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A robust signal preprocessing framework for wrist pulse analysis

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ABSTRACT

Wrist pulse has been a physical health indicator in Traditional Chinese Medicine (TCM) for a long history. With the development of sensor technology and bioinformatics, quantifying pulse diagnosis by using signal processing technology is attracting increasing attentions in recent years. Since wrist pulse signals collected by the sensors are often corrupted by artifacts in real situations, many approaches on the wrist pulse preprocessing including pulse de-noising and baseline wander removal are introduced for more accurate wrist pulse analysis. However, these scattered methods are incomplete with some limitations when used to preprocess our special pulse data for the clinical applications. This paper presents a robust signal preprocessing framework for wrist pulse analysis. The cascade filter based on frequency-dependent analysis (FDA) is first introduced to remove the high frequency noises and to select the significant pulse intervals. Then the curve fitting method is developed to adjust the direction and the baseline drift with minimum signal distortion. Last, the period segmentation and pulse normalization is applied for the feature extraction. The effectiveness of the proposed pulse preprocessing is validated through experiments on actual pulse records with biochemical markers. In contrast with the traditional methods, the proposed preprocessing framework is effective in extracting more accurate pulse features. And the highest classification rate 91.6% is obtained on diabetes diagnosis. The results demonstrate that our method is superior to the former pulse preprocessing researches and practical for wrist pulse analysis.

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1. Introduction

Wrist pulse contains rich information of human body. It has been applied to health diagnosis in Traditional Chinese Medicine (TCM) since ancient times [1]. The Chinese medicine practitioners used to feel the pulsations by placing three fingers at the radial artery to judge the health status of patients. Thus, the pulse diagnosis depends heavily on the subjective analysis of practitioners and turns out to be unreliable and inconsistent [2]. With the advances in sensor technology, a number of pulse acquisition platforms are developed to collect the computerized wrist pulse waveforms for more objective and accurate pulse diagnosis recently [3–6].

We design a novel wrist pulse acquisition platform with multi-channel and fusion sensors. The pulsations at the wrist are first detected by the sensor arrays, and then transformed into the digital voltage outputs through the analog and digital circuit. Since the wrist pulses are weak vibrations inside human body, they are often noised by disturbances from environments. Three dominant artifacts present in our wrist pulse signals are: (1) high-frequency noise caused by 50 Hz power line interferences and artifact motions acting on the sensors; (2) baseline wander caused by respiration; (3) cycle deviation that may be due to the chaos phenomenon. All these artifacts badly influence the accuracy of wrist pulse analysis and should be removed to avoid false-positive classification.

It is well known that wrist pulse is a periodic physiological signal with each single period representing a heartbeat cycle as electrocardiogram (ECG). These two physiological signals are both driven by the heart and somewhat reflect the health status of heart [7,25]. Thus, ECG has been widely used for the heart monitoring and arrhythmia checkup [8]. The heart rhythms can be accurately obtained from the periods of the both two signals. Compared with ECG, the wrist pulse waveform flows a long way from the heart. As a result, it is not only influenced by the heart conditions, but also affected by the conditions of nerves, muscles, skin, arterial walls and blood parameters (volume, contents, viscosity, pressure, and velocity) [9]. Therefore, the wrist pulse contains more information than ECG due to the interactions of inside organs [10]. And the methods for ECG preprocessing could not be applied to preprocess the wrist pulse directly.

A number of methods have been proposed for the wrist pulse preprocessing, but to data all have been flawed for our wrist pulse database. In summary, the former researches on pulse

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preprocessing can be divided into two categories, pulse de-noising and baseline drift removal. For the pulse de-noising, Ciaccio and Drzewiecki [11] propose a differential steepest descent (DSD) adaptive noise cancelation method. However, there is a large shift in the baseline level. Xia et al. [12] introduce a zero-phase filtering on pulse trend, which processes the input pulse data in both forward and reverse directions to overcome the phase shift. Arunkumar et al. [28,29] and Sareen [30] use wavelet based method for removing the noise in the acquired pulse signals. An approach of Dynamic Time Warping (DTW) is utilized for the identification of outlier pulses in the wrist pulse series by Thakker and Vyas [31]. But the evaluation criterions of the filters are not verified through the wrist pulse analysis. Empirical mode decomposition (EMD) is introduced for the pulse de-nosing by Wu and Lee [13]. However, the experiment is conducted by adding a white noise series to the targeted data under simulated environments. And it is not suitable for our actual pulse records collected under real environments. As a result of the baseline drift, the wrist pulse has a relatively low frequency component throughout the entire signal. This kind of distortion also appears in ECG and other physiological signals [14,15]. Approaches from frequency view, including Finite Impulse Response (FIR) filter, Kalman filter and wavelet cascade filter, are applied to remove the baseline drift [15–19]. They all attempt to suppress the baseline wander with high pass filter, which would introduce nonlinear phase distortion as well as the key-knots displacement caused by time-domain convolution. Besides, the wrist pulse signals in these experiments are corrupted by adding the drift manually, which is not convincing for practical application.

