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An Educational Interface for Automatic Recognition of Analog Modulated Signals

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Abstract: In this study, an interface for automatic classification of the analog modulated communication signal is introduced. An educational approach is adopted here to present an interface which can be used as a tool for education and demonstrative purposes. While emphasis has been placed on the designed interface, the certain type of the analog modulated communication signals can also be recognized and visualized for the teaching of analog modulation types. The designed Graphical User Interface (GUI) is written in Matlab and can recognize Amplitude Modulation (AM), Frequency Modulation (FM) and Continuous Wave (CW) signals. A number of key features are used for characterizing analog modulation types. A Fuzzy C-means classifier is embedded into the interface. B+K Precision Model 2040 universal signal generator is used for the experimental verification. Good performance has been obtained even at low signal-to-noise ratios.

Key words: Modulation recognition, modulation classification, Matlab interface, Fuzzy C-means

INTRODUCTION

Signal Processing systems for communications will operate in open environments, where it is required that signals of different sources be processed, which come from different emitters, hence with different characteristics and for different user requirements[1].

Communication signals traveling in space with different modulation types and different frequencies fall in very wide band. These signals use a variety of modulation techniques in order to send information from one location to another. Usually, it is required to identify and monitor these signals for many applications, both defense and civilian. Civilian applications may include monitoring the non-licensed transmitters, while defense applications may be Electronic surveillance systems[2]. Modulation recognition is extremely important in communication intelligence applications for several reasons. Firstly, applying the signal to an improper demodulator may partially or completely damage the signal information content. Secondly, knowing the correct modulation type help recognize the threat and to determine suitable jamming wave-form. At the moment, the most attractive applications area is radio and other re-configurable communication systems. There are two kinds of philosophies in approaching modulation classification problems; these are decision-theoretic approach and pattern recognition or feature extraction approach. In a decision theoretic approach, probabilistic arguments are employed to derive a proper classification rule. Typically this rule is hard to implement exactly. Modulation recognizers, like general pattern classification systems, consist of measurement; feature extraction and decision part.

The following is an overview of some of the recently published modulation recognition methods. Fabrizi *et al.*[3] suggested a modulation recognizer for analog modulations, based on the variations of both instantaneous amplitude and the instantaneous frequency. This recognizer is used to discriminate between some types of analog modulation AM, FM and SSB. Chan and Godbois[4] proposed a modulation recognizer based on the envelope characteristics of the received signal. Al-Jalili[5] proposed a modulation recognizer to discriminate between the USB and LSB signals. Azzouz and Nandi[6] proposed a modulation recognizer to classify the whole analog modulation types. Jovanovic *et al.*[7] introduced a modulation recognizer to discriminate between a low modulation depth (AM) and pure carrier wave (CW) in a noisy environment. Azzouz and Nandi[6] proposed an ANN classifier for modulation recognition.

In this study, a Matlab graphical user interface for automatic classification of analog modulated communication signals is introduced. Fuzzy C-means (FCM) classifier is embedded into the interface.

The automatic analog modulation recognition system is composed of three main subsystems which are acquisition and pre-processing of the intercepted signals, feature extraction and classification as shown in Fig. 1.

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Fig. 1: Modulation recognition system

In order to process the analog signals in computers, the information carried by the analog signal should be represented in a digital form. The pre-processing block includes the analog/digital (A/D) conversion which converts analog signals into digital form by a sequence of its instantaneous values measured at discrete time instants. The feature extraction block which gives the feature vectors which are different for different modulation types is the most important block of the overall system. Modulation recognition of an intercepted signal is finally realized by the classification subsystem which classifies the type of the modulation using FCM classification algorithm.

The proposed system is able to classify the incoming modulation type and can be used to choose an appropriate demodulator to be used. Alternative uses include spectrum management and surveillance, military threat evaluation, source and interference identification, etc. The effectiveness of the proposed scheme is verified by using both theoretically produced and real analog modulated signals.

KEY FEATURES EXTRACTION

Key features are crucial for all pattern recognition systems. A well defined key feature is one of the most important issues in pattern recognition because it increases the accuracy and efficiency of the subsequent processing. The features, which are proposed in Nandi and Azzouz[6], are also used in this study. For discriminating AM from the other modulation types, the following definition is used:

$$\sigma_{dp} = \sqrt{\frac{1}{C}\left(\sum_{A_n(i)>t_a} \phi_{NL}^2(i)\right) - \left(\frac{1}{C}\sum_{A_n(i)>t_a} \phi_{NL}(i)\right)^2} \tag{1}$$

Here, ϕ_{NL} is the value of the nonlinear component of the instantaneous phase at the time instants $t=i/f_s$, t_a is a threshold for $A_n(i)$ and C is the number of samples in $\phi(t)$. Thus σ_{dp} is the standard deviation of the centered nonlinear component of the direct phase component.

