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A New method for Radar Target Recognition Based on Wavelet and Neural Network[i]

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Abstract Wavelets decomposition is known to be a useful tool to characterize and decompose a signal. Artificial neural networks, automatically construct associations based upon the results of known situations. In this paper, how to use the wavelet transform and ART neural network on radar target recognition is discussed. An algorithm of constructing feature vector for automatic recognition based on multi-range cell is proposed, it can make the dimension of feature vector be much smaller than dimension of primitive echo signal. The simulation results indicate that the performance of the new algorithm is better than the existing ones.

Keywords radar, wavelet transform, multi-resolution analysis, neural network, and target classification

1. Introduction

In a radar imaging system, the information, which describes the target, is a function of time delay, containing the backscattered signal and Doppler frequency. Nowadays, most approaches to the automatic radar object recognition are based mainly on utilization of high-resolution radars.

How to get the feature vector of radar target from complex background and recognize it, accurately is one of the critical technologies for military purposes. Here, a method for radar target recognition is proposed. Wavelet transform, which can not only improves recognition correct rate, but also reduce the space dimension of feature vector, which fed to the neural network, is used to extract the feature vector of the radar target from echo signal and a ART-2 neural network is used as the classifier.

In this paper, the simulation is focus on the signals of the MMW radar system. The simulation results show that this method is very effective.

2. Wavelet Transformation

Wavelet transform is a tool that cuts up data or functions or operators into different frequency components, and then studies each component with a resolution matched to its scale. It is widely used in many of signal processing. For radar signal processing, it has been used to detect moving targets and classification targets.

Wavelet transform of a signal evolving in time depends on two variables: scale and time. The continuous Wavelet transform of $x(t)$ is defined as:

$$W_x(a,b) = a^{-\frac{1}{2}} \int_{-\infty}^{+\infty} x(t)\, g^*\left(\frac{t-b}{a}\right) dt \qquad (1)$$

g(.) is a wavelet which changes according to the scale parameter a and translates by *a* factor *b*.

Discrete wavelet transform of $x(i)$ is defined as:

$$DWT(m,n) = a^{-\frac{m}{2}} \sum x(i)\, h\left(\frac{i - nb_0 a_0^m}{a_0^m}\right) \qquad (2)$$

Where *h(.)* is discrete wavelet, a_0 and b_0 are the discrete scale and translation step sizes, respectively.

Discrete wavelet transform can be calculated by Mallat's pyramid algorithm, which shown in figure 1. Where L, H represents a low-pass and a high-pass filter respectively decided by the wavelet basis separately.

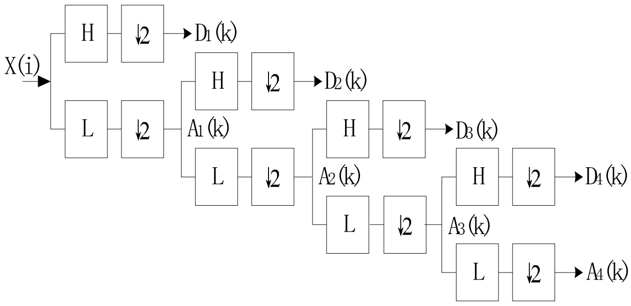

Fig. 1 Mallat's pyramid algorithm

3. ART neural network

ART is a kind of competitive neural network, can self-organize and self-stabilize in response to complex input vectors. When given an input vector, it tries to classify it into one of existed categories depending on which of stored patterns it most resembles. If the input vector does not match any stored pattern, a new category is created. No stored pattern is modified if it does not match the current input pattern.

Fig2 gives the architecture of ART network. It has two layers, F1 (N neurons), the comparison layer, F2 (M neurons), the recognition layer. F1 and F2 layers store pattern information during Short-Term Memory (STM) process. They are interacted by bottom-up b_{ij} and top-down t_{ji} Long-Term Memory (LTM). Gain1, Gain 2 and STM Reset are control functions for training and classification.

