

# SOURCE CLASSIFICATION USING POLE METHOD OF AR MODEL

*Jianguo Huang, Jianping Zhao and Yiqing Xie*

College of Marine Engineering  
Northwestern Polytechnical University, Xi'an, 710072, P.R.China

## ABSTRACT

An easy and efficient method to classify the underwater sources for passive sonar by extracting poles of AR model as the feature of source emitted noise is proposed. Our research demonstrates that poles of AR model can represent the intrinsic spectral characteristic of sources, and the simple statistical classifiers can be used to have excellent recognition performance due to the good cluster property and robustness of poles corresponding to different sources. It is more important that poles of low order AR model can represent the basic feature of source, thus the computation burden will be reduced significantly. Real data are processed and classification results show the efficiency even for short data records.

## 1. INTRODUCTION

Source identification and classification is an important research area in radar, sonar and so on. A main difficulty lies in extraction and selection of features of sources contained in observed data. The common way is to project original data on a low dimensional space so as to capture parameters representing the essential attributes of a source. The set of candidate features should be formed under the following considerations: 1) It should contain the characteristics of source that can be discriminated from the others; 2) It has consistence under different measurements; 3) It has immunity to environments; 4) It is easy to be extracted and classified using simple classifier. Many people have studied this problem with various tools, such

as FFT, wavelet transform, and modern spectral analysis [1], while there exists some defaults in the selection of feature such as high dimension of feature space, the sensitivity to environment and poor cluster property. Although advanced classifiers such as ANN, expert system are designed, the improvement of recognition performance is not so satisfied, and the implementation is more complex.

Some authors find that natural resonance of source is a valuable feature for classification [2][3][4] and use Prony algorithm to extract poles of Radar target[4]. Based on the idea of natural resonance frequency we deeply study the nature of spectrum of noise from underwater sources, and find that some spectral lines yielded by the oscillation of mechanical parts contain characteristics of source. From the point of view of modern spectral analysis[5] a high-order AR model can be used to approximate the PSD of the process and the spectral peaks in the PSD can be represented by the poles of AR model. Our method extracts the poles of AR model as intrinsic features of source which satisfy the above 4 conditions and use the simple statistical classifiers to achieve efficient recognition performance.

## 2. SPECTRUM OF SOURCE NOISE AND AR MODEL POLES

It has been proven theoretically and practically that the power spectrum density(PSD) of noise emitted by ships is constructed by continuous wideband spectrum plus discrete spectral lines

located in low frequency band. Fig.1 shows the typical PSD (periodogram) of 4 kind of noise data representing different ships. Modern spectral estimation technique is more suitable to model the noise data and obtain a more reasonable estimation of PSD with less bias and variance for short data records.

For a WSS sequence  $x(n)$ , it can be well approximated by a rational transfer function model as

$$x(n) = -\sum_{k=1}^p a(k)x(n-k) + \sum_{k=0}^q b(k)u(n-k) \quad (1)$$

where  $u(n)$  is the driving noise. This is the well known ARMA model whose system function is

$$H(Z) = \frac{B(Z)}{A(Z)} \quad (2)$$

where

$$A(Z) = \sum_{k=0}^p a(k)Z^{-k}, \quad B(Z) = \sum_{k=0}^q b(k)Z^{-k} \quad (3)$$

If all the  $b(k)$  coefficients are zero, except  $b(0)=1$ , in the ARMA model, then

$$x(n) = \sum_{k=1}^p a(k)x(n-k) + u(n) \quad (4)$$

which becomes an AR process of order  $p$ . Its PSD is

$$P_{AR}(f) = \frac{\sigma^2}{|A'(f)|^2} \quad (5)$$

where  $\sigma^2$  is the variance of driving noise  $u(n)$ , and

$$A'(f) = A(e^{-j2\pi f}) = 1 + \sum_{k=1}^p a(k)e^{-j2\pi f k} \quad (6)$$

There exist many efficient algorithms to solve the  $a(k)$  coefficients such as the Yule-Walker method, the covariance method, the Burg method, Marple method, the recursive MLE method, etc., so this model has been widely applied in various cases. In addition, Kolmogorov theorem states that any WSS process can be modeled as an AR process with a high enough order, that is why high order AR model is widely applied in signal modeling. According to the nature of the PSD of ship emitted noise, we can model the noise sequence with an AR

model with sufficient high order.

