New Algorithms for Automatic Modulation Recognition for Analogue Signals Using Multi Features

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***Abstract*—In this paper, we suggested new algorithms to discriminate between eight analogue modulated signals (amplitude modulation (AM), frequency modulation (FM), double side band (DSB), lower side band (LSB), upper side band (USB), vestigial side band (VSB), combined (AM-FM) and carrier wave (CW)). The simulation results show that the overall recognition of the new algorithms over 97% when the signal to noise ratio (SNR)=0dB. These new algorithms not only achieve a better recognition rate, but also reduce the computational loads.**

***Index Terms*—features, modulation recognition, analogue modulated signals and algorithm**

I. Introduction

Nowadays the digital modulations are used rather than an analogue one. However, the analogue modulations are still used in many organizations wide world. Since it is difficult to assume a proper probability distribution function (PDF) for the modulating signal (i.e., the information-bearing signal), the classification of analogue communication signals is generally based on some selected features derived from the received signals [1].

The following is an overview of some of the recently published analogue modulation recognition algorithms. Y. T. Chan *et al.* in [2] proposed algorithm to discriminate between some types of analogue modulated signals (AM, FM, DSB and SSB) based on the envelope characteristics of the received signal. The quantity of interest is the ratio (R) of the variance of the envelope to the square of the mean. The overall recognition rate of this algorithm reached 97% when SNR=7dB. Nandi and Azzouz in [3] and [4] proposed five algorithms for analogue modulation recognition to discriminate between seven analogue modulated signals (AM (with different modulation depth), FM (with different modulation index), DSB, LSB, USB, VSB, combined (with different modulation depth and index). Four key features are proposed to fulfil the requirement of these algorithms, these key features derived from instantaneous amplitude (maximum value of the spectral power density of the normalized-centered instantaneous amplitude of the intercepted signal), instantaneous phase (standard deviation of the absolute value of the centered non-linear component of the instantaneous phase and standard deviation of the centered non-linear component of the direct instantaneous phase) and signal spectral (spectrum symmetry around the carrier frequency, and it is based on the spectral powers for the lower sideband and the spectral powers for the upper side band of the intercepted signal). The overall recognition rate of these algorithms over 97% when SNR=10dB. Druckmann *et al.* in [5] suggested algorithm to discriminate between analogue modulated signals (AM, FM, DSB and SSB). The overall recognition rate of this algorithm reached 95% at SNR>10dB. A new method for envelope extraction, which does not require Hilbert Transform computation, is proposed. Also mentioned this recognizer need short data records compare to [2]. Seaman and Braun [6] analysed the cyclostationarities of AM, DSB, SSB, CW and noise signals. The estimated cyclic spectral density (CSD) of the received signal is used in signal classification. But how to implement the approach has not been discussed. Guldemir and Sengur in [7] proposed four different Clustering Techniques to discriminate between analogue modulated signals (AM, FM, DSB, LSB and USB). These clustering techniques are K-means clustering, fuzzy, c-means clustering, mountain clustering and subtractive clustering. Two key features are used in this study for generating the data set. The first feature is the maximum value of the normalized centred instantaneous amplitude of the intercepted signal; the second key feature is the signal spectrum symmetry around the carrier.The performance of this technique was not mentioned. Richterova *et al.* in [8] used the Artificial neural networks and features proposed by [3] to discriminate between analogue modulated signals (AM, FM, DSB, LSB and USB). P. M. Fabrizi *et al.* in [9] proposed a modulation recognizer based on the variations of both the instantaneous amplitude and the instantaneous frequency. This recognizer is used for the recognition of some analogue modulated signals AM, FM, CW and SSB. AM and CW could be discriminated from FM and SSB at SNR>35dB. However, SSB could be separated from FM signals at SNR>5dB. Nagy [10] proposed a modulation recognizer based on the instantaneous frequency, addition to the feature proposed in [2]. This recognizer is used for the recognition of some analogue modulated signals AM, DSB, SSB, FM, CW and noise signals. The SSB has been

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classified with a success rate>94% at SNR≥15dB and the other types has been classified with a success rate of 100%. S. D. Jovanovic *et al.* in [11] proposed a modulation recognizer to discriminate between a low modulation depth AM and a pure carrier wave (CW) in a noisy environment. The only thing mentioned about the performance is that the proposed key feature is highly reliable to discriminate between aforementioned signals even if the SNR is poor.

