Modulation Classifier of Digitally Modulated Signals Based on Method of Artificial Neural Networks

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Abstract: - In this paper is described a new original configuration of subsystems for the automatic modulation recognition of digital signals. The signal recognizer being developed consists of five subsystems: (1) adaptive antenna arrays, (2) pre-processing of signals, (3) key features extraction, (4) modulation recognizer and (5) output stage. The choice of maximum value of spectral power density of the normalized-centred amplitude, standard deviation of the absolute value of the centred non-linear component of the instantaneous phase, standard deviation of the absolute value of the normalized-centred instantaneous amplitude, standard deviation of the absolute value of the normalized-centred instantaneous frequency, as key features for the digital modulation recognizer based on the artificial neural networks (ANNs). The new original structure of the recognizer of digital signals is described. The modulation recognizer using the ANNs with two hidden layers. The results are summarized for real signals.

Key-Words: - Automatic modulation recognition, Modulation recognizer, Artificial neural networks, Matlab

1 Introduction

Communication signals travelling in space with different modulation types and different frequencies fall in a very wide band. Usually, it is required to identify and monitoring these signals for many applications.

Some of these applications are for civilian purposes such as signal confirmation, interference identification and spectrum management. Automatic modulation recognition of communication signals is a rapidly evolving area of signal analysis. In recent years, interest from the academic research institutes has focused on the research and development of modulation recognition algorithms.

In this paper we describe the classifier of digitally modulated signals on base artificial neural networks (ANN). Section 2 deals with key feature extraction. In the section 3 is described the new original configuration of subsystems for the automatic modulation recognition of digital signals. Section 4 summarizes results of experiments for real signals. The digital modulation types that can be classified by the recognizer based on artificial neural networks are: ASK2, PSK2, PSK4, FSK2 and FSK4.

2 Key feature extraction

In the proposed modulation classifiers (MC), the key features used are derived from three important qualifying parameters - the instantaneous amplitude, the instantaneous phase, and the instantaneous frequency.

The first key feature, $\gamma_{\max}$, is defined by [1], [2]

$$\gamma_{\max} = \max \left| DFT\left(a_{cn}(i)\right)\right|^2 / N_S, \qquad (1)$$

where N_S is the number of samples per segment and $a_{cn}(i)$ is the value of the normalized-centred instantaneous amplitude at time instants $t = \frac{i}{f_s}, (i = 1,2,\ldots,N_S)$.

$\gamma_{\max}$ represents the maximum value of the spectral power density of the normalized-centred instantaneous amplitude of the intercepted signal.

The second key feature, σ_{ap}, is defined by [1] , [2]

$$\sigma_{ap} = \sqrt{\frac{1}{C}\left(\sum_{a_n(i) \rangle a_t} \Phi_{NL}^2(i)\right) - \frac{1}{C}\left(\sum_{a_n(i) \rangle a_t} \left|\Phi_{NL}^2(i)\right|\right)^2}, \qquad (2)$$

where $\Phi_{NL}(i)$ is the value of the centred non-linear component of the instantaneous phase at time instants $t = \frac{i}{f_s}$, C is the number of samples in $\{\Phi_{NL}(i)\}$ for which $a_n(i) \rangle a_t$ and a_t is a threshold. $\Phi_{NL}(i)$ are the values of phase characteristic without the contributions of the carrier frequency, i.e.

$$\Phi_{NL}(i) = \Phi_{uw}(i) - \frac{2\pi f_c}{f_s},$$

where $\Phi_{uw}(i)$ is the unwrapped phase sequence, f_c carrier frequency and f_s sampling frequency.

σ_{ap} is the standard deviation of the absolute value of the centred non-linear component of the instantaneous phase.

The third key feature, σ_{dp}, is defined by [1], [2]

$$\sigma_{dp} = \sqrt{\frac{1}{C}\left(\sum_{a_n(i)\rangle a_t} \Phi_{NL}^2(i)\right) - \left(\frac{1}{C}\left(\sum_{a_n(i)\rangle a_t} \Phi_{NL}^2(i)\right)^2\right)}. \quad (3)$$

σ_{dp} is the standard deviation of the centred non-linear component of the direct (not absolute) instantaneous phase.

The fourth key feature σ_{aa} is defined by [1] , [2]

$$\sigma_{aa} = \sqrt{\frac{1}{N_S}\left(\sum_{i=1}^{N_S} a_{cn}^2(i)\right) - \left(\frac{1}{N_S}\sum_{i=1}^{N_S} \left|a_{cn}^2(i)\right|\right)^2}. \quad (4)$$

σ_{aa} is the standard deviation of the absolute value of the normalized- centred instantaneous amplitude of a signal segment.

The fifth key feature, σ_{af}, is defined by [1] , [2]

$$\sigma_{af} = \sqrt{\frac{1}{C}\left(\sum_{a_n(i)\rangle a_t} f_N^2(i)\right) - \frac{1}{C}\left(\sum_{a_n(i)\rangle a_t} \left|f_N^2(i)\right|\right)^2}, \quad (5)$$

where f_N is the normalized-centred instantaneous frequency. σ_{af} is standard deviation of the absolute value of the normalized-centred instantaneous frequency.

