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Study of wrist pulse signals using time domain spatial features ☆

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ABSTRACT

Blood travels throughout the body and thus its flow is modulated by changes in body condition. As a consequence, the wrist pulse signal contains important information about the status of the human body. In this work we have employed signal processing techniques to extract important information from these signals. Radial artery pulse pressure signals are acquired at wrist position noninvasively for several subjects for two cases of interest, viz. before and after exercise, and before and after lunch. Further analysis is performed by fitting a bi-modal Gaussian model to the data and extracting spatial features from the fit. The spatial features show statistically significant ($p < 0.001$) changes between the groups for both the cases, which indicates that they are effective in distinguishing the changes taking place due to exercise or food intake. Recursive cluster elimination based support vector machine classifier is used to classify between the groups. A high classification accuracy of 99.71% is achieved for the exercise case and 99.94% is achieved for the lunch case. This paper demonstrates the utility of certain spatial features in studying wrist pulse signals obtained under various experimental conditions. The ability of the spatial features in distinguishing changing body conditions can be potentially used for various healthcare applications.

1. Introduction

Pulse pressure is a manifestation of arterial palpation of the heart beat. When heart contracts oxygenated blood flow occurs from left ventricle to aorta. At that time a pulse waveform is produced by the heart. After blood is ejected into aorta, blood continues its flow to the other parts of body because of compliance of arteries. The velocity of pulse pressure waveform depends on the compliance of arteries. During systolic period the pulse wave travels away from the heart and during diastolic period the pulse wave reflects back towards heart. Hence the pulse wave is a combination of forward wave and reflected wave [1]. The person's pulse can be felt at any place that allows an artery to be compressed against a bone, such as at wrist (Radial artery). The wrist pulse has been recognized as the most fundamental signal of life, containing vital information of health because any pathological changes of a person's body condition are reflected in the wrist pulse. In order to detect the pathological changes in the body, pulse diagnosis is gaining importance in recent times. As an important source on

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health status evaluation, pulse signal contains much more information such as pressure and temperature. This paper mainly addresses the processing of wrist pulse pressure signal.

Normally palm of physicians supports the wrist of patient and pulse examination is done using fingertips. Without the benefit of any physical recording and analysis, the diagnosis requires a long period of study and practice by individual physician [2]. Hence there is a need to use the power of digital signal processing to make a computerized analysis of pulse signals.

A heart beat generates pressure wave which propagate throughout the arterial system. The shapes of wrist pulse waveforms are altered by their continuous interaction with the non-uniform arterial system. These waves expand the arterial walls as they travel along and the expansions are palpable as the wrist pulse. A typical pulse signal has a multi period trend. Systolic wave with higher amplitude constitutes the main component of the pulse signal. The diastolic wave has lower amplitude accompanied by a phase shift. The information regarding heart is contained in the systolic wave whereas the secondary wave provides information on the reflection sites and the periphery of the arterial system [3]. Many efforts have been made recently to process wrist pulse pressure signals using efficient signal processing techniques [4–9]. Though several nonlinear techniques [10–11] have emerged lately for processing of signals, they are mostly data driven, while we have used a model driven approach in this work. In this paper, we extract time domain spatial features from wrist pulse signals and then use these features for the analysis of wrist pulse waveforms recorded under various experimental conditions. The wrist pulse typically has two maxima and three minima in one cycle. The magnitudes and time indices of these extrema points and various combinations of differences between these times are termed as spatial features of the pulse wave. The spatial features will be useful in the understanding and classification of the wrist pulse signals recorded before exercise and after exercise, as also before lunch and after lunch. There is very limited literature on analysis of wrist pulse signals in case of exercise [12] and also in case of food intake [13], hence this work attempts to contribute towards understanding the behavior of the cardiovascular system during physical activity as well as during food consumption using wrist pulse signals. This parallel study of both exercise and lunch cases aims at better understanding of the application of spatial features to understand biological signals. The next section on methods discusses preprocessing of the pulse signals, feature extraction and classification. This is followed by results, discussion and conclusion.

2. Methods

2.1. Preprocessing of wrist pulse signals

We have used wavelet de-noising technique for removal of noise from recorded pulse signals. Wavelet methods [14] allow us to find low frequency information during long intervals and high frequency information during short intervals. By using a properly chosen mother wavelet function we obtain decomposition of the signals. Usually high frequencies appear in low scales whereas low frequencies appear in high scales. Upon removal of these low and high scale detail coefficients we can obtain cleaned signals. Usually wrist pulse signals are contaminated by noise due to electronic nonlinearities (high frequency) and due to movement of hand during recording (low frequency).

Segmentation of single period pulse waveform is useful in further analysis. The aim is to segment the complete wrist pulse time series into single period waves [15]. An amplitude threshold is chosen manually by inspection. A simple peak detection algorithm is employed to find the peak of the pulse signal which crosses the threshold. We next find the local minimum which occurs before this peak. We search points in the reverse direction from peak until a positive derivative is reached, and that point is chosen as the pulse's starting point. One cycle is taken as the signal from the starting point of the current pulse to the starting point of the next pulse.

2.2. Power spectral density analysis

Welch's power spectral density (PSD) is obtained for all subjects in both exercise and lunch cases. The spectrum is divided into four equally spaced frequency bands in the range 0–8 Hz. Energy of the signal in each of these bands is calculated and normalized to reflect relative energies. These normalized energies are tabulated and compared between the groups.

2.3. Feature extraction and classification

The magnitudes and time indices of the two maxima and three minima points of a single period pulse wave, and various combinations of differences between these times are together termed as spatial features of the pulse wave (original and derived). Such spatial features are obtained for both before exercise and after exercise. Totally seventeen spatial features are compared and classified.

It is necessary to see if the spatial features show statistically significant difference across groups. A paired t-test is performed between before exercise and after exercise groups using all the features of all the subjects. Resulting p-values are used to see if the parameters are statistically significant or not.

It is important to see if the spatial features can distinguish between the groups. A Recursive Cluster Elimination based Support Vector Machine (RCE–SVM) is used to classify between the groups [16]. Though there are advanced neural network methods used for the classification of biomedical signals [17], using them to classify recursively still remains difficult. They also do not provide information about those top classifying features which contributed maximum towards a high