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AUTOMATIC CLASSIFICATION OF M-ary PHASE SHIFT KEYING (MPSK) SIGNALS

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ABSTRACT

In this paper, a procedure for automatic classification of MPSK signals, with M=2,4 and 8 is proposed. The developed algorithm utilizes the pattern recognition approach. This is based on counting the number of states in the signal constellations, which is derived from the complex envelope of a received signal. Computer simulations for 100 realizations of each type of band-limited MPSK signal (M=2, 4, and 8) corrupted with band-limited Gaussian noise are performed. It is found that the number of levels is correctly estimated at the SNR of 10 dB.

KEY WORDS

Digital Modulation Classification, Clustering Techniques,

I- INTRODUCTION

In modern communication systems, the digital modulation techniques are frequently used. So, the current trend is the digital modulation classification. In electronic warfare applications, electronic support measures system plays an important role as a source of information required to conduct electronic counter measures, threat detection, warning, target acquisition and homing. Generally, any surveillance system in COMINT applications consists of three main blocks: receiver front-end (frequency down conversion and activity detection), modulation recognizer (key features extraction and classification) and output stage (normal demodulation and information extraction). At the output stage there are several functions performed and they are mainly related to information extraction, recording and exploitations. All these functions are preceded by signal demodulation. The information obtained from the receiver front-end and modulation recognizer are gathered to perform the signal demodulation and information extraction.

Modulation recognition environment may vary between two extremes - from no

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significant noise in the best situation to a very noisy one with interference and fading. Moreover, there are many practical problems facing the modulation recognition process. Some of these problems are due to the radio communication channel and the intercept receiver. These problems are such as: multi-path fading, signal distortion, frequency instability, and interference from adjacent channels. These problems should be solved in the receiver front-end stage. The other problems are due to the nature of the received signal. These problems are such as: weak segments of a signal, carrier absent or reduced, lower SNR reception, and the high sampling rate and the required computational speed. The details for some of these problems and the suitable solutions are discussed in [1].

Generally, there are three philosophies for approaching the modulation recognition process in the available references namely 1) a decision-theoretic approach, 2) a statistical pattern recognition approach and 3) an artificial neural networks (ANNs) approach [1]. The modulation recognizers, in the available references, were developed according to any of these approaches. There are also some recognizers combining some of these approaches. Also, there are five techniques for solving the modulation recognition problem. These are: 1) spectral processing, 2) instantaneous amplitude, phase, and frequency parameters, 3) instantaneous amplitude, phase, and frequency histograms, 4) combination of the previous three techniques and 5) universal demodulators. In this paper, the features used in the proposed algorithm are extracted from the complex envelope of a signal and the decision criterian is derived from the number of states in the signal constellation. Extracting the features from the complex envelope representation rather than the instantaneous phase avoid the problems related to the phase computation such as: the division operation, the linear phase component, the phase wrapping. So, the processing speed of the developed algorithms may be higher than those utilize the instantaneous phase.

In this section, an overview for some of the more recently published recognizers for digital modulations is presented. **Liedtke** [2] proposed a modulation recognizer for some types of digital modulations - ASK2, FSK2, MPSK (M=2, 4, 8) and CW. This recognizer utilizes the universal demodulator technique. The key features used to discriminate between these types are the amplitude histogram, the frequency histogram, the phase difference histogram, the amplitude variance, and the frequency variance. In [2], it is claimed that an error free signal, i.e. all the signal parameters are exactly known, can be recognized at SNR >18 dB. **Polydoros and Kim** [3] introduced a modulation recognizer, following the decision-theoretic approach, using the log-likelihood ratio to discriminate between PSK2 and PSK4. It is claimed that that recognizer can be extended to address MPSK signals classification with M > 4.

