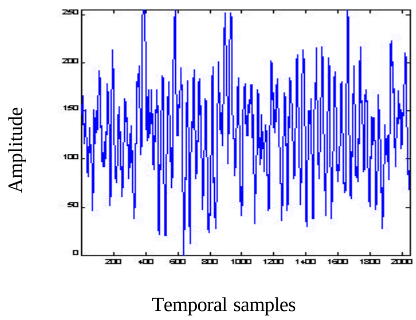

Fig 3. Real data sampled from PRC-CW radar

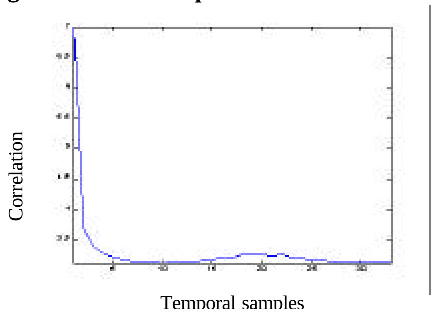

Fig. 4. Estimating Correlation Dimension

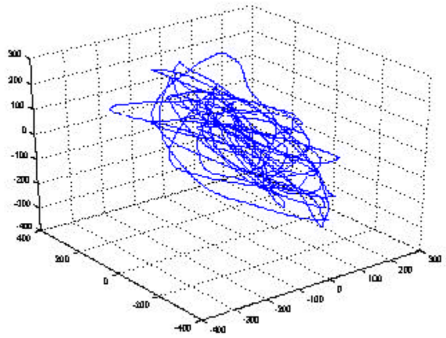

Fig.5. Reconstructed State Space (attractor)

	One man	three men	tractor
λ_1 mean	0.80426	0.88704	0.76641
λ_1 variance	0.03352	0.02999	0.04785
D_2 mean	1.44364	1.48671	1.85576
D_2 variance	0.05196	0.07677	0.02199
K_2 mean	0.56698	0.50111	0.17764
K_2 variance	0.19539	0.09286	0.20513

Table.1 Extracted Chaotic Features of different targets

From above Table.1, we can find maximum Lyapunov exponent, correlation dimension and Kolomogrov entropy of different target echoes are all-positive, which indicate the echoes from PRC-CW radar are chaotic. And different invariants reflect internal dynamical characteristics of these attarctors.

4. PRC-CW Radar target recognition based on Chaotic invariants and Neuron Network

While tractor's Doppler shift centralizes around 520Hz due to its 15m/s radial velocity to radar, walking man Doppler shift centralizes 60Hz due to their 1m/s radial velocity. So to discriminate walking man and tractor is easily realized by Doppler filtering. But it is nearly impossible to recognize one walking man and three walking men only by frequency information, because the radial velocities of these targets are almost same and undulated.

From Table.1, it is obvious that the correlation dimension and Kolmogrov entropy serves well features to discriminate tractor and walking man like Doppler shift. And we also cannot recognize these above three targets directly from the extracted chaotic features because many feature values are overlaid and unstable, especially for one walking man and three walking men. So only nonlinear classifier with statistical features can be expected to achieve more excellent performance in target recognition by exploiting all three chaotic invariants. An Artificial Neuron Network (ANN) classifier based on Adaptive Resonance

Theory (ART) is designed to realize this processing.

S.Grossberg and G. .A.Carpenter presented ART in 1987, and it has become a useful tool in pattern recognition. The self-organization function of ART ANN is used to serve a kind of classifier, and ART can flexibly extract valuable information to time-varied input vectors. With ART the input vectors can be adaptive clustered, and the number of clusters adaptively change according to pre-set alarm threshold. The chaotic features are some kinds of dynamical feature, and they will undulate around certain value by different segments of sampled series. So we form four-dimensional training vectors including maximum Lyapunov exponent, correlative dimension, Kolmogrov entropy and Doppler frequency extracted from 2048 points echo to train the ART classifier. During recognition we divide the sampled series into L echoes with 2048 points, when the real sampling echoes have L*2048 points. At last we get the last recognition result d from these L classifying results.

$$d = \max\{N(c_i)\} \quad i = 1,......,L \tag{5}$$

Where $N(\cdot)$ is a $N^L \rightarrow N^M$ function, and it gets frequency of M targets from L segments classifying result. Now we form a complete PRC-CW target recognizer structure based on chaotic invarians and ART classifier as Fig.6.

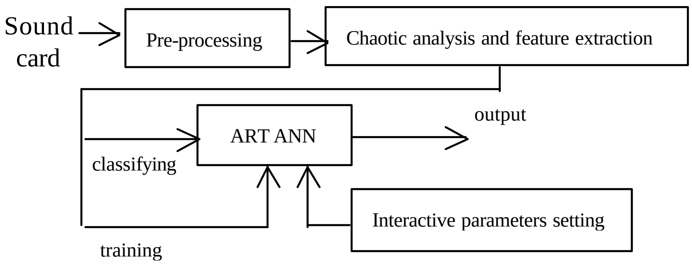

Fig.6 PRC-CW target recognizer based on ART classifier

It should be pointed out that there are many advantages to use ART ANN as a classifier.

1) The ART ANN adopts Non-supervisor learning method to train the whole network, but we can adjust the alarm threshold, the neuron number of different layer of ANN and so on interactively to control and determine the cluster number and classifying precision.
2) The converging velocity of ART ANN is real time;
3) It is easily to extent above recognizer to many other new kinds of targets with ART ANN Classifier.

We get the last classifying result based on real data as Table.2. Using some of them to train the classifier and using other for classifying. We choose the data set of different target to be classified are all 100 and limit the L to 8 for keep the comparability among different targets.

	One man	Three men	Tractor
Correct ratio	92%	91%	100%

Table.1 Extracted Chaotic Features of different targets

4. Conclusions and Prospect

From above table, the validity and practicability of PRC-CW moving target recognition based on chaotic invariants and ART classifier is proved. The next steps of our research include two aspects, one is to research the cause of PRC-CW radar target chaotic dynamics in-depth, and the second is to apply the recognizer to many other new kinds of PRC-CW moving target.

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