AiMT Advances in Military Technology
Vol. 3, No. 2, December 2008

The 3-class Classifier of Frequency Shift Keying and Phase Shift Keying Signals Based on Karhunen-Loeve Transform

M. Richterová[1*], D. Juráček[2] and A. Mazálek[1]

[1] *Department of Communication and Information Systems, University of Defence, Brno, Czech Republic*
[2] *Institute of Criminalistics Prague, Prague, Czech Republic*

The manuscript was received on 5 May 2008 and was accepted after revision for publication on 18 September 2008

Abstract:

This paper describes the use of Karhunen-Loeve transform (KLT) for the modulation recognition in HF and VHF bands. The input real signal is pre-processed and converted to the "phase image". The KLT is applied and the dimensionality reduction is implemented and the classifier recognized the signal. The method clustering analysis was chosen by acclamation for 3-class recognition of 2-FSK, 4-FSK and PSK signals. The 3-class minimum-distance classifier of modulation was created in the programme Matlab. The tests of designed algorithm were implemented on real signal patterns.

Keywords:

Modulation recognition, orthogonal transforms, Karhnunen-Loeve transform, modulation classifiers, digital modulation, signal processing

1. Introduction

Automatic modulation recognition is rapidly evolving signal analysis area. In recent years, much interest by academic and military research institutes has focused around the research and development of modulation recognition algorithms. There are two mains reasons for knowing the correct modulation type of a signal: to preserve the signal information content and to decide the suitable counter action such as jamming [1].

The Karhunen-Loeve transform [2, 3, 4] (named after Kari Karhunen and Michel Loeve) is a representation of a stochastic process as an infinite linear combination of orthogonal functions, analogous to a Fourier series representation of a function on a bounded interval.

* *Corresponding author: Department of Communication and Information Systems, University of Defence, Kounicova 65, CZ-612 00 Brno, Czech Republic, phone: +420 973 444 818, fax: +420 973 444 816, E-mail: Marie.Richterova@unob.cz*

In contrast to a Fourier series where the coefficients are real numbers and the expansion basis consists of sinusoidal functions (that is, sine and cosine functions), the coefficients in the Karhunen-Loeve transform are random variables and the expansion basis depends on the process. In fact, the orthogonal basis functions used in this representation are determined by the covariance function of the process. The KLT is a key element of many signal processing and communication tasks.

2. Principle of the Recognition of FSK and PSK Signals

The common fundamental diagram for recognition of 2-FSK, 4-FSK and PSK signals is introduced on Fig. 1. We describe generally working of this system for the recognition.

The inquiry analog signal $x(t)$ enters into an A/D converter, where is sampling, quantization and make-up into matrix 32×32, this way we obtaining a "phase image" of the inquiry input signal $x(t)$. The orthogonal transform (KLT) is implemented on this matrix after with the aim to highlight important elements image and at the same time to suppress the circumstantial and disturbing elements and the components.

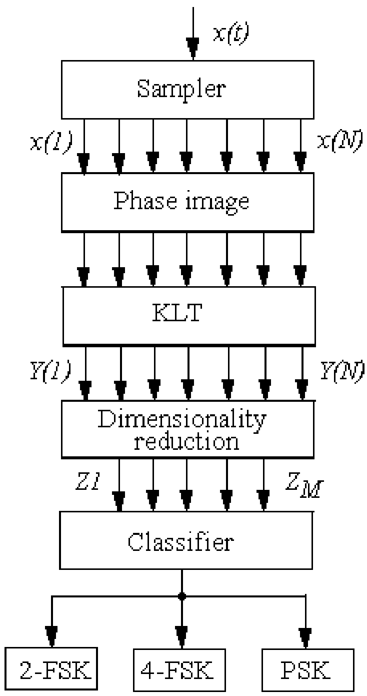

Fig. 1 Block diagram for recognition of digital modulated signals

The property of Karhunen-Loeve transform will be used for the recognition of 2-FSK, 4-FSK and PSK signals. All samples of signal pattern are not needed to the proper recognition, is possible to use the dimensional reduction of the matrix. The proper classification of signal and his enlistment into corresponding group of signals follow up the block of orthogonal transform.

