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Analysis and Classification of Communication Signals

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Abstract. Pattern recognition techniques are being increasingly used in analysis and classification in areas of communication. Probability distributions for classification of various types of signals and FFT analysis for feature extraction are presented. A novel processing system is also suggested.

1. Introduction

With increased use of the frequency spectrum—surveillance, analysis, classification, and monitoring of communication signals has assumed utmost importance. Classification of a signal with respect to the type of main carrier modulation and the nature of modulating signal is an important part of communication signal processing. Several factors like the crowding of the frequency spectrum (especially at HF/VHF), the large variety of communication signals that are employed by various users, high ambient noise level and the non-stationery nature of communication signal, have to be considered in detail in arriving at an optimum scheme of signal processing. There are 52 types of signals specified in the latest CCIR recommendations[1,2]. The signal processing scheme has to employ various methods of feature extraction and pattern recognition to identify each of this type of modulation.

This paper considers the problem in detail. However, commonly used types of modulation like analog AM, FM, FSK, MFSK, etc., are only considered. Various probability density functions are utilised for signal classifications. The normal surveillance receiver employing sweeping superheterodyne principle is not well suited for instantaneous narrowband analysis. Hence, this paper proposes a novel system configuration employing Fast Fourier Transform analyser and a desktop computer for signal classification and analysis.

2. Signal Classifier Block Diagram

The classification system is composed of five major subsystems as presented in Fig. 1. It consists of a receiver, modulation meter, the classifying computer, a high frequency signal digitizer and a FFT processor. The classifier software developed in Defence Electronics Research Laboratory (DLRL), Hyderabad consists of compact algorithms to analyse and classify the signals based on the type of modulation. Since the communication signals are non-stationery in nature and corrupted by noise, the classification process has been carried out statistically.

The classification system recognizes the type of modulation on the basis of probability density functions of amplitude, frequency, modulation index. The processing has been carried out both on video and audio signals. The software has been developed to classify various types of signals as shown in the Fig. 2.

3. Signal Classification

For the purpose of classification of the RF signal, first the main carrier has to be analyzed to determine the type of emission namely, pulsed RF, amplitude modulation, frequency shift keying and frequency modulation. The system does this by examining probability density distribution of amplitude of video signal of the receiver, modulation index/frequency deviation of the RF carrier and amplitude probability

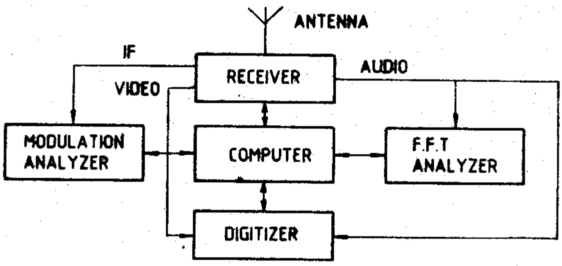

Figure 1. System block diagram.

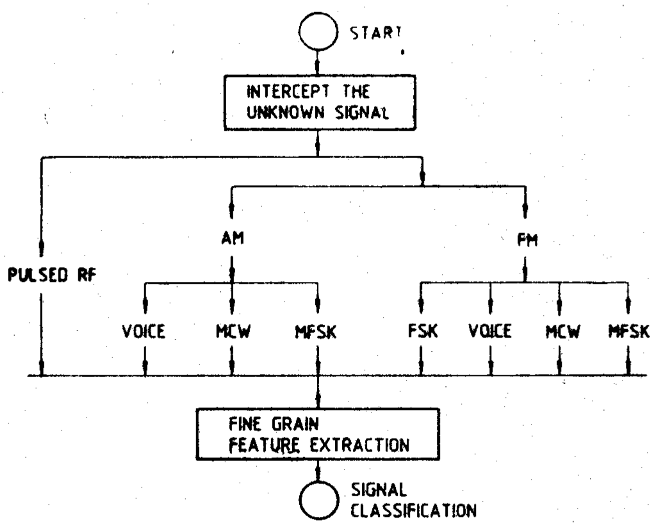

Figure 2. Classification tree diagram.