The second key feature is the maximum value of the normalized instantaneous amplitude of the intercepted signal and it is calculated as follow;

$$\gamma_{max} = \max(|FFT(a(i))|^2/N) \tag{2}$$

Where, a(i) is the normalized centered instantaneous amplitude of the intercepted signal and N is the number of the sample in the range. This feature is used for discriminate FM signals as a subset.

The third one is a frequency domain key feature which shows the number of the peaks in the RF signal spectrum. This feature is used for discriminating CW signals. We developed a peak counter in the RF spectrum.

FUZZY C-MEANS ALGORITHM

The Fuzzy C-Means clustering method creates a membership grade to belong to the cluster using a fuzzy coefficient and it allocates patterns to the cluster[8]. The Fuzzy C-Means (FCM) algorithm is a constrained optimization problem which minimizes the following objective function with respect to membership functions μ_{ij} and cluster centroid v_i,

$$J_m(U, V; X) = \sum_{j=1}^{n}\sum_{i=1}^{c} \mu_{ij}^m \left\| x_j - v_i \right\|^2 \tag{3}$$

where, $V = (v_1, \Lambda, v_c)$ is a vector of cluster centers $U = [\mu_{ij}]$is a c×n matrix, c is the number of clusters, n is the number of data points, satisfying the conditions as:

$$M_{fcn} = \left\{ U \in R^{cn} \left| \begin{array}{l} \mu_{ij} \in [0,1] \ \forall i, j;\ 0 < \sum_{j=1}^{n} \mu_{ij} < n \ \forall i \text{ and} \\ \sum_{i=1}^{c} \mu_{ij} = 1 \ \forall j \end{array} \right. \right\} \tag{4}$$

$V = (v_1, \Lambda, v_c)$ is a vector of cluster centers, $v_i \in R^p$ for $c \geq i \geq 1$ and $\|\bullet\|$ denotes any inner product norm. The parameter $m \in [1, \infty]$ is a weighting exponent on each fuzzy membership. Minimization of the above objective function, J_m requires the membership values to be defined as:

$$u_{ij} = \left[\sum_{k=1}^{c} \left(\frac{D_{ijA}}{D_{jkA}} \right)^{\frac{2}{m-1}} \right]^{-1}, \quad 1 \leq i \leq c;\ 1 \leq j \leq n \tag{5}$$

and the class centers as:

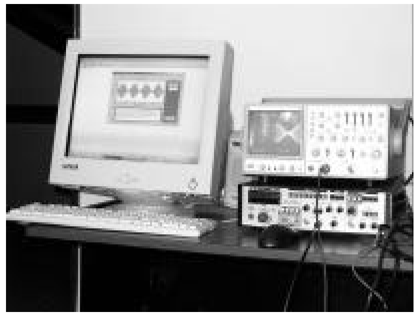

Fig. 2: The designed GUI

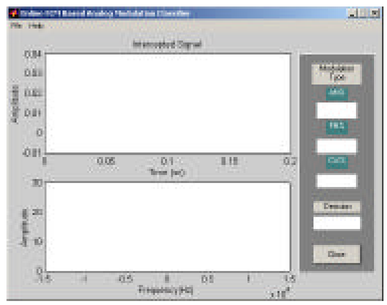

Fig. 3: Automatic analog modulation recognition system

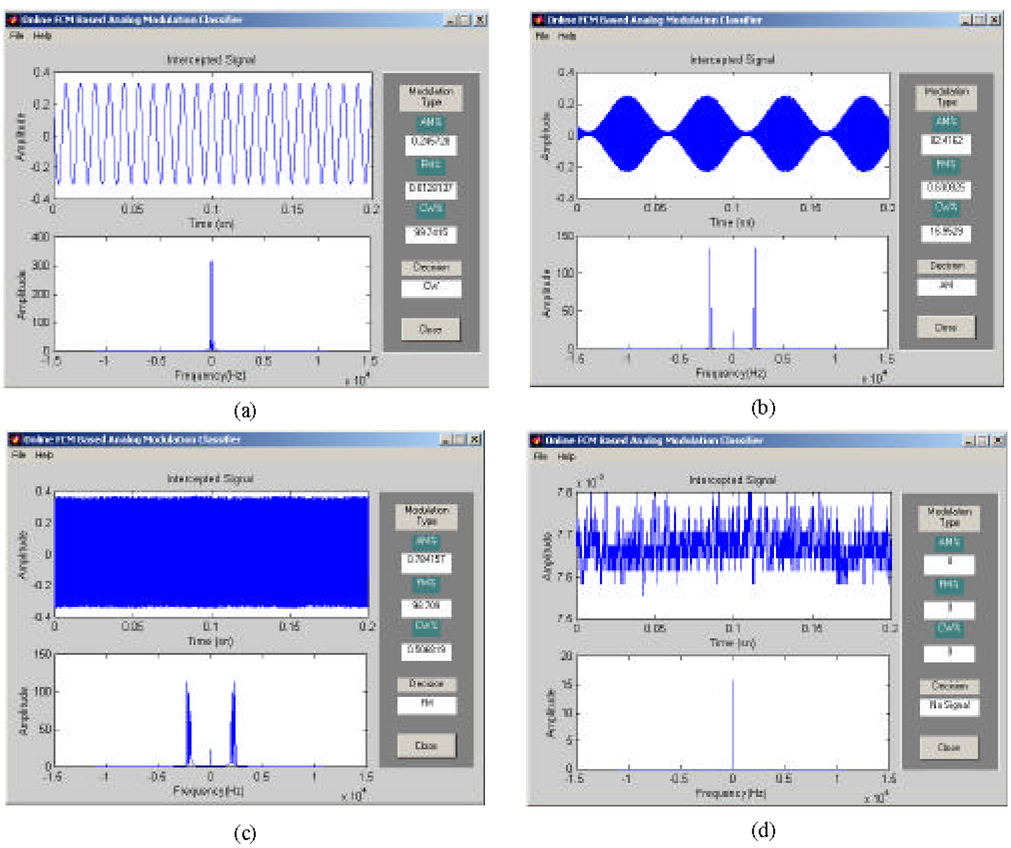

Fig. 4: Snapshots of interface (a) CW signal (b) AM signal (c) FM signal (d) No signal

$$v_i = \frac{\sum_{j=1}^{c} \mu_{ij}^m x_j}{\sum_{j=1}^{n} \mu_{ij}^m}, \; 1 \le i \le c. \quad (6)$$

where:

$$D_{ij} = \|x_j - v_i\|_A > 0 \;\; \forall i, j, \quad (7)$$

D_{ij} is distance between the feature vector X and the cluster center v_i. Each class represents one of the given spectral signatures in the prototype library. This study use training data from the analog modulated signals according to the key features as described previous section to define the class centers(v^0_i) and then the patterns are classified by calculating the membership degree μ_{ij}.

AUTOMATIC MODULATION RECOGNITION SYSTEM

A Graphical User Interface (GUI) is designed using Matlab and Data Acquisition Toolbox and can automatically recognize the specified analog modulations. The developed program receives the analog modulated signals via a PCL-812PG Enhanced Multi-Lab Card which is a high performance, high speed multi-function data acquisition card for personal computers, is used to acquire the analog modulated RF signals from the signal generator. After pre-processing, feature extraction and classification, the type of the modulated signal is shown on the GUI together with the original signal waveform, the spectral density of the received signal. When the modulation type of the incoming signal is changed, the type of the modulation changes immediately on the GUI showing the correct modulation type online. The Fig. 2 shows the screenshot of the designed Matlab GUI. The automatic modulation recognition system is shown in Fig. 3.

A number of simulations have been done with theoretically produced different modulated signals with various SNR and various modulation parameters. The modulation types were restricted to the types commonly used in analog communication. The modulation was carried out by using Matlab functions in Communication Toolbox. An additive white Gaussian noise with SNR of between 0 and 40 dB is used in the modeling of theoretically produced analog modulated signals.

For the experimental verification a B+K Precision Model 3040 universal signal generator is used. The signal generator provides outstanding phase-noise performance and analog modulation features for all general purpose test needs. It has a comprehensive analog modulation capabilities including AM, FM and CW (Fig. 4). The length of the screened cable between the computer and signal generator is kept minimum in order to avoid the noise at high frequencies and it is ended by a 50 ohm resistor.

Table 1: Performance of the interface

Simulated modulation type	Deduced modulation type AM (%)	FM (%)	CW (%)	Other (%)
AM	98	0	0	2
FM	0	96	4	0
CW	0	5	95	0

CONCLUSION

Automatic modulation recognition is important for both civilian and military purposes so intelligent demodulators have been needed so far. We designed an automatic analog modulation classifier interface on MATLAB environment and an experimental study has been carried out. A number of key features are used to fulfill the requirement of the interface. The training of the classifier is offline but the test is carried out online. The interface can recognize AM, FM and CW signals (Fig. 4). The interface's performance is satisfactory. The correct modulation recognition rates can be seen at Table 1.

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