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Empirical Mode Decomposition and Principal Component Analysis implementation in processing non-invasive cardiovascular signals

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ABSTRACT

Biomedical signals are relentlessly superimposed with interferences. The nonlinear processes which generate the signals and the interferences regularly exclude or limit the usage of classical linear techniques, and even of wavelet transforms, to decompose the signal.

Empirical Mode Decomposition (EMD) is a nonlinear and adaptive technique to decompose data. Biomedical data has been one of its most active fields. EMD is fully data-driven, thus producing a variable number of modes. When applied to cardiovascular signals, the modes expressing cardiac-related information vary with the signal, the subject, and the measurement conditions. This makes problematic to reconstruct a noiseless signal from the modes EMD generates.

To synthesize and recompose the results of EMD, Principal Component Analysis (PCA) was used. PCA is optimal in the least squares sense, removing the correlations between the modes EMD discovers, thus generating a smaller set of orthogonal components. As EMD–PCA combination seems profitable its impact is evaluated for non-invasive cardiovascular signals: ballistocardiogram, electrocardiogram, impedance and photo plethysmogram.

These cardiovascular signals are very meaningful physiologically. Sensing hardware was embedded in a chair, thus acquiring also motion artefacts and interferences, which EMD–PCA aims at separating. EMD is seen to be important, because of its data adaptability, while PCA is a good approach to synthesize EMD outcome, and to represent only the cardiovascular portion of the signals.

1. Introduction

Monitoring the cardiovascular activity recurring to electrophysiological signals is the most appropriate way of non-invasively assessing the cardiovascular activity. From cardiovascular signals, the foremost is recognizably the electrocardiogram (ECG). The photoplethysmogram (PPG) is increasingly popular due to its implementation in pulse oximeters. Two other signals have gained some attention lately the impedance plethysmogram (IPG) and the ballistocardiogram (BCG), due to the possibility of being acquired without the patient's awareness.

The devices acquiring and processing these signals are becoming smaller and more common [1–6], but all face similar problems: motion artefacts, baseline oscillation and other signal-specific issues, as power line frequency interference. Moreover, cardiovascular signals exhibit nonlinear and non-stationary behavior, even if the devices are completely immune to artefacts, because of the unrepeatability of the stimuli provided by a living subject's cardiopulmonary system.

The classical frequency domain techniques have harsh limitations to deal with nonlinear, non-stationary signals. However the majority of real world signals belong to this category, namely those of physiological origin [7]. Analysis

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techniques based on time–frequency properties of the signals have tried to overcome this [8,9].

Within strictly data-based time–frequency methods, the recently introduced Empirical Mode Decomposition (EMD) may be considered [10,11]. EMD, also known as Hilbert–Huang Transform, is a method for decomposing nonlinear, multi-component signals, into Intrinsic Mode Functions (IMFs). Each IMF admits an unambiguous definition of instantaneous frequency and amplitude through the Hilbert transform. However, our understanding of EMD comes from experimental algorithm application rather than analytical results [12]. EMD has become an attractive tool and has been used is various engineering areas [13], including biomedical engineering, for automated detection of venous gas bubbles, classification of EEG, and ECG denoising [14–16].

EMD outputs a variable number of components with the same length of the original signal. The problem of minimizing the set of components, while maximizing the cardiac data provided, has an unpredictable solution for every situation and signal. Applying Principal Component Analysis (PCA) to the EMD outcome is an approach, optimal in the least squares sense, to isolate the cardiac information, as it removes the correlations between the different modes.

PCA is a classical technique in multivariate statistical data analysis, used for feature extraction and data compression [17,18]. It obtains a small number of orthogonal principal components (PCs), from a large data set of correlated variables, accounting for the diversity of the original data [17]. This technique has been extensively applied to ECG signals, mostly related to the morphological analysis of its waves [18], and in some other applications [19–21]. In this work, it were combined the time–frequency decomposition of EMD with the synthesis methods of PCA, to reconstruct a noiseless signal from the modes EMD generates.

The purpose of this paper is to assess the potential of combined EMD–PCA implementation in ECG, BCG, PPG, and IPG acquired from a high sampling rate chair-based system with published results [1,2,22]. The paper is divided into four sections including the introduction and the conclusions. Section 2 describes the hardware and software developed for the EMD–PCA implementation. The assessment tests on time performance, and representation efficiency and improvement are presented in Section 3.

2. Implementation

2.1. Hardware overview

ECG is the well-known signal produced by the electrical activity of the heart, while the BCG records the vibrations produced in the body during the cardiac cycle [2]. Plethysmography is a measurement of the volumetric changes of an organ. To measure the PPG the patient's skin is illuminated in a spot, usually the finger, being acquired the variations on the amount of single wavelength light transmitted or reflected into a photodetector. The IPG measures the electrical resistance changes, due to blood passage, of a body tissue of interest. Fig. 1 presents a depiction of the four signals, recorded from a healthy subject.

To acquire the BCG, a piezoelectric film sensor was embedded in the seat of a normal office chair. The voltage BCG signal was obtained by connecting the sensor output to a high input impedance charge amplifier. The ECG was recorded using three chest leads followed by filtering and amplification stages built using high input impedance operational amplifiers. The PPG curves were gathered by means of controlled red light emission and transduction of the amount of absorption of the radiation in the subject's index finger. IPG sensing circuitry was embedded in the backrest of the office chair. It is composed of a tetrapolar arrangement of plane electrodes, two injecting current and two measuring the resulting voltage. Again high input impedance operational amplifiers were required. Fig. 2 presents the hardware setup.

All the signals were synchronously sampled at 1 kHz. This frequency is used for cardiac analysis of high precision

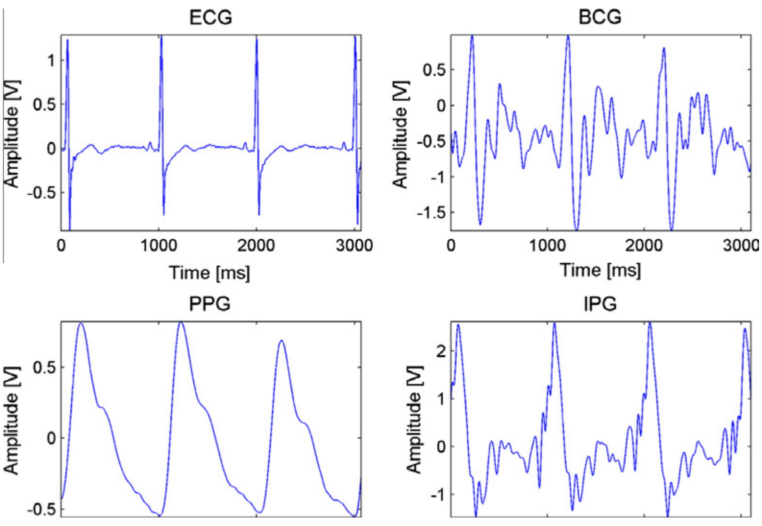

Fig. 1. Segments of 3 s of the acquired cardiovascular signals ECG, BCG, PPG, and IPG.