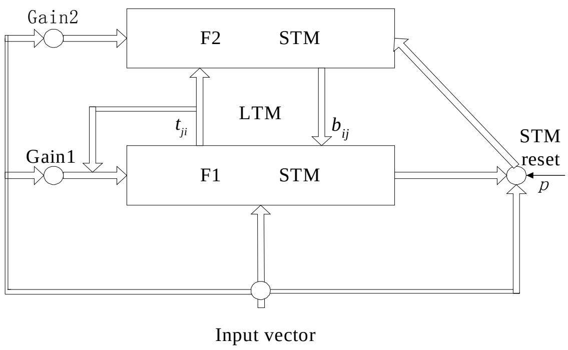

Fig. 2 Architecture of ART network

Conventional back propagation (BP) algorithm, too often, learning a new pattern modifies previous trained weights. The network needed is making it not to retrain the entire set of input vectors when a new input vector is given. ART neural network can solve this dilemma.

When given a new non-zero binary input vector *X* ($x_i \in \{0,1\}$, i=1,2…N), the network attempts to classify it into one of the existing categories.

Define:

b_{ij} - the weights of F2 node j from the input vector *X*.

Bj - the value of F2 node j(has the maximum output value) to F1 layer nodes.

T_j- the vector of F2 node j(has the maximum output value) to F1 layer nodes.

t_{ji} - the weights of the top-down connection between F2 node j and F1 node i.

C – the binary vector of the value of bit AND between the input *X* and T_j. $C = X \cap T_j$.

ρ - the system parameter called vigilance.

β (>1)- learning rate.

For each node j in the F2 layer,

$$B_j = \sum_{i=1}^{N} b_{ij} x_i \quad (3)$$

Then the top-down vector T_j ($t_{ji} \in \{0,1\}$, i =1, 2…N) of the F2 node with the highest *Bj* is compared to the current input vector X at F1.

If $$\frac{|C|}{|X|} \geq \rho \quad (4)$$

Then the input X is classified to F2 node j. And the bottom-up and top-down weights are adjusted by

$$b_{ij}^{new} = \frac{c_i}{\beta + |C|} \quad (5)$$

$$t_{ji}^{new} = c_i \quad (6)$$

The operator $|X| = \sum_{i=1}^{N} x_i$. And $V \cap W$ equals the bit wise AND of vectors V and W.

If the selected category F2 node j does not match the input pattern sufficiently, “STM Reset” unit will reset F2 layer, the former selected F2 node is disabled and a new F2 node will be selected. It will be repeated until either the network finds a stored category that matches the input based on equation (6) or create a new F2 node as a new category.

The system parameter ρ defines the category size: the higher the vigilance, the more finer categories will be created. If ρ =1, the ART will produce a new category for every different input vector.

Based on the above principle, the ART classification algorithm is:

1. Initialization.
2. Apply new input vector $X=\{x_1, x_2 \dots x_N\}$.
3. Find the closet prototype vector from the set of candidate feature vectors.
4. Check if the selected feature vector is far from the input vector.
5. Update the matched feature vectors or create a new category.

ART-1 is designed to accept only binary input vectors, whereas ART-2 can classify both binary and continuous input. Here, ART-1 is referred to as ART.

4. Construction of Feature Vector and Radar Object Recognition System

The goal of the radar target recognition system is to assign observed input vector to one of several types. The configuration of the radar object recognition system is show in figure 3.

In general, an object recognition system involved three stages, signal pre-processing, extraction stage and recognition.

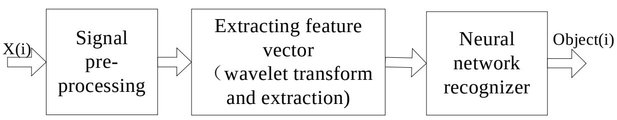

Figure 3.Radar object recognition system

Output of the neural network is vector, which the nonzero element corresponding to the one of the recognized radar object.

4.1 Signal pre-processing

We define feature vector as [y (1), y (2)…y (l)] and range profile vector as [x (1), x (2)…x (n)] ，that has been pre-processed focuses on removing effect of profile shift and its absolute amplitude. When the range profile vector pre-processing as below, then absolute amplitude’s effect is removed.

$$x_p = \frac{x(i)}{\sum_{i=1}^{N} x(i)^2} \qquad (7)$$

4.2 Extraction stage

The purpose of the feature extraction stage is to reduce the complexity of the input space by mapping raw input into feature vector in a feature space.

Firstly, extracting feature by wavelet transformation.