distribution of audio signal. Based upon the above three histograms the type of main carrier modulation can be determined accurately. Later the base band signal analysis has to be carried out. Here the modulating signal has to be voice, modulated C. W and modulated FSK. This can be classified based on the frequency probability distribution of audio signal by Fast Fourier Transform analysis:

4. Emitter Classification by Pattern Recognition

There are three different types of pattern recognition algorithms which have been considered for this type of application:

(i) Template Matching Method.

(ii) Minimum Distance Classification Method.

(iii) Linear Discriminant Function Method.

In communication signal classification[3] the data patterns are not deterministic. From Fig. 3 we can see that the percentage of modulation take any value of 0 to 10 per cent depending upon the type of main carrier modulation. The percentage of modulation in communication systems will be varying based on the type of speaker and gain of amplifier stages. The measured patterns will be falling in the X-axis or Y-axis in an ideal condition. Hence either template matching or minimum distance classification method is not suitable. It is found that the linear discriminant function method is most suitable for this type of applications.

Here the proposed system classifies the pattern into one of the various transmitter categories by Linear Discriminant Function Method[4].

The Feature space diagram for identifying the type of modulation either amplitude or frequency modulation is shown in Fig. 3. Here the X-axis represents percentage of amplitude modulation and Y-axis represents percentage of frequency modulation. In this case there are four regions to be identified namely AM modulation, FM modulation, combinational modulation and no-modulation (CW). These four classes are separated by two bisector lines, whose functions are $D(X)$ and $D(Y)$ crossing 1 per cent points in both the axis respectively. The 1 per cent index point is selected because

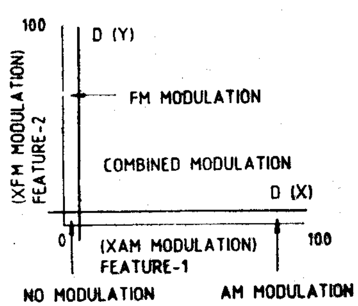

Figure 3. AM/FM classification diagram.

for the normal FM transmitter the incidental AM may not exceed that threshold and *vice versa.*

Where

$$D(X) : Y = C$$

$$D(Y) : X = C$$

where $C = 1$ per cent

Based on the measured value falling in one of these regions the software determines the type of modulation of the main carrier.

5. Video Signal Classification

The classifier system first acquires one or more samples of the time video data containing 1024 data points. The captured video data can be processed to produce amplitude versus frequency of occurrence information called amplitude probability distribution. The classifier then identifies significant signal features from the distribution like first peak and second peak value. Based on the above features it can take a decision whether the signal is pulsed RF or CW.

In the case of pulsed RF signal the software takes a decision based on

$$\begin{array}{c} \text{Number of sample} \\ \text{points at the first} \\ \text{peak} \end{array} + \begin{array}{c} \text{Number of sample} \\ \text{points at the} \\ \text{second peak} \end{array} = \begin{array}{l} \text{Total number of samples} \\ \text{collected.} \end{array}$$

If it is CW signals :

Number of sample points at the first peak = Total number of samples collected.

Here due to the noise embeded in the signal there will be a spread in the probability distribution function. So we have to select proper window to find exact frequency of occurrence of the particular amplitude level. In our system we have incorporated software amplitude normalisation to improve the resolution. At present we are using the fixed window width of 40 Bins (400 MV). However, there is a scope for introducing a scheme wherein the window is optimised based on the signal to noise ratio of the signal.

The Figs. 4 (a) and 4 (b) show the video output of the receiver for pulsed RF and CW signals. The Figs. 4 (c) and 4 (d) show the amplitude probability distribution of the above. Finally Fig. 4 (e) shows the feature space diagram to identify whether the signal is pulsed RF or CW. Here X-axis represents frequency of occurrence of peak-1 and Y-axis represents frequency of occurrence of peak-2.