Since AR coefficients can represent the PSD, they can act as the features for classification, as stated by many authors. In this paper we don't use AR coefficients to construct feature space because they will vary greatly with the change of environment and posture of ships. Although the poles are derived by the solution of AR coefficients, they have relevantly lower variability than AR coefficients. The poles can represent not only the PSD of signal stably but also, in some degree, the natural oscillation frequencies of mechanical parts of ships, which are the intrinsic characteristics of ship emitted noise. It is more important that poles construct good cluster and little overlap occurs among different types of emitted noise.

### 3. EXPERIMENTS AND RESULTS

There are two approaches to accomplish the classification by using poles method of AR model. First, we choose a high-order AR model and extract poles from AR coefficients. Experiments show that 20-order AR model is enough to model ship emitted noise. Because 20-order poles provide redundant information as well as heavy computation to classifier, we have to compress the dimension of the feature space through applying Karhunen-Loeve(K-L) transform to map the 20-order poles to 6-order or lower. [6] states that the imaginary part of poles is more suitable to act as the features but didn't explain why. Our research and experimental results show the reason. The distribution of real part and imaginary part of poles of 2-dimension compressed using K-L transform from 20-order poles of AR model are shown in Fig.2 and Fig.3 respectively. The different symbols represent the 4 different ships respectively. It is obvious that the imaginary parts do construct better cluster than real parts.

According to AIC criteria low-order AR model can represent the basic feature of ship emitted noise

appropriately. That is to say , poles of low-order AR model can be used to construct the feature space so as to avoid complex computation and K-L transform. Fig.4 shows the PSD of 6-order AR model of 4 kinds of ship emitted noise data. It can describe the PSD in a concise way.

In order to reduce the dimension of feature space further we even apply 4-order AR model. The poles extracted from 4-order AR model of the 4 kinds of ship noise are drawn in Fig.5 when data length is 256 points and the classification result is shown in Table 1. Figure 6. is that for data length 128. It is obvious that even lower order AR model and short data record can still yield satisfied classification results as shown in Table 1 and Table 2.

#### 4. CONCLUSION

Our research demonstrates that pole method of low-order AR model can construct a good feature space in classification of underwater passive sources, and it is easy to implement the process of feature extraction and classification eventhough using the simple nearest neighbor classifier. Results based on real data indicate that this is a prospective method in practical applications.

#### REFERENCES

- [1] Amlan Kundu,et al., "Transient Sonar Signal Classification using Hidden Markov Model", Proc. ICASSP'94 325-338
- [2]R.K.Main,D.Moffatt, "Complex Natural Resonance of an Object in Detection and Discrimination", TR-3424-1, Ohio State Univ., Electroscience Lab., June 1974
- [3]P.C.Reddy, "Radar Target Classification by Natural Resonance: System Analysis", AD-A241, Sep. 1990
- [4] Chuang C.,W.et al, "Natural Resonance of Radar Target via Prony's Method and Target

Discrimination", IEEE Trans.on AES, Vol.12,No.2. 1976

[5] S.M.Kay, *Modern Spectral Estimation: Theory and Application*, Prentice Hall,1988

[6]Zheng Zhaoben et.al, "Underwater Target Recognition Using Poles", Physics Journal, Vol.33. No.4, April 1984

