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ECG compression method using Lorentzian functions model

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Abstract

An ECG compression algorithm using a combination of Lorentzian functions model is proposed in this paper. In order to estimate the parameters of the Lorentzian functions, the discrete Fourier transform (DFT) is first applied to a mean removed ECG signal from which only the most significant DFT coefficients are retained. The obtained coefficients are, then modeled as the sum of a given number of superimposed exponentially damped sinusoids (EDS), commonly identified by their amplitudes, real damping factors, frequencies and initial phases. Finally, these EDS parameters are estimated, using SVD method, then coded. The algorithm has been tested for its coding efficiency and reconstruction capability by applying it to several popular, benchmark ECG signals. Encouraging results have been obtained.

Keywords: ECG compression; SVD; Lorentzian functions; Exponentially damped sinusoids

1. Introduction

It is well known that the storage and transmission of digital ECG signals are of great importance for various applications. In these applications, compressing ECG waveforms without any considerable degradation in quality is of a great consideration.

The ECG compression techniques can be classified in three broad categories: direct methods, transform-based methods, and parameter extraction methods.

In the direct methods category, the original samples are directly compressed [1,2].

In the transformation methods category, the original samples are transformed and the compression is performed in the new domain. Among, the algorithms which employ transform-based techniques, there are several algorithms based on discrete cosine transform [3], and wavelet transform [4–7].

In the category of the methods with extraction of parameters, one extracts some features of the signal that are used later for its reconstruction [8,9].

This paper presents an algorithm based on modeling the ECG signal as a linear combination of Lorentzian functions, to achieve effective ECG data compression.

The estimation of unknown parameters of Lorentzian functions from a finite number of noisy data observations has been considered in many applications, particularly in NMR biomedical signals analysis [10].

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In this paper, we consider the estimation of unknown parameters of Lorentzian functions for the analysis of the data obtained from the ECG signals.

The present paper is organized as follows. In Section 2, we briefly describe the SVD 's algorithm [11] used in estimating the parameters of the model. In Section 3, we describe the proposed algorithm for compressing the ECG signals. Section 4 is devoted to the presentation of experimental results obtained with the MIT-BIH database. Finally, Section 5 concludes this work.

2. SVD algorithm and the Lorentzian functions model

2.1. Data model

We consider that the ECG signal $x(t)$ is modeled as a linear combination of M functions $f_i(t)$,

$$x(t) = \sum_{i=1}^{M} A_i f_i(t) + b(t) \tag{1}$$

with $f_i(t)$ is a sinusoidal, power of t, Gaussian or a Lorentzian function, and $b(t)$ is a zero mean white Gaussian with variance σ^2, representing the instrumental noise. In this paper among the functions $f_i(t)$ we choose the Lorentzian functions:

$$f_i(t) = \frac{1}{\pi} \frac{\alpha_i}{\alpha_i^2 + (t - t_i)^2}. \tag{2}$$

Since the Lorentzian function has Fourier transform $F_i(f) = FT[f_i(t)] = e^{-j2\pi f t_i - \alpha_i \pi |f|}$, the ECG signal has its Fourier transform $X(k)$ as a linear combination of M exponentially damped sinusoids (EDS). Then, the resulting complex-valued $X(k)$ may be expressed as

$$X(k) = \sum_{m=1}^{M} A_m \exp(j\phi_m) \exp(\alpha_{\mathrm{m}} k + j2\pi k f_m), \quad k = 1, N/2, \tag{3}$$

where M is the order of the model, N is the number of samples, $A_m \in \Re_+^*$ are the amplitudes, α_m are the real damping factors, $f_m \in [-1/2, 1/2]$ are the frequencies, and $\phi_m \in [-\pi, \pi]$ denote the initial phases. All these parameters must be estimated.

Given N samples, the problem is then to estimate the unknown parameters $\{A_m, f_m, \alpha_m, \phi_m, \}_{m=1}^{M}$.

Several algorithms were previously proposed for parameter estimation of exponentially damped sinusoids include those based on linear prediction, those based on systems identification such as KiSS/IQML iterative, and those based on iterative estimation of the parameters of the individual components such as AP and EM algorithms.

A direct implementation of an exact maximum likelihood (ML) estimator for EDS model has a prohibitive cost of performing such a large order multidimensional search. Many of these algorithms are either computationally expensive and/or do not have good estimation performance.

It is also possible to use a general ARMA model as an alternative to model the EDS signal. In this case we obtain a particular ARMA model with identical autoregression and moving average parameters, so a lot of variants of the SVD may be used.

The order of the model M may be assumed known.

The first aim of this paper is to verify that, with the model (1) we may achieve a good approximation of signal ECG. The estimation of the model parameters is performed by using the SVD method [11], and then used to reconstruct the ECG signal. One limits the study to the Tufts and Kumaresan (TK) method which allows more efficient estimators of the parameters than others methods like Prony or linear prediction methods.

2.2. Description of the SVD method

Consider the following linear system:

$$A\underline{\beta} = -\underline{c}, \tag{4}$$