Advances in Computer, Signals and Systems (2024)
Clausius Scientific Press, Canada
DOI: 10.23977/acss.2024.080615
ISSN 2371-8838 Vol. 8 Num. 6

Development Design and Signal Processing Algorithm Optimization of Traditional Chinese Medicine Pulse Acquisition System Based on CP301 Sensor

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Keywords: Traditional Chinese Medicine Pulse Diagnosis, Pulse Signal Collection, Improved EMD Algorithm, SOM Algorithm, Digital Pulse Diagnosis System

Abstract: Based on the "Three Parts and Nine Symptoms" pulse diagnosis in TCM, a wristband pulse signal acquisition device with adjustable pressure is designed. It uses soft PVDF sensors for comfort and adjustable Cun-Guan-Chi positions for simulating TCM pulse diagnosis. To address weak, interference-prone signals, impedance conversion, bandpass filtering, and amplification circuits are integrated. A six-channel digital acquisition system and PC-based interface are developed for signal processing. An improved EMD algorithm removes pseudo-baselines, and dimensionality reduction is achieved by extracting features. Pulse signals generated by the Nektar 1D model are classified using SOM and decision tree algorithms, with SOM showing higher accuracy. The hardware includes optimized PVDF sensors, two-stage amplification, 50Hz notch filters, and fourth-order bandpass filters, with FPGA-based six-channel acquisition. The software, developed on LabVIEW, manages initialization, data acquisition, storage, and calibration. While objective signal acquisition is achieved, hardware optimization, portability, and signal processing need improvement. Enhancing the TCM pulse diagnosis feature database will further promote objectivity in TCM pulse diagnosis.

1. Introduction

Traditional Chinese Medicine, also known as Han Medicine, originated in the Spring and Autumn Period and the Warring States Period. Based on traditional Chinese medicine, it has undergone continuous development and formed a systematic theory of diagnosis and treatment, which is still widely used today. As an important discipline for studying human physiology and pathology, traditional Chinese medicine plays a unique role in the diagnosis and treatment of diseases. Traditional Chinese Medicine is based on the theory of Yin Yang and Five Elements, which regards the human body as a unified entity of form, qi, and spirit, and analyzes it through the four diagnostic methods of "observation, hearing, questioning, and cutting". Among them, pulse diagnosis, as a part of "palpation", obtains physiological information of organs and meridians through finger touch, reflecting cardiovascular activity and the operation status of organs. Pulse is the image of the pulsation felt by traditional Chinese medicine when touching the pulse. The common diagnostic method is the "three parts and nine symptoms" method, in which doctors judge the condition by touching the three parts of the inch, the guan, and the chi and adjusting the pressure. Traditional Chinese Medicine believes that there are six pulse systems in each person's left and right hands, and each pulse system is associated with a specific organ. Abnormal pulse systems may reflect pathological changes in the corresponding organ. However, there are differences in the specific correspondence between pulse patterns and organs among different ancient texts. Combining traditional Chinese medicine pulse diagnosis with modern technology, accurately describing its clinical diagnostic value based on experimental data, and promoting digital and objective research on pulse diagnosis have become important trends in the development of traditional Chinese medicine.

This study is based on the theory of "Three Parts and Nine Symptoms" in traditional Chinese medicine pulse diagnosis, and designs and develops a wrist worn pulse acquisition system[1]. An improved EMD algorithm is proposed for filtering and processing pulse signals. The pulse signal database was generated using the pulse wave propagation numerical model [2]Nektar 1D, and the feature extraction and dimension reduction were carried out according to age group. SOM and decision tree algorithm are used to classify and recognize the pulse signal. The research content is divided into four parts: signal acquisition, preprocessing, feature extraction, and classification recognition, and corresponding design schemes are proposed. The hardware part includes front-end acquisition structure, pulse signal preprocessing circuit, and multi-channel digital acquisition system, which realizes signal acquisition, filtering and noise reduction, A/D conversion, and USB transmission; The software part has developed an upper computer system to complete instruction sending, pressure control, data storage, and result display. In terms of signal processing, an improved EMD algorithm based on single cycle comparison is proposed to remove pseudo baselines, and combined with the pulse wave model of the wrist to obtain pulse signals of different age groups. Time domain and frequency domain features are extracted, and after dimensionality reduction, classification and recognition are carried out through SOM and decision tree algorithms. The experiment used actual pulse signals of current students as test samples to verify the classification performance of the two algorithms. Finally, it summarizes the research content, points out the shortcomings, and looks forward to the future work.