Hsue and Soliman [4] introduced a modulation recognizer for constant amplitude signals such as CW, MPSK, and MFSK. It utilizes the zero-crossings characteristic of the intercepted signals to derive the phase and frequency information. The decision about the modulation type is based on the variance of the zero-crossing interval sequence as well as the frequency and phase difference histograms. In this recognizer, the classification strategy comprises two main steps; first discrimination of single-tone (CW and MPSK) from MFSK signals, and secondly determination of the number of states (M). The determination of the number of states in single-tone signals is achieved by measuring the similarity of the normalized phase difference histogram. Finally, the performance of this recognizer was derived from 100 realizations for each modulation type of interest. In [4] it is claimed that a reasonable average probability of correct classification is achievable for SNR > 15 dB. Also, **Soliman and Hsue** [5] introduced another modulation recognizer based on the statistical moments of the intercepted signal phase. In this recognizer, the even order moments of the signal phase are used to estimate the number of levels, M, in MPSK signals. In [5], it is claimed that the second order moment is sufficient to discriminate the CW from the MPSK signals and, the eighth order moment is adequate to identify BPSK signals with reasonable performance at low SNR.

Nagy [6] introduced a suggested procedure for modulation classification of multichannel systems. This classifier was accomplished by dividing the analyzed signal into individual components and each signal component is classified using a single tone classifier. The types that have been classified by this recognizer are CW, ASK, PSK2, PSK4 and FSK2. In [6] the performance of the developed recognizer was derived from 100 realizations for each modulation type of interest. Finally, it is claimed that all the single-tone types (CW, ASK2, PSK2 and PSK4) have been classified with success rate > 90.0 % at 10 dB SNR except the ASK2 (=87.0 %).

Azzouz and Nandi [7] proposed a modulation recognizer for the digital modulation types up to 4-levels (ASK2, ASK4, PSK2, PSK4, FSK2, and FSK4). The key features used are derived from the instantaneous amplitude, the instantaneous phase, and the instantaneous frequency of a signal. In [7], all the digital modulation types of interest have been classified with success rate > 90.0 % at the SNR of 10 dB except PSK4 (89.25 % success rate). At the SNR of 20 dB all the modulation types of interest have been classified with success rate > 96.0 %. Moreover, **Nandi and Azzouz** proposed a modulation recognizer which utilizes the ANN approach [8]. It is based on a single hidden layer ANN and the same data set used in [7]. It was found that all the modulation types of interest have been classified with success rate > 93.0 %. at 10 dB SNR and with success rate > 97.0 % at 20 dB. In [1], **Azzouz and Nandi** introduced a double hidden layer ANN modulation recognition algorithm. Using the same data set in [6] and [7], it was found that all the modulation types of interest have been classified with success rate > 96.0 % except FSK2 (=92.5%) at the SNR of 10 dB but at SNR of 20 dB, the success rate is > 99.0%. However as the number of levels, M, increases the classification problem becomes more complicated, especially in the dense noise.

II- PROPOSED ALGORITHM FOR MPSK SIGNALS CLASSIFICATION

Recently, the modern communication systems prefer the phase shift keying with different levels M=2, 4, and 8. The interference phenomena confuse the COMINT receiver to decide which scheme is used in the intercepted signals - binary, quadrature, octal, ... etc. Figure 1 illustrates the problem. One can see from Figs. 1 a, b, and c the phase state constellation for ideal MPSK with M= 2, 4, and 8 respectively. However, the received signal will be constelated as shown in Fig. 1-d where it is not easy to decide which scheme is used. In this paper, an algorithm is developed to decide reliably about the number of levels of MPSK signals. The proposed procedure for number of levels estimation comprises the following steps:

1- Computing the smoothed real and imaginary parts of the complex envelope of a signal as shown in Fig. 2 and obeying the following steps:

- Computing the analytic representation, z (t), of the intercepted signal, x (t), as

$$z(t) = x(t) + j\,y(t), \qquad (1)$$

Where y (t) is the Hilbert transform of x (t)

- Computing the complex envelope of the signal x (t) as

$$\alpha(t) = z(t)\exp\{-j\,2\pi\,f_c\,t\} \quad (2)$$

Where f_c is the carrier frequency. Also, α (t) can be expressed as

$$\alpha(t) = R(t) + j\,I(t) \quad (3)$$

The real and imaginary parts of the complex envelope as well as the phase states of MPSK signals are presented in Appendix A.