6. Modulation Index Analysis

The modulation analyser output is sampled both in amplitude and frequency modulation modes. The percentage of modulation, frequency deviation is drawn as histogram. Here X-axis represents percentage of modulation as a class interval and Y-axis represents probability of occurrence of the particular value of modulation which is shown in the Fig. 5. From these histograms peak frequency deviation and peak percentage of modulation is plotted in two feature space diagram. Based on the above, the type of modulation can be determined. The region of FM and AM modulation of the main carrier is shown in the Fig. 3. In the case of FSK signal the audio output of the receiver is sampled and based on the amplitude probability distribution one can define whether it is FSK (square wave output) or FM-analog signal. The identification method is similar to the video signal classification.

7. Base Band Signal Classification

The system classifies by examining the power spectrum[5] of one or more samples of the audio signal in the domain of frequency and time. For converting 'time domain'

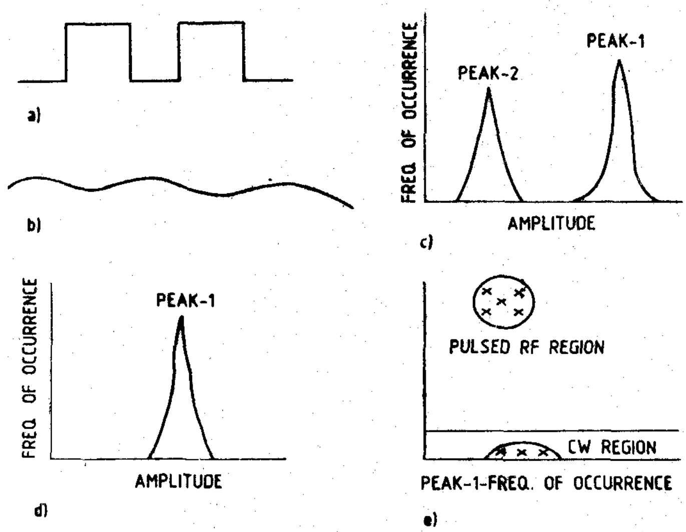

Figure 4 (a) Pulsed RF video waveform.
(b) CW video waveform.
(c) Pulsed RF amplitude probability distribution.
(d) CW amplitude probability distribution.
(e) Pulsed RF/CW classification diagram.

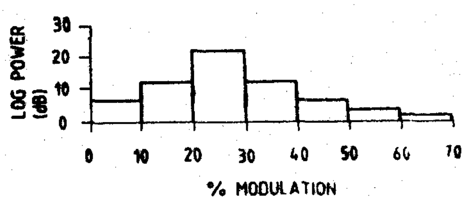

Figure 5. Modulation index histogram.

signal to 'frequency domain' in real time, Fast Fourier Transform (FFT) technique is used. The system first acquires one or more samples of the signal, each sample being typically around 100 mS duration and containing 1024 data points for the above processing. The sampled data blocks are multiplied by a window function (Hanning or Hamming) to reduce the leakage due to the truncation of the continuous data points. Later the weighted data is moved to the FFT processor for the purpose of computation of the log power spectrum. Here the outputs of 10 successive transforms are added to provide an estimate of the average. Later the averaged data are sent to the controller for further processing.

As an example Fig. 6 (a) shows the log power spectrum of a 1000 mS sample of a typical base band signal. There appear to be two strong spectral features suggesting the signal is FSK. Figs. 6 (b) and 6 (c) show CW and voice signal. For low duty cycle signals such as voice, we may have to consider a number of 100 mS samples for accurate classification, so as to increase the probability of a correct result. This indicates that the signal classification rate will not be the same for all signal types.