The minimum distance classifier will be used for the solution of the problem of the recognition of 2-FSK, 4-FSK and PSK signals. The principle of minimum distance classifier will be described in the next section.

3. "Phase Image"

The input signal is given by sequence of the samples corresponding to the digital form of recognition signal. The input vector has the length 2048 samples. The ”phase image“ of modulated signal is composed so, that they are generated of points about ”the coordinates“ – the value of sample and the difference between samples.

These points are mapping into the rectangular net about proportions 32×32 so, that a relevant point of net is allocated the number one. If more points fall through into the identical node, then is adding the number one next. These output values are standardized and quantized [5, 6]. The ”phase images“ of 2-FSK and 4-FSK signals are presented on Fig. 2.

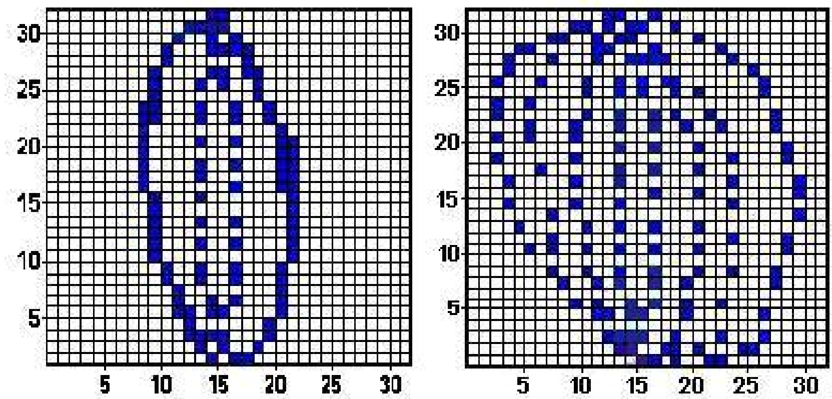

Fig. 2 "Phase images" of 2-FSK signal and "phase image" of 4-FSK signal

Lower frequency of FSK signal is corresponding to the ellipse, which lies near to centre of image. Higher frequency of FSK signal corresponded to the ellipse, which is on a margin of image. The ”phase image“ of PSK is one ellipse.

4. Minimum-distance Classifier

The minimum-distance classifier is designed to operate on the following decision rule [5, 6, 7]:

A given pattern Z belongs to C_i, if Z is the closest to $\overline{Z}_i, i=1,2,3...$ Let D_i denotes the distance of Z from $\overline{Z}_i, i=1,2,3$. Then we have [see Fig 3]

$$D_i^2 = \left\| Z - \overline{Z}_i \right\|^2 = \left(Z - \overline{Z}_i \right)^T \left(Z - \overline{Z}_i \right), \tag{1}$$

Simplification of D_i yields

$$D_i^2 = \left\| Z \right\|^2 - 2 \cdot \left(\overline{Z}_i^T Z - \frac{1}{2} \left\| \overline{Z}_i \right\|^2 \right), \tag{2}$$

Clearly, D_i^2 is a minimum, when the quantity $\left(\overline{Z}_i^T Z - \frac{1}{2}\left\|\overline{Z}_i\right\|^2\right)$ is a maximum. Thus, rather than having the classifier computes D_i^2 in Eq. (2), it is simpler to require it to compute the quantity $\left(\overline{Z}_i^T Z - \frac{1}{2}\left\|\overline{Z}_i\right\|^2\right)$. The classifier is then described by the discriminant functions

$$g_i(Z) = \overline{Z}_i^T Z - \frac{1}{2}\left\|\overline{Z}_i\right\|^2, \qquad i = 1,2,3 \tag{3}$$

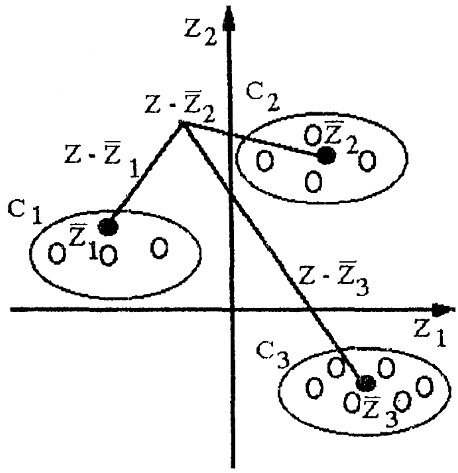

Fig. 3 A 3-class classifier of FSK and PSK signals

The classifier thus computes three numbers $g_1(Z)$, $g_2(Z)$, $g_3(Z)$ as shown in Fig. 3 and then compares them. It assigns Z to C_1 if $g_1(Z)$ is maximum, to C_2 if $g_2(Z)$ is maximum and to C_3 if $g_3(Z)$ is maximum.