- Applying median filters on the real and imaginary parts, R (t) and I (t) respectively.

2- Constructing the signal constellation from the derived real and imaginary parts of the complex envelope. Plotting the imaginary part versus the real part of the complex envelope of a signal performs the signal state constellation.

3- Dividing the states space into nine regions (eight on a unit circle and one at the origin (corresponding to noise and band limitation effects)). It is known that the phase state of MPSK signals (constant amplitude signal) lie on a unit circle. Thus, dividing the state space by this way gives the ability to estimate the number of levels of MPSK signals with M=2, 4, and 8.

4- Clustering the phase states in each region according to the procedure presented in the flowchart shown in Fig 3.

5- Counting the number of clustered states in each region and ignores the regions that contain number of samples less than a chosen threshold (e. g. number of samples per bit duration).

III- COMPUTER SIMULATIONS & PERFORMANCE EVALUATIONS

Let the carrier frequency, f_c, the sampling rate f_s, and the symbol rate r_s were assigned the values 100 kHz, 1000 kHz, and 9.6 kHz respectively. The modulating symbol sequence was derived from N_s independent random numbers to increase the degree of realism. The MPSK signals were derived from a general expression [1] and it is explained in Appendix A. Also, as it is usual in practice and to increase the degree of realism, the simulated modulated signals were band-limited to make them representing more realistic test signals. In this case the simulated digitally modulated signals were band-limited to bandwidth containing 97.5% of the total average power. Any way, a complete illustration for computer simulations of band-limited MPSK signal was presented in [1]. The results of the performance evaluation of the proposed procedure for MPSK classification are derived from 400 realizations, each with 4096 samples, for each modulation type. Sample results are presented at two values of SNR (5, and 10 dB) in Tables 1, and 2. Consider Table 1 for example; It can be observed that all modulation types of interest have been classified with success rate > 95.0%. The results in Table 2 correspond to the SNR of 10 dB. It is clear that the probability of correct MPSK classification has been increased with increased SNR and now all the modulation types of interest have been classified with 100% success rate.

Table 1. Success rate of different modulation type at the SNR of 5 dB.

Simulated Modulation Types	Deduced Modulation Types		
	PSK2	PSK4	PSK8
PSK2	96.0%	4.0%	
PSK4		98.0%	2.0%
PSK8			100%

Table 2. Success rate of different modulation type at the SNR of 10 dB.

Simulated Modulation Types	Deduced Modulation Types		
	PSK2	PSK4	PSK8
PSK2	100%		
PSK4		100%	
PSK8			100%

IV- CONCLUSIONS

The aim of this paper is to introduce a fast and reliable algorithm for MPSK classification. The current approach is to carry out this task utilizing the pattern recognition approach. An extensive number of simulations for different types of MPSK is introduced to measure the performance of the developed algorithm. It is found that the threshold SNR for modulation recognition at a success rate > 95% is about 5 dB, which is a better result, compared with those in the referenced papers. Furthermore, the used key features are derived from the complex envelope which make the developed algorithm faster than those utilize the instantaneous phase in addition to avoid the problems related to the phase computation such as : the division operation, the linear phase component, the phase wrapping. Now the work is under going for implementing and testing the developed algorithm on real signals and applying the same ideas for recognition of QAM signals.