Y. O. Al-Jalili in [12] proposed a modulation recognizer to discriminate between the USB and LSB signals. This recognizer is based on the fact that the instantaneous frequency of the USB signal has more negative frequency spikes than positive ones, and contrary for LSB. The overall recognition rate has reached 100% when the SNR⩾0dB. R. Waller and G. D. Brushe in [13] proposed a modulation recognizer based on demodulator, modulator and correlator used to discriminate PM from FM. No performance evaluation result has been reported for this recognizer. Taira and Murakami [14] proposed a new automatic classification procedure of analogue modulation signals including phase continuous FSK signals. As for the discrimination between frequency modulation signals and amplitude modulation signals the statistical parameters of signal envelope is used. The compactness of instantaneous frequency distribution proposed by [4] is used for the classification among frequency modulation signals (FM, PM and FSK). The feature proposed by [2] is used for the classification among amplitude modulation signals (AM, DSB and SSB). The good classification possibility has been ascertained by the computer simulations when SNR≥10dB.

All the algorithms proposed in [2], [5]-[14] were used a few types of analogue modulated signals. While the algorithms proposed by Azzouz and Nandi do not have acceptable performance (effective at SNR≥10dB).

Our paper aims at the development of new algorithms for the automatic modulation recognition of analogue signals using multi features at the same time instead of one feature used in most Algorithms depend on the feature extraction approach to get better recognition rate. Three features extracted from instantaneous information (amplitude and phase) and spectra of the intercepted signal are used to discriminate between eight modulated signals same as in [3] and [4], in addition to carrier wave (CW) at low SNR. Our algorithms not only achieve a better recognition rate, but also extended the number of analogue signals and reduce the computational loads.

This paper is arranged as follows: the second Section presents the key features used. In the third Section, Computer simulations, including the flowchart and the simulation results are presented. Finally, the paper is concluded by presenting the conclusion.

II. Feature Extraction

To discriminate the analogue modulated signals, three features extracted from instantaneous information (amplitude and phase) and spectra of the intercepted signals are used. All these features proposed by Nandi and Azzouz in [3] and [4].

The first key feature is $\gamma_{\max}$ defined by

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

where $\gamma_{\max}$ is the maximum value of the spectral power density of the normalized-centred instantaneous amplitude of the intercepted signal, N_s is the number of samples per segment and $a_{cn}(i)$ is the value of the normalized centred instantaneous amplitude at time instant $t = i / f_s$, $(i = 1, 2, \ldots, Ns)$ and it is defined by $a_{cn}(i) = a_n(i) - 1$, and $a_n(i) = a(i) / m_a$, $a(i)$ is the instantaneous amplitude, m_a is the sample mean value.

The second key feature is σ_{dp} defined by

$$\sigma_{dp} = \sqrt{\frac{1}{C}\left(\sum_{a_n(i)>a_t} \varnothing_{NL}^2(i)\right) - \left(\frac{1}{C}\sum_{a_n(i)>a_t} \varnothing_{NL}(i)\right)^2} \qquad (2)$$

where σ_{dp} is the standard deviation of the centred non-linear component of the direct instantaneous phase, evaluated over the non-weak interval of signal segment., $\varnothing_{NL}(i)$ is the value of the centred non-linear component of the instantaneous phase at time instant $t = i / f_s$, c is the number of samples in $\{\varnothing_{NL}(i)\}$ for which $a_n(i) > a_t$ and a_t is the threshold to get non weak samples.

The third key feature is defined by

$$P = \frac{P_l - P_u}{P_l + P_u} \qquad (3)$$

This key feature is used for measuring the spectrum symmetry around the carrier frequency, and it is based on the spectral powers for the lower sideband (P_l) And the spectral powers for the upper sideband (P_u).

$$P_l = \sum_{i=1}^{f_{cn}} |X_c(i)|^2 \qquad (4)$$

$$P_u = \sum_{i=1}^{f_{cn}} |X_c(i + f_{cn} + 1)|^2 \qquad (5)$$

where P_u is the Fourier transform of the RF signal $X_c(i)$, $(f_{cn} + 1)$ is the sample number corresponding to the carrier frequency, and then is defined as

$$f_{cn} = \frac{f_c N_s}{f_s} - 1 \qquad (6)$$

III. Computer Simulations

The software used is Matlab R2011b and the simulation parameters (data length, carrier frequency, symbol rate and sampling frequency) same as men-tioned in [3].

A. Flowchart of Automatic Recognition of Analogue Signals

The sequence order of selecting the features to discriminate between signals of interest for the first algorithm and second algorithm are shown in the Fig. 1 and Fig. 2, and the specific values of the thresholds are shown in Table I.

IV. Simulation Results and Analysis

500 iterations averages were used to get the recognition rates in Table II and III.

A. Simulation Results of the First Algorithm

The Table II shows the performance of this algorithm at specific SNR levels and the Fig. 3 shows the overall performance.

Table II shows that, by using multi features at the same time to discriminate analogue modulated signals, the average recognition rate can reach 97.33% when SNR=0dB.