The second method of classifying the base band signal is based on frequency probability histogram. Here the processing has to be carried out on 10 to 20 mS data frames. From the log power spectrum data of various frames frequency probability histogram is drawn. Then the classifier software identifies the type of base band signals from the above histogram. The frequency probability histogram of various types of signals are shown in the Figs. 7 (a), 7 (b) and 7 (c).

8. Conclusion

Analysis and classification of communication signals is a complex process. The system proposed in this paper can be used to classify several commonly used communi-

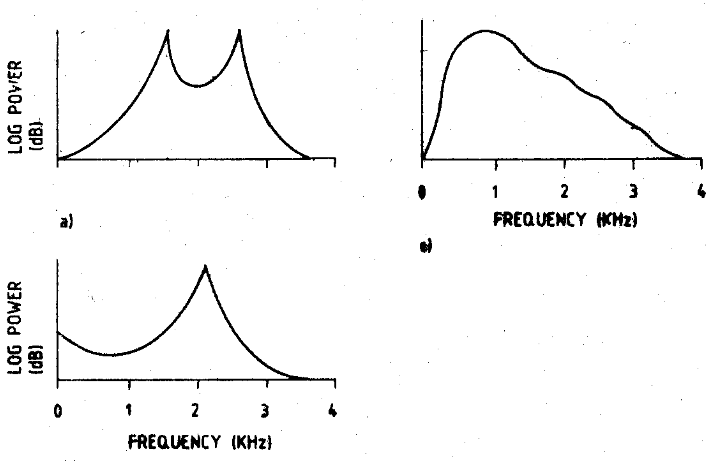

Figure 6 (a). Modulated FSK-spectrum.
(b). Modulated CW-spectrum.
(c). Voice-spectrum.

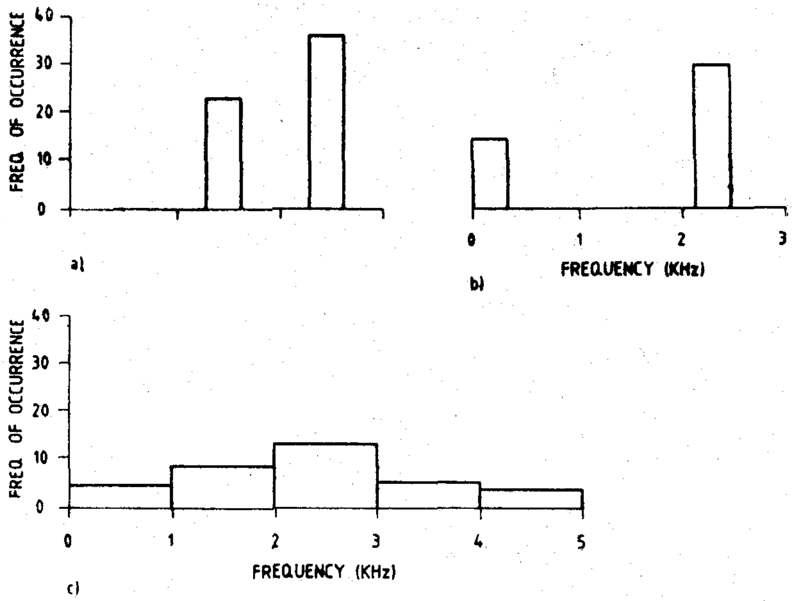

Figure 7 (a). MFSK-Freq. probability histogram.
(b). MCW-Freq. probability histogram.
(c). Voice Freq. probability histogram.

cation signals. Such a system will find applications for military intelligence agencies and for regulatory bodies for the frequency spectrum management. The level of confidence of the classification will depend upon the signal to noise ratio, nature and level of interference, ambient noise and the number of samples collected for analysis. However, the level of confidence can be improved to a certain extent by using adaptive algorithms depending upon the amplitude of the received signal.

As the system is computer controlled, it could be configured to meet a particular requirement with necessary software modifications. There is further scope for research in this area for classification of a larger number of communication signals and selection of other features for classification.

Acknowledgement

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