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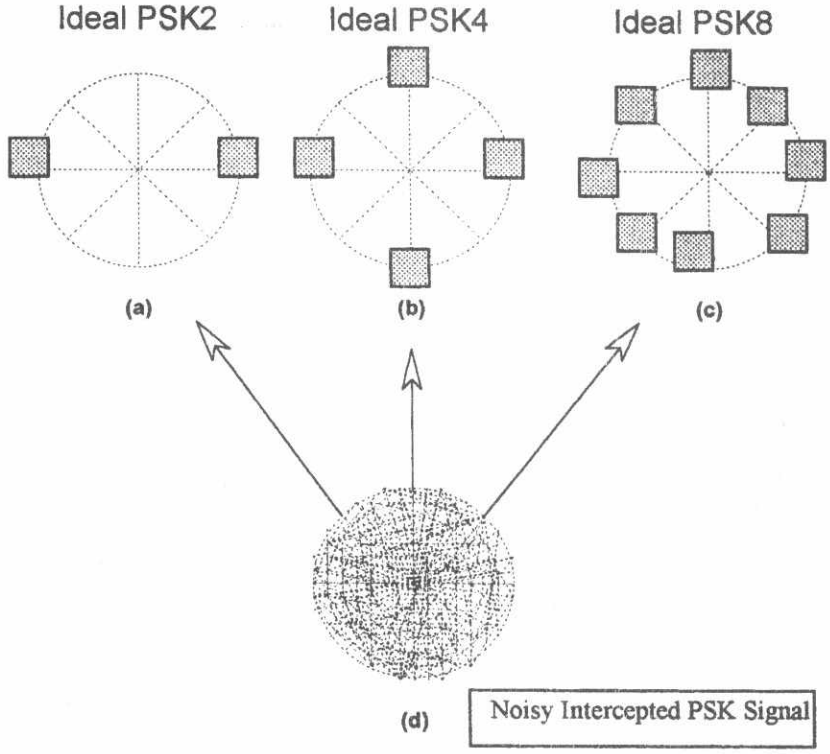

Fig. 1. Phase states constellation for MPSK signals [a, b, c] Ideal and [d] Noisy