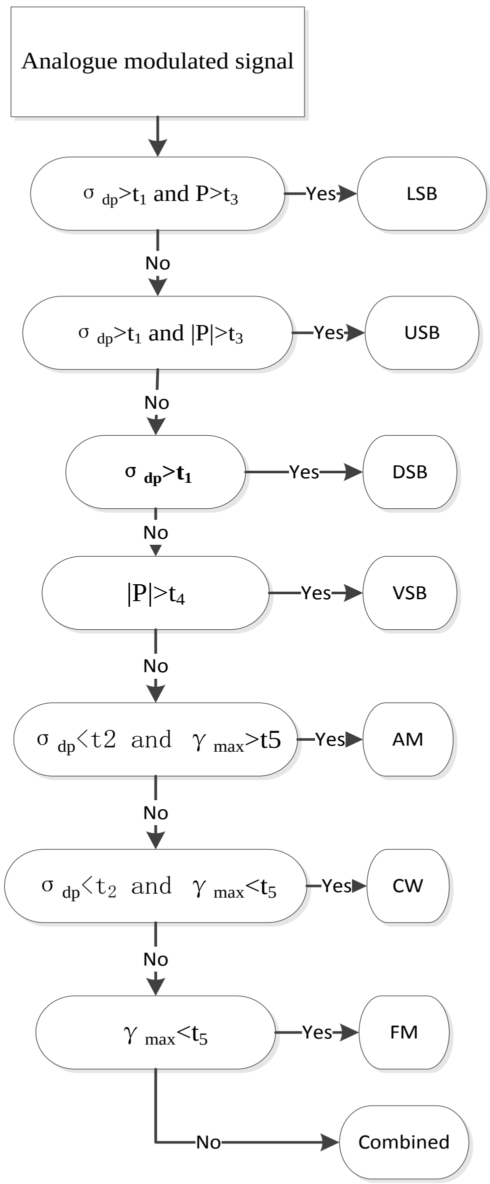

Figure 1. The flowchart of the first algorithm

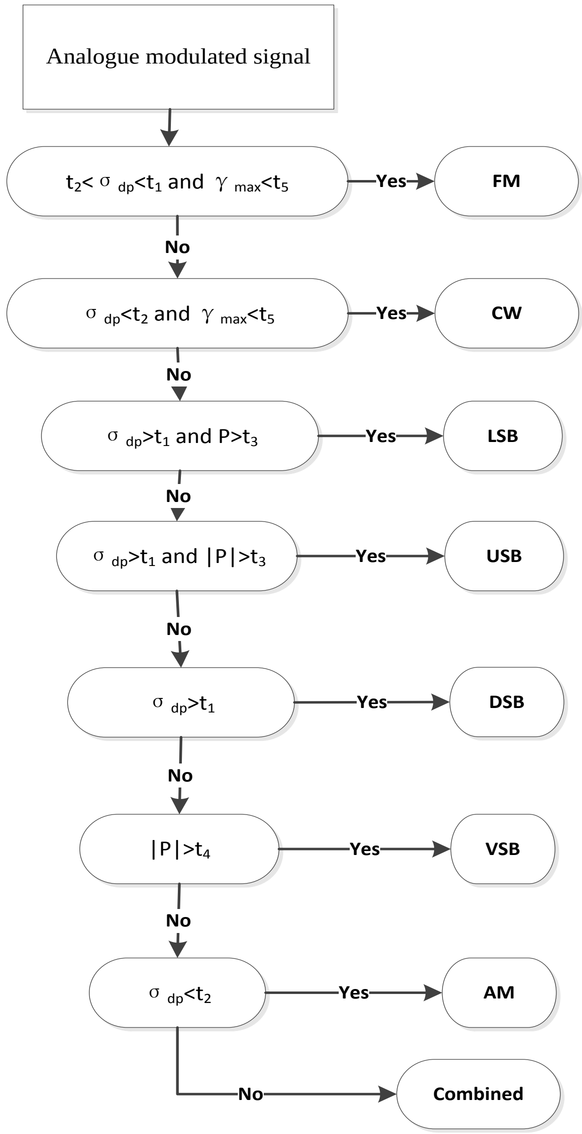

Figure 2. The flowchart of the second algorithm

TABLE I. The Value of Thresholds

Feature	Threshold
σ_{dp}	t1=1.2
	t2=0.685
$\|P\|$	t3=0.5
	t4=0.325
γ_{max}	t5=4.39

TABLE II. The Performance of First Algorithm

Modulated signals	Recognition rate at SNR (dB)		
	-2	0	>2
AM	66.4%	93%	100%
FM	97.6%	99.4%	100%
DSB	99.6%	100%	100%
LSB	98%	100%	100%
USB	82.2%	99.4%	100%
VSB	44.4%	96.2%	100%
COM (AM-FM)	97.2%	100%	100%
CW	30.2%	90.6%	100%
Overall recognition	76.95%	97.33%	100%

