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ScienceDirect
Digital Signal Processing 19 (2009) 153–183
Digital Signal Processing
www.elsevier.com/locate/dsp

Time–frequency feature representation using energy concentration: An overview of recent advances

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Available online 16 February 2008

Abstract

Signal processing can be found in many applications and its primary goal is to provide underlying information on specific problems for the purpose of decision making. Traditional signal processing approaches assume the stationarity of signals, which in practice is not often satisfied. Hence, time or frequency descriptions alone are insufficient to provide comprehensive information about such signals. On the contrary, time–frequency analysis is more suitable for nonstationary signals. Therefore, this paper provides a status report of feature based signal processing in the time–frequency domain through an overview of recent contributions. The feature considered here is energy concentration. The paper provides an analysis of several classes of feature extractors, i.e., time–frequency representations, and feature classifiers. The results of the literature review indicate that time–frequency domain signal processing using energy concentration as a feature is a very powerful tool and has been utilized in numerous applications. The expectation is that further research and applications of these algorithms will flourish in the near future.

Keywords: Time–frequency analysis; Energy concentration; Feature extraction and classification

1. Introduction

Signal processing is often used for feature extraction and classification in medical disease diagnosis [1–3], industrial process control [4], fault detection [5], and many other fields. The primary goal of signal processing in the aforementioned applications is to provide underlying information on specific problems for decision making [6]. These techniques can be classified either as time, frequency or time–frequency domain based algorithms. At the classification level, there also exist several different methodologies. Typical approaches along with sample features used in extraction and classification are shown in Fig. 1. Understanding of the problem at hand is crucial in deciding which framework to employ for feature analysis. Some features, such as amplitude levels in the time domain, are easily extracted and classified, but are susceptible to noise. Others, such as energy concentration in the time–frequency domain, even though require more involved operations, can lead to more robust feature extraction and more accurate classification. Furthermore, not every feature yields plausible conclusions. For example, in the analysis of heart sounds, which

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1051-2004/$ – see front matter
doi:10.1016/j.dsp.2007.12.004

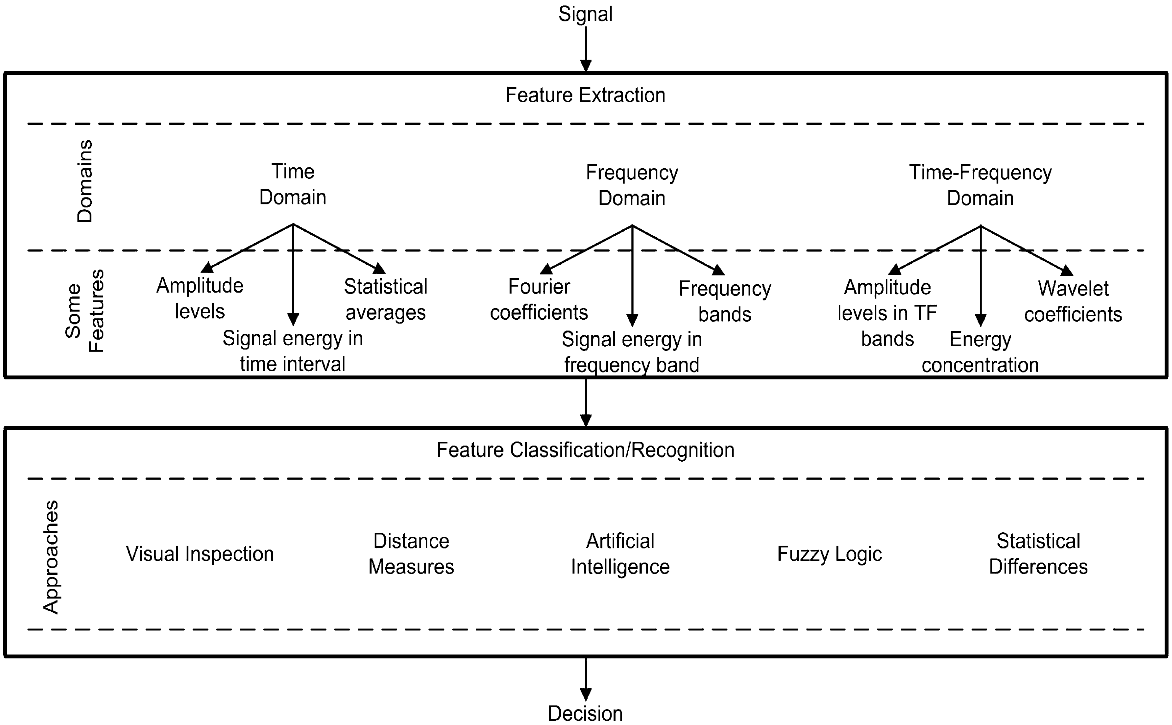

Fig. 1. Signal processing for pattern classification in a typical application.

are nonstationary, the amplitude rarely provides conclusive information. The intensity of the recorded heart sounds is affected by many factors, which are not necessarily pathological. On the other hand, the amplitude in the time domain will provide sufficient information when considering control of the liquid level in a tank. Therefore, depending upon whether the phenomenon under analysis is stationary or nonstationary, and on the nature of the desired feature, different algorithms have to be used. The question is what signal processing algorithms should be used for feature analysis in a given situation? The answer simply depends on a priori knowledge about the phenomenon under consideration. Parametric signal processing algorithms can be used for feature extraction and classification if an accurate model of the signal exists in a selected representation space [7]. However, such modeling techniques have limitations as well. Modeling of nonstationary signals is more difficult and consistent parametric models often do not exist, except in very few special cases, e.g., mono or multi component chirp signals [8]. Most of the signals encountered in practice do not satisfy the stationarity conditions, which explains the growing interest in nonstationary signal processing.

1.1. Time–frequency analysis

Time–frequency analysis (TFA) is of great interest when the signal models are unavailable. In those cases, the time or the frequency domain descriptions of a signal alone cannot provide comprehensive information for feature extraction and classification. The time domain lacks the frequency description of the signals. The Fourier transform of the signal cannot depict how the spectral content of the signal changes with time, which is critical in many nonstationary signals in practice. Hence, the time variable is introduced in the Fourier based analysis in order to provide a proper description of the spectral content changes as a function of time. Therefore, the basic goal of the TFA is to determine the energy concentration along the frequency axis at a given time instant, i.e., to search for joint time–frequency representation of the signal [10]. In an ideal case, the time–frequency transform would provide direct information about the frequency components occurring at any given time by combining the local information of an “instantaneous frequency spectrum” with the global information of the temporal behaviour of the signal [11,12].

The time–frequency representations (TFRs) can be classified according to the analysis approaches. In the first category, the signal is represented by time–frequency (TF) functions derived from translating, modulating and scaling a basis function having a definite time and frequency localization. For a signal, $x(t)$, the TFR is given by