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An intelligent system using adaptive wavelet entropy for automatic analog modulation identification

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ABSTRACT

In this paper, an intelligent analog modulation identification system is presented for interpretation of the analog modulated signals. This paper especially deals with combination of the feature extraction and classification for analog modulated signals. The analog modulated signals used in this study are six types (AM, DSB, USB, LSB, FM, and PM). Here, a discrete wavelet neural network-adaptive wavelet entropy (DWNN-ANE) model is used, which consists of two layers: discrete wavelet-adaptive wavelet entropy and multi-layer perceptron neural networks for intelligent analog modulation identification. The discrete wavelet layer is used for adaptive feature extraction in the time-frequency domain and is composed of DWT and adaptive wavelet entropy. The performance of the used system is evaluated by using total 1080 analog modulated signals. These test results show the effectiveness of the used intelligent system presented in this paper. The rate of correct classification is about 98.34% for the sample analog modulated signals.

1. Introduction

Nowadays, automatic modulation identification has become an important topic in many applications for several reasons [1]. First reason is the selecting an appropriate demodulator to unknown modulation type. This state prevents partially or completely damages the communication signal information content. Thus, this signal information content is correctly obtained from intercepted signal. Second reason is the knowing the correct modulation type helps to recognize the threat and determine the suitable jamming waveform [1]. Thirdly reason is automatic modulation identification is significant for national security.

In the oldest modulation identification studies are used a bank of demodulators, each designed for only one type of modulation [2]. In this applications, a modulation operator by examining or listening to these demodulators output can estimate the modulation type of the intercepted signal [1]. This method has many disadvantages such as requiring long signal durations and experienced modulation operators, etc. For overcoming these disadvantages, recently intelligent decision algorithms have been used but these algorithms are complex and need excessive computer storage [1,3–6].

So far, some studies have realized in automatic analog modulation area. These studies can be classified into three categories according to the methods used in these studies. The studies in first category use a statistical pattern recognition approach [1]. The studies in second category use a decision-theoretic approach [1]. The studies in third category use artificial neural networks (ANNs) for modulation identification problem [7]. Some of studies in these categories are given as below [1,3–6].

In Ref. [3], it is proposed a modulation classifier based on the changing of both the instantaneous frequency and the instantaneous frequency. Here, ratio of the envelope peak to its mean, and the mean of the absolute value of the instan-

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taneous frequency are used as key features. In Ref. [3], it is claimed that at different SNR ratios, this method capable of discrimination among AM, FM, and DSB by using these two key features.

In Ref. [4], it is suggested a modulation classifier based on the envelope characteristics of the intercepted (receiving) signal. In this method, Hilbert transformer is calculated for instantaneous amplitude of the intercepted signal. This classifier is used for the identification of some analog modulated signals (AM, FM, DSB, and SSB).

In Ref. [5], it is suggested a modulation classifier for analog radio signals. In this method, variance of the instantaneous frequency normalized to the squared sample time is used as key feature to discriminate among the different modulation type (AM, DSB, SSB, FM, and CW) of interest.

In Ref. [6], it is introduced a modulation classifier to discriminate among a low modulation depth AM and a pure carrier wave (CW) in a noisy environment. Here, the ratio of the variance of the in-phase component to that of the quadrature component of the complex envelope of a signal is used as the key feature.

In Ref. [8], it is proposed a modulation classifier to discriminate among the USB and LSB signals. In this method, instantaneous frequencies of USB and LSB signals are used for identification the modulation type.

In Ref. [9], Nandi and Azzouz suggested a modulation classifier for the well-known analog modulation types, which are AM, DSB, VSB, LSB, USB, FM, and combined modulated signals. In this study, the maximum value of the spectral power density of the normalized-centered instantaneous amplitude, the standard deviation of the absolute value of the centered non-linear component of the instantaneous phase in the non-weak intervals of a signal segment, the standard deviation of the direct (not absolute) value of the centered non-linear component of the instantaneous phase, and the RF spectrum symmetry measure around the carrier frequency of the intercepted signal.

Last progresses in the area of ANN have made them a powerful tool to pattern recognition and classification [10]. The ANNs represent the promising new generation of intelligent systems. ANNs are good at tasks such as pattern recognition and classification, optimization, function approximation, and data clustering [11].

Many studies have realized on the topic of automatic modulation identification using ANNs approximations [12–14]. In Ref. [15], Nandi and Azzouz proposed a single hidden layer ANN structure for automatic modulation classification. This network has a 4-node input layer, a 25-node hidden layer and a 7-node output layer. Nevertheless a degradation of performance at higher signal noise ratios (SNR) will appear when the ANN is trained on signals with lower SNR. The generalization capability of ANNs must be increased for overcoming this shortcoming of ANNs classifiers. Therefore, a compact set of features, which capture all the major characteristics of the intercepted signals in a relatively small number of the components must be obtained from intercepted signal [10]. Than, these features must be given to ANN inputs for modulations classification. For this reason, the wavelet transform is used for the extraction of key features at pattern recognition and classification areas [16]. In many areas such as signal processing, especially image compression, speech processing, computer vision, the wavelet transform types are commonly used [10]. The wavelet transforms have been used in automatic digital modulation identification for communication signal processing [10]; however, to date wavelet neural network analysis for automatic analog modulation identification using adaptive entropy approach is a relatively new approach.

In this paper presents a new method in automatic analog modulation identification. The novelties presented in this study can be arranged in order as below:

- The effectiveness of the discrete wavelet transform (DWT) features is shown to be used for automatic analog modulation identification.
- A discrete wavelet neural network based on adaptive norm entropy (DWNN-AWE) algorithm is used for increasing the effectiveness of the automatic analog modulation identification at various SNR rates and various parameters changing.
- At this study, DWT and DWNN-AWE methods in automatic analog modulation identification field is firstly have been used for automatic analog modulation literature. More success results at various SNR rates and various parameters changing than preceding studies realized by using statistical pattern recognition, and decision-theoretic approach were obtained from this application.

This paper is organized as follows: In Section 2, the theory of the analog modulations is briefly reviewed. In Section 3, generation of analog modulated signals is explained. In Section 4, the feature extraction and classification realized using DWNN-AWE method is discussed in detail. In Section 5, evaluation of the results obtained from experimental studies, and in Section 6, conclusion and discussions are given.

2. Analog modulations

In this study, many analog modulation types are used. These analog modulation types are double side band with transmission carrier amplitude modulation (AM), double side band with suppress carrier amplitude modulation (DSB), single side band (SSB) (SSB separates two types are upper side band modulation (USB), lower side band modulation (LSB)), frequency modulation (FM), and phase modulation (PM). A modulated signal $c(t)$ can be given as below:

$$c(t) = b_c r(t) \cos\bigl(2\pi f_c t + \psi(t) + \theta_0\bigr) \tag{1}$$

where $r(t)$ is the signal envelope, $f_c(t)$ is the carrier frequency, $\psi(t)$ is the phase, θ_0 is initial phase and b_c controls the carrier power. Special modulation types are composed by encoding the base band message into $r(t)$ and $\psi(t)$. In this study,