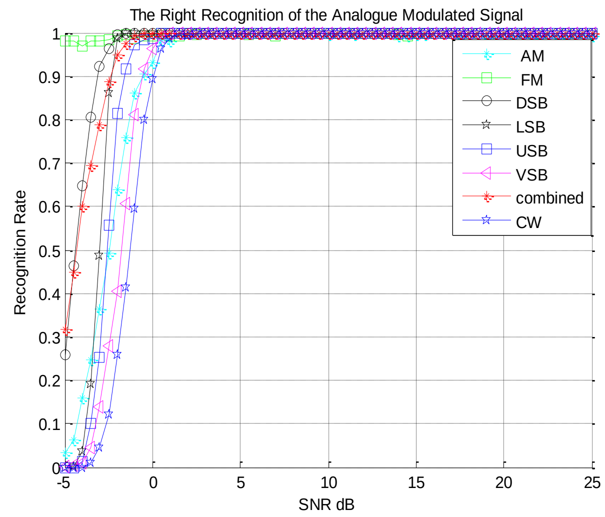

Figure 3. Overall performance of the first algorithm

B. Simulation Results of the Second Algorithm

Table III shows the performance of this algorithm at specific SNR levels and the Fig. 4 shows the overall performance.

Table III shows that, by using multi features at the same time to discriminate analogue modulated signals, the average recognition rate can reach 97.25% when SNR=0dB.

TABLE III. THE PERFORMANCE OF SECOND ALGORITHM

Modulated signals	Recognition rate at SNR (dB)		
	-2	0	>2
AM	61.6%	94.8%	100%
FM	98.4%	99.8%	100%
DSB	99%	100%	100%
LSB	97.6%	100%	100%
USB	80.4%	99.2%	100%
VSB	36.4%	94%	100%
COM (AM-FM)	96.2%	100%	100%
CW	25.2%	90.2%	100%
Overall recognition	74.35%	97.25%	100%

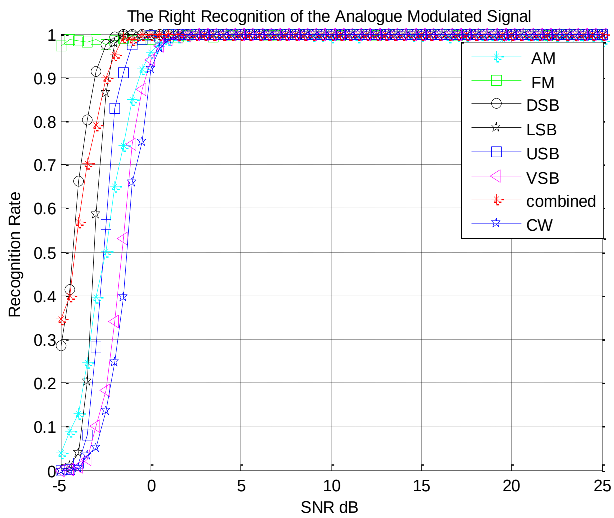

Figure 4. Overall performance of the second algorithm

C. Comparing the New Algorithms with the Existing Algorithms

TABLE IV. COMPARES THE NEW ALGORITHMS WITH NANDI AND AZZOUZ ALGORITHMS

	Nandi and Azzouz algorithms			**Our work**	
	I & V	II & III	IV	I	II
SNR	10dB	10dB	10dB	0dB	0dB
Overall recognition	99.37%	97.19%	98.04%	97.33%	97.25%
Number of features	4	4	4	3	3
AM	100%	100%	100%	93%	94.8%
FM	100%	100%	100%	99.4%	99.8%
DSB	100%	99.5%	99.5%	100%	100%
LSB	99.8%	94%	100%	100%	100%
USB	97.8%	94%	94%	99.4%	99.2%
VSB	98%	92.8%	92.8%	96.2%	94%
COM (AM-FM)	100%	100%	100%	100%	100%
CW	-	-	-	90.6%	90.2%

From the Table IV above it is clear that the new algorithms have 10dB better than Nandi and Azzouz algorithms. Also the new algorithms used just three features instead of the four features that lead to reduce the computational loads. These newer algorithms have a better recognition rate than most existing analogue automatic modulation recognition algorithms such as [2]-[14].

V. CONCLUSION

In this paper we propose new procedures of using multi features at the same time to discriminate between analogue modulated signals. By using these new procedures many advantages can be achieved: improve the overall recognition rate of the algorithms, reduce the computational loads and reduce the effect of the sequence order of selecting features.

Nowadays, digital modulation techniques are used rather than analogue modulated signals. So the new trend is the digital modulation recognizers. The aforementioned of using multi features algorithms are also can be successfully applied to the digital modulation recognition algorithms.

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