Besides the two conventional preprocessing methods, we add the pulse period segmentation into the framework for the first time. The period segmentation plays an important role in pulse analysis to extract the intra-class information. Xia et al. [12] propose a period segmentation and estimation method to represent the pulse trend. Chen et al. [20] introduce a period segmentation for pulse analysis by using modified Gaussian models. Joshi et al. [26,27] extracted peaks in the pulse signals using a complex frequency b-spline wavelet method. However, these methods all choose the average single-period pulse from the entire signal after the period segmentation, resulting in the loss of detail information.

In this paper, our focus is on building a robust signal preprocessing framework for wrist pulse analysis. We first introduce the proposed pulse acquisition platform and specify the inherent properties of the coarser pulse data. Then, a cascade filter based on frequency-dependent analysis is proposed for the wrist pulse de-noising. Next, the interval selection is performed to remove the distortion sections. For the baseline drift in our database, the direction correction and curve fitting method is employed to adjust the baseline wanderings. Last, the pulse normalization is developed for feature extraction.

Besides the description of the wrist pulse preprocessing algorithms and the related theoretical derivations, in this paper, much attention is paid on comparisons of the methods through the quantitative and qualitative evaluations. We do experiments using the real wrist pulse records with definite labels, which are acquired from the volunteers of Prince of Wales Hospital, Hong Kong. The experiment results indicate that the classification accuracy is increased significantly by using the proposed preprocessing framework. And the experimental studies also demonstrate that the proposed pulse preprocessing framework outperforms the previous methods, especially for the wrist pulse analysis. The contributions of this work lie in two aspects. First, we introduce the novel algorithms in pulse signal enhancement. Second, the preprocessing framework is applied to extract the intra-class features for wrist pulse analysis.

The remainder of this paper is organized as follows. In Section 2, we introduce the pulse acquisition platform and the characteristics of the original pulse database from both time-domain and frequency-domain. The preprocessing framework and the comparisons of the preprocessing methods are outlined in Sections 3 and 4, respectively. Finally, a conclusion is given in Section 5.

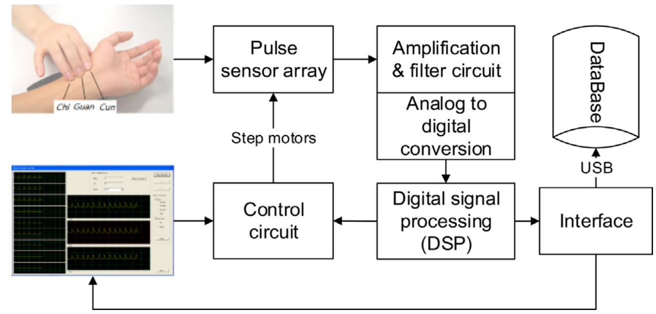

Fig. 1. A brief flow chart of the proposed pulse system.

2. Description of pulse database

2.1. Data acquisition

In TCM, the practitioners took pulse by feeling the pulsations at "*Cun*", "*Guan*" and "*Chi*" three adjacent positions of the wrist with proper pressures (deep, middle and superficial). The pressures and positions yield the concept of nine indicators. The health status of specific internal organs could be obtained from the relationships between nine indicators and the internal organs [21]. The relations are based on the "*Maijing* (The Pulse Classic)" compiled by Wang Shuhe, which is the first extant book specializing in sphygmology. Thus, the pulsations from "*Cun*", "*Guan*" and "*Chi*" three parts should be collected as a whole for the pulse diagnosis.

In our work, an USB-based pulse acquisition platform with multi-channel and fusion sensor array is developed to collect the wrist pulse signals from "*Cun*", "*Guan*" and "*Chi*" simultaneously (see Fig. 1). The proposed system is composed of three parts, pulse sensor array, circuit and interface. And the three independent channels correspond to the *Cun*, *Guan* and *Chi* positions. Each channel contains a pulse sensor array to transform the physical beatings into weak voltage outputs. Then, the millivolt voltages are processed by the amplification and filtering module. The amplified voltages from the sensor array are converted into digital signals simultaneously using a 12-bit data acquisition card at a sample rate of 500 Hz. Next, the micro digital signal processing module is applied to control the

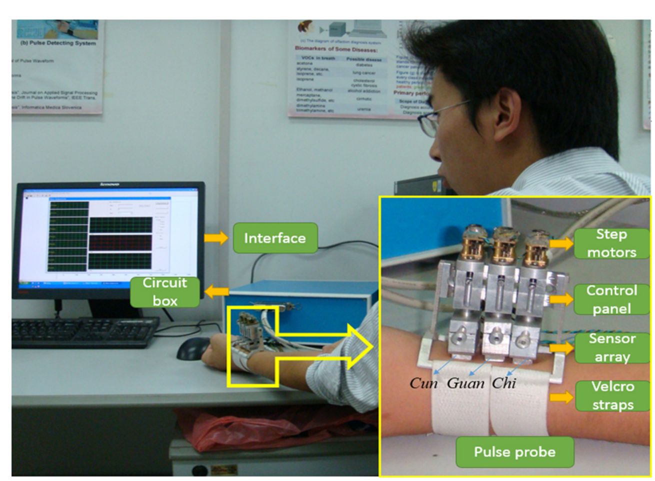

Fig. 2. The proposed pulse acquisition platform.

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