The key features is used as a input layer for the MC based on the ANN. The MC will described in next section.

3 Original configuration of subsystems for the automatic modulation recognition of digital signals

The modulation classifier being developed consists of five subsystems: (1) adaptive antenna arrays, (2) pre-processing of signals, (3) key features extraction, (4) modulation recognizer and (5) output stage. Fig.1 shows the original configuration of subsystems for the automatic modulation classsification.

3.1 Adaptive antenna arrays and pre-processing of the real signals

The adaptive antenna arrays are used for the capture of real signals. Generally, the planar or circular or cylindrical antenna arrays are applied. The real signal inputs into the subsystems for the pre-processing. The real signal is filtered and segmented. Every segment has 4096 samples. The segments of real signals are stored in a database.

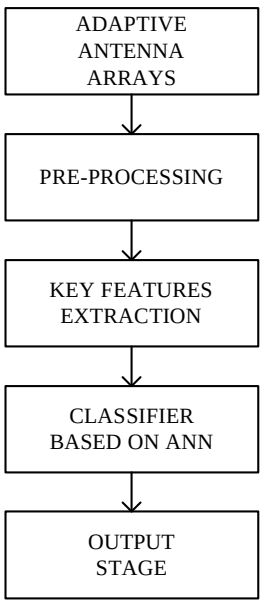

Fig. 1 The subsystems for the automatic modulation recognition of digital signals

3.2 Subsystem for key features extraction

This subsystem is designed by autors in the Matlab. The original algorithm for the key features extraction of the real signal can utilize either the off-line key features extraction or the on-line key features extraction. The algorithm processes the segments of the real signals from the database.

3.3 Modulation classifier based on ANN

This original software system in Matlab V6.5, Release 13 and NN-Toolbox, ver. 4 for Windows 98, 2000 and XP is presently under construction. This system serves for the automatic recognition of digitally moduled signal.

The modulation clasifier is composed of an ANN based on back propagation. The ANN has 5-nodes in input layer, 12-nodes in the first hidden layer, 12-nodes in the second hidden layer and the number of the output layer nodes equals the number of digital modulation signals (ASK2, PSK2, PSK4, FSK2 and FSK4). The architecture of the ANN is shown in Fig. 2.

4 Experimental Results

The performance evaluations of the proposed MC (see Fig. 1) are introduced for five digital modulated signals. We have classified 40 000 segments of real modulated signals. The results of the performance are summarized in Table 1.

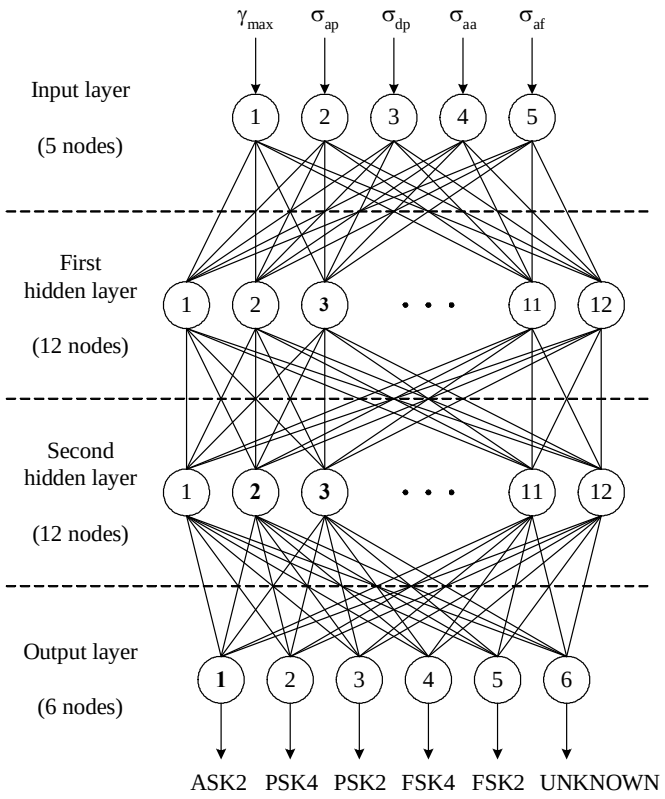

Fig. 2 Two hidden layers ANN architecture for digital modulation recognition

Real signal	Classified modulation type [%]					
	ASK2	PSK2	PSK4	FSK2	FSK4	UNK
ASK2	80.2	11.2	-	-	7.4	1.2
PSK2	-	86.1	-	-	-	13.9
PSK4	-	-	81.9	-	-	18.1
FSK2	-	-	-	83.8	6.2	10.0
FSK4	-	-	-	7.3	87.3	5.4

Table 1 Performance for the two hidden layers ANN.

In Table 1, the ASK2 and FSK2 signals are classified as FSK4. From Table 1, it is clear that all the types of digital moduled signals have been correctly classified with more than 80% success rate.

5 Conclusion

This paper describes the original classifier based on ANN for the recognition of digital modulated signals. Experimental results show that modulation classifier is capable of recognizing correctly real signals with more than 80% probability.

Better results and effectivity of classification can be reached by using combination methods for the modulation recognition but also by detection of other key features.

More details about other modulation classifiers are presented in [1], [2], [3], [4].

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