5. Experimental Results

The learning process of the 3-class minimum-distance classifier was effected for 30 realizations of the simulation patterns of 2-FSK, 4-FSK, 2-PSK and 4-PSK signals with the modulation velocity 50, 100, 150 and 200 Bd and SNR 15, 20, 30 [dB].

The experimental tests for the 3-class minimum-distance classifier were implemented on 200 realizations of real patterns of 2-FSK, 4-FSK, 2-PSK and 4-PSK signals. Parameters of real signal patterns, which were used to experimental process, are presented in Table 1.

The results of classification of modulation type for 200 realizations of 2-FSK, 4-FSK, 2-PSK and 4-PSK signals are introduced in Table 2.

Tab. 1 Parameters of real digital modulation patterns

Modulation type	Carrier frequency [Hz]	Sampling frequency [Hz]	Modulation velocity [Bd]
2-FSK	2400	44100	150
4-FSK	4800	44100	150
2-PSK	2400	44100	100
4-PSK	2400	44100	100

Tab. 2 Results of classification of modulation type by 3-class minimum-distance classifier for 200 realizations

Modulation type	Correct classification in [%]
2-FSK	75
4-FSK	72
PSK	64

The experimental results indicate, that the 3-class minimum-distance classifier based on Karhunen-Loeve transform is able recognize of three types of digital modulated signals. The number of correct classification for real patterns of FSK signals reaches approximately 70 %. The real patterns of PSK signals are classified correctly about 60 %. The designed classifier is not able recognize modulation type 2-PSK and 4-PSK because the characteristic features of modulation type 2-PSK and 4-PSK are very similar. If we want recognize the groups of 2-PSK and 4-PSK, we must propose other type of modulation classifier.

6. Conclusions

The practical programming solution and performed experiments were verified a working 3-class minimum-distance classifier for the recognition of 2-FSK, 4-FSK and PSK signals. The results show, that this principle can be used for the technical analysis of signals in the branch, where necessary is obtained the information about the modulation type in the automatic system.

References

[1] NANDI, AK. and AZZOUZ, EE. Algorithms for Automatic Modulation Recognition of Communication Signals. *IEEE Transactions on Communications*, 1998, vol. 46, no. 4, p. 431-436.

[2] HUA, Y. and LIU, W. Generalized Karhunen-Loeve Transform. *IEEE on Signal Processing Letters*, 1998, vol. 5, no. 6, p. 141-142.

[3] GRIMALDI, D., RAPUANO, S. and DE VITO, L. An Automatic Digital Modulation Classifier for Measurement on Telecommunication Networks. *IEEE Transactions on Instrumentation and Measurement*, 2007, vol. 56, no. 5, p. 1711-1720.

[4] PARK, C.-S. and KIM, DY. A Novel Robust Feature of Modulation Classification for Reconfigurable Software Radio. *IEEE Transactions on Consumer Electronics*, 2006, vol. 52, no. 4, p. 1193-1200.

[5] RICHTEROVÁ, M. *Contribution to Recognition of Data Modulated Signals* (in Czech) [PhD Thesis]. Brno : Military Academy, 2001. 70 p.

[6] RICHTEROVÁ, M. A 2-class Classifier of FSK Signals. (in Czech) In *Proceedings of STO-6.* Brno : Military Academy, 1997, p. 22-27.

[7] AHMED, NU. and RAO, KR. *Orthogonal Transforms for Digital Signal Processing.* Berlin : Springer, 1975. 263 p.

Acknowledgement

The work presented in this paper has been supported by the Institute of Measurements of the Ministry of Defence in Litoměřice.