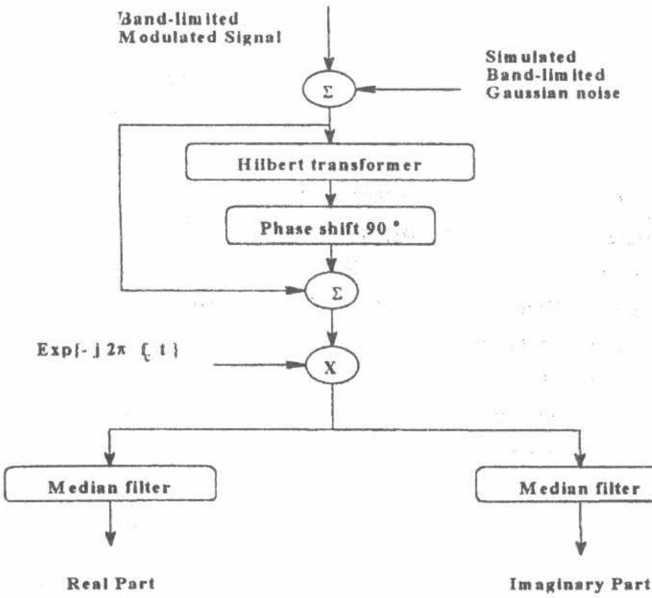

Fig. 2. Extraction of real and imaginary parts of the complex envelope

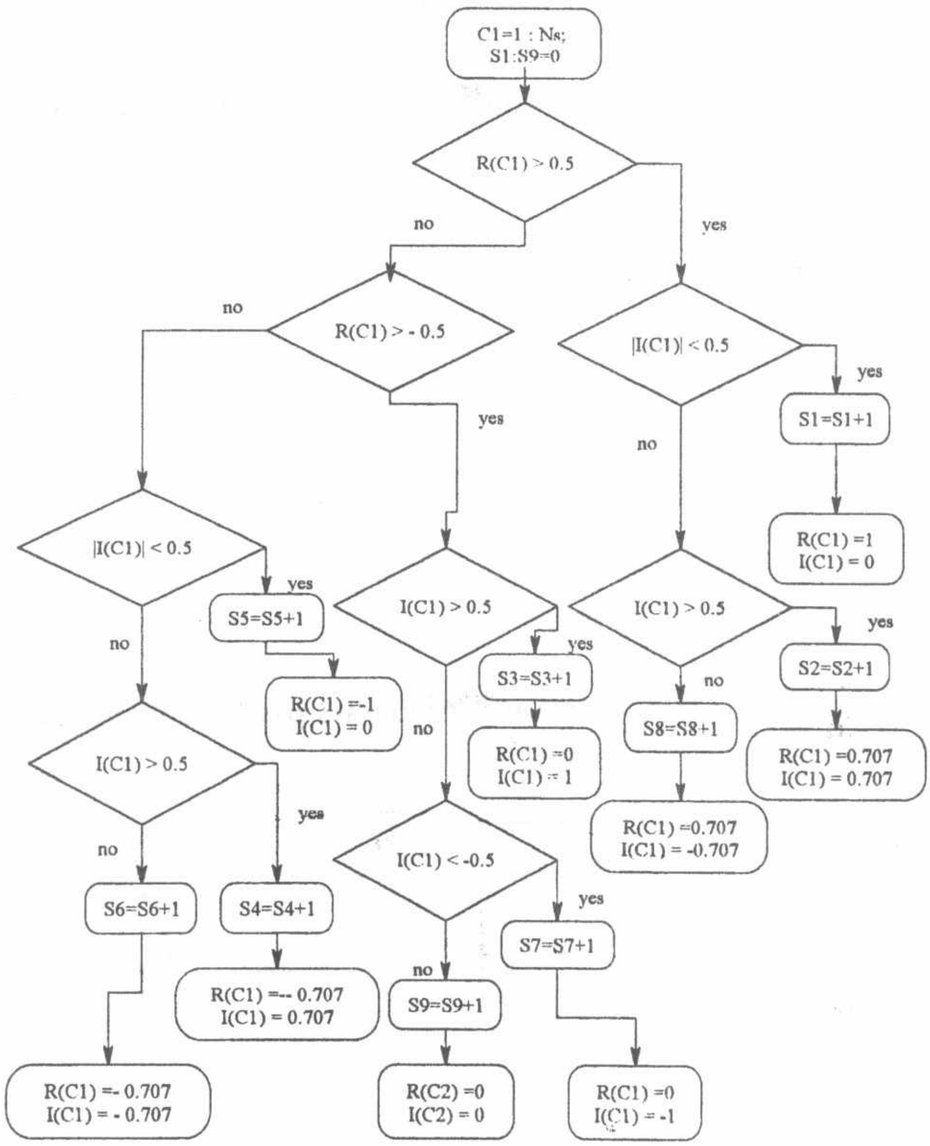

Fig. 3. Functional flowchart for clustering the signal states.

Where, N_s is the number of samples per frame,

C1 is a counter for the sample number in the frame,

S1-S9 are counters for the signal states, and

R and I are the real and Imaginary parts of the complex envelope of a signal.

Appendix A

Real and imaginary parts of the complex envelope of MPSK signals

The MPSK signals can be expressed by [1]

$$S_i(t) = A \cos [2 \pi f_c t + \phi_i(t)] ; i = 1, 2, ..., M \quad (A.1)$$

By straight forward analysis, the associated complex envelope, $\alpha_i(t)$, is given by

$$\alpha_i(t) = A \, Exp\{j \phi_i(t)\} \quad (A.2)$$

Thus, the real and imaginary parts are given by

$$R(t) = A \cos [\phi_i(t)] \text{ and } I(t) = A \sin [\phi_i(t)] \quad (A.3)$$

The values of phase states, and the real and imaginary parts of the complex envelope are shown in the following table.

Table A.1. Phase states, and the real and imaginary parts of the complex envelope of MPSK signals

Modulation Types	$\phi_i(t)$	R(t)	I (t)
BPSK	0	1	0
	π	-1	0
QPSK	0	1	0
	π/2	0	1
	π	-1	0
	3 π/2	0	-1
8-PSK	0	1	0
	π/4	0.707	0.707
	π/2	0	1
	3 π/4	-0.707	0.707
	π	-1	0
	5 π/4	-0.707	-0.707
	3 π/2	0	-1
	7 π/4	0.707	-0.707