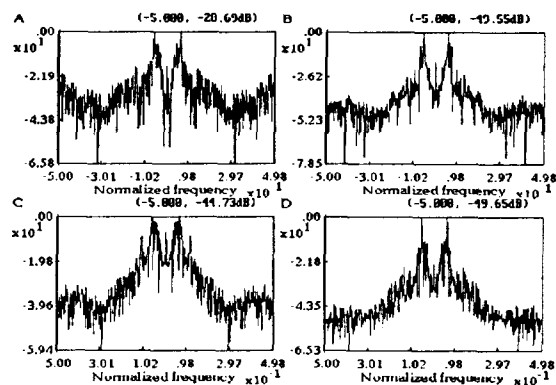


Figure 1: Periodograms of noises from 4 different ships A,B,C,D

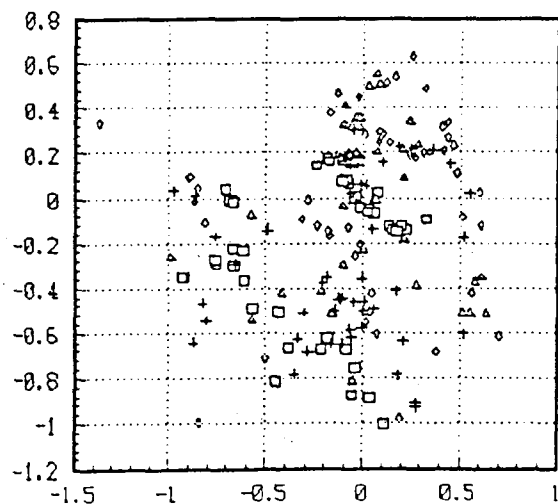


Figure 2: The distribution of real part of poles of 2-dimension compressed from 20-order AR model poles by K-L transform

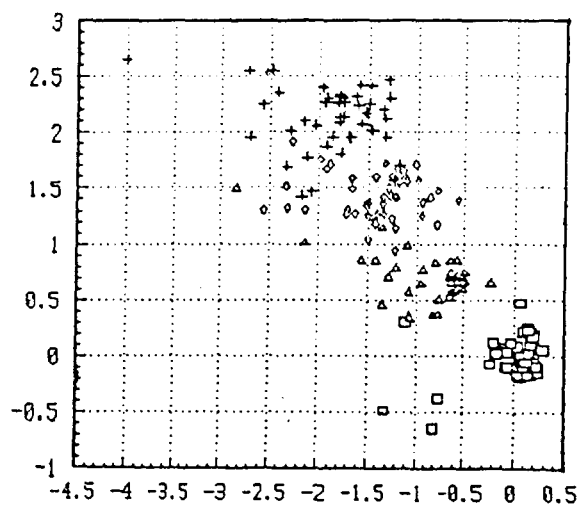


Figure 3: The distribution of imaginary part of poles of 2 dimension compressed from 20-order AR model poles by K-L transform

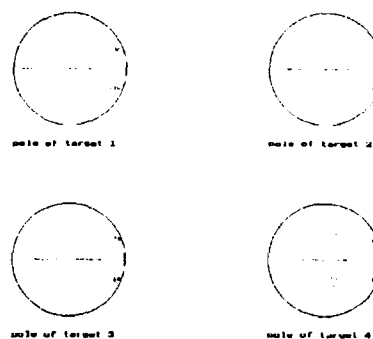


Figure 6: Poles of 4-order AR model of 4 ships(num.of sample=50,data length=128)

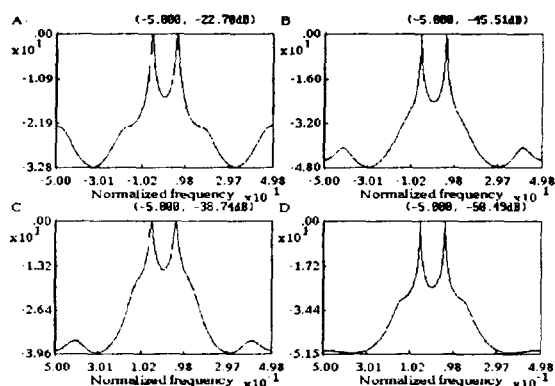


Figure 4: The PSD of 6-order AR model for the 4 ships A,B,C,D

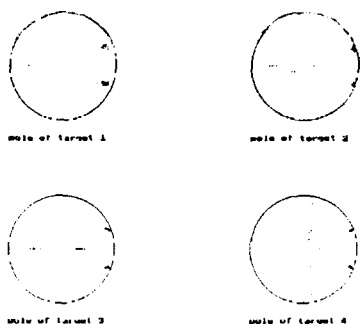


Figure 5: Poles of 4-order AR model for 4 ships(num.of samples=50,data length=256)

test set	sample num	A	B	C	D	
A	50	50	0	0	0	100%
B	50	0	46	4	0	92%
C	50	0	2	46	2	92%
D	50	0	0	0	50	100%

Table1. Classification results when data length is 256

test set	sample num.	A	B	C	D	
A	50	47	3	0	0	94%
B	50	0	44	6	0	88%
C	50	0	5	42	3	84%
D	50	0	0	3	47	94%

Table2. Classification results when data length is 128