In this step, we can separate useful signal from noise by using prior information. Concretely, for each level, a threshold $f_T(j)$, which decided by the singularities of signal and noise, acts on $w^j f(j)$ wavelet coefficients. For each scale, if the wavelet coefficient grates than $f_T(j)$, we can reckon that it includes useful signal and hold it. Otherwise, it is considered that breed by noise, and set as zero. After approach, signal can be separated from noise effectively, so it can be from new signal sequence.

The wavelet transformation has advantage of a physical meaningful interpretation that cannot be claimed by classical detection method such as matched filtering. But we cannot feed the entire wavelet transformation to recognizer, for it will result in too large recognizer and long calculation time. The feature vector of small dimension is expected, and the same time, the feature vector must represent main properties of wavelet coefficients.

Secondly, constructing feature vector from wavelet coefficients. The algorithm consist of next steps:

For details coefficient of each level:

$$D_j = \frac{\sum_{k=1}^{N} D_j(k)}{2^{J-j}} \qquad (8)$$

Constructing feature vector's other elements:

$$y(i) = \frac{D_j}{\sum_{j=1}^{J} D_j} \qquad (i=1,2\ldots J) \qquad (9)$$

$$y(J+1) = \frac{1}{N}\sum_{k=1}^{N}\left[A_J(k) - \frac{1}{N}\sum_{k=1}^{N} A_J(k)\right]^2 \qquad (10)$$

Where j is level decomposition and J is number of decompositions.

4.3 Recognition stage

In this stage, an ART-2 neural network is utilized as the recognizer. Based on the ART system, bottom-up weights are initialized to low values while top-down weights must be initialized to ones.

5. Result of Simulation

For simulation, there are four kinds of simplify targets, Tank, car, plane and metallic building. The simulated backscattered signal of tank is shown in figure 4.

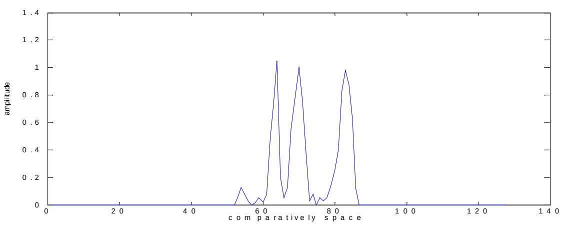

Fig. 4 Simulated primitive echo signals of tank

The simulated primitive echo signal has 128 samples in range and 100 periods in cross range. Six-step multi-resolution decomposition is done using Mallat's pyramid algorithm. The dimension of output feature vector is 7, and ART-2 neural network vigilance parameter ρ is 0.8. The result of simulation for different SNR (signal noise ratio) is shown in table 1. From the simulation result, we can see that even if in the case of low SNR, the recognition ratio is still high.

Table 1. Recognition correct ratio for SNR=10dB

Object	Correct recognition ratio(%)	
	SNR=10dB	SNR=4dB
Tank	100	97
Car	98	96
Plane	100	98
Building	84	76

6. Conclusion

This paper presents radar object recognition method based on wavelet transform and ART-2 neural network. The algorithm of extracting feature vector with wavelet transformation is proposed above. Here, wavelet transform also takes the place of data compression and noise depression. The simulation results show that, this method is very effective for MMW radar object recognition, Even if in the case of low SNR, the recognition ratio is still high.

References

1 S.Mallat, "A theory for multisolution signal decomposition: the wavelet representation", IEEE Trans. Pattern Analysis and Machine Intelligence, Vol.11, No.7, July 1989.

2 S. Mallat and W.L.Hwang "Singularity detection and processing with wavelet", IEEE Trans. Inform. Theory, Vol. 38, No 2, Mar.1992.

3 S. Mallat and Sifen Zhong, "Characterization of signals from multiscale Edges", IEEE Trans. Pattern Analysis and Machine Intellligence, Vol. 14, No. 7, July 1992.

4 E.F.Knott, J.F.Shaffer, and M.T.Tuley, "Radar Cross Section", Artech House, 1993.

5 Ross, R.W, Hibler, D.L, "Target Recognition Using Neural Networks for Model Deformation Measurements", Neural Networks, 1999. IJCNN '99. International Joint Conference on , Volume: 5 , 1999, Page: 3152 -3155

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