2. Correlation theory

2.1 Research experience of pulse signal acquisition system

The research on pulse signal acquisition system has gone through multiple important stages. The earliest pulse recorder was designed by the British and used a lever structure to record the wrist pulse signal through a spring. Subsequently, the French added a pulse wave recorder on this basis, marking that the pulse research entered the wave graphic era. With the passage of time, foreign scholars have integrated modern technology into the objective research of pulse diagnosis and introduced wrist pulse meters with watch structures, using array pressure sensing elements. Subsequent research will focus on pulse signal acquisition devices based on microcontrollers, which adjust pulse pressure through an air pump; In addition, researchers have analyzed pulse signals by shooting wrist videos and used Euler video amplification method to obtain feature points for predicting cardiovascular diseases. The research on pulse meters in China began in the 1950s, when lever pulse meters were first combined with traditional Chinese medicine pulse diagnosis theory. However, due to technological limitations, they were not further developed. After entering the 21st century, several cities have formed objective research teams for pulse diagnosis and achieved significant results. Among them, the digital pulse collection glove designed based on traditional Chinese medicine pulse diagnosis theory achieves three channel pulse signal collection through finger positioning and pressure. Subsequent research includes a three channel pulse sensor that integrates pulse wave detection and static pressure detection, a portable pulse diagnosis device with a touch screen, and a three channel pulse diagnosis device using photoelectric sensors, which verifies the relevant statements in traditional Chinese medicine theory. In addition, the design of a wireless portable pulse detection system has achieved portable transmission of pulse signals through Bluetooth modules, further promoting the research and application of pulse meters.

2.2 Research on Pulse Signal Processing Methods

Pulse signal processing [3] faces challenges such as small amplitude and low frequency, and belongs to nonlinear and non-stationary weak physiological signals. During the acquisition process, signals are often subject to interference such as pseudo baseline, motion artifacts, and high-frequency noise, resulting in errors in feature information extraction and processing. Common denoising methods include FIR filtering, median filtering, wavelet adaptive filtering, cubic spline interpolation filtering, and time-varying filtering. FIR filtering has a fixed cutoff frequency and lacks adaptability, which may lead to over processing or incomplete filtering; Although median filtering can reduce noise, it may blur signal details and lose important features; Wavelet adaptive filtering has high accuracy, but it is difficult to select reference signals; Triple spline interpolation is difficult to accurately find the signal reference point; Time varying filtering requires precise measurement of heart rate when removing pseudo baselines, and the operation is complex. The Empirical Mode Decomposition (EMD) method [4] can decompose a signal into a set of Intrinsic Mode Function (IMF) components[5], and reconstruct the signal by selecting some IMF components to remove pseudo baselines. In terms of IMF component selection, various methods have been proposed, such as low-pass filtering high-order IMF components to preserve signal components, setting a threshold through wavelet transform to screen IMF components for better representation of signal features, and screening noisy IMF components through zero crossing rate detection. Although these methods can achieve noise removal, there are still subjectivity and lack of adaptability in the selection of IMF components. In addition, research on improving the EMD algorithm has gradually increased, and new algorithms such as EEMD and CEEMDAN have emerged, further enhancing the denoising effect of pulse signals.

3. Research method

3.1 Research on the Mechanism and Objectification of Pulse Signal Generation

The human pulse signal is closely related to the contraction and relaxation of the heart, reflecting the state of blood circulation. The signal collected by the pulse meter presents a three peak diagram, mainly composed of the main wave, main wave trough, and pre pulse wave. According to heart movement, pulse signals are divided into ascending and descending branches. The ascending branch reflects the ability of the heart to contract, while the descending branch indicates the state of the heart during diastole. Pulse signals are influenced by physiological, pathological, and external factors, and further exploration is needed to objectify them. Objective research is divided into four modules: signal acquisition, preprocessing, feature extraction, and classification, with signal acquisition as the foundation. To ensure effective data collection, PVDF pressure sensors were selected, which exhibit superior sensitivity. The specific design includes a length of 30mm, a width of 12mm, and a thickness of 28 μ m. An arc-shaped flexible substrate is used to enhance adhesion. The sensitivity of sensors was tested through COMSOL simulation, and empirical mode decomposition (EMD) [6] was used for denoising, combined with self-organizing map (SOM) algorithm[7] for classification, to ensure the accuracy and clarity of pulse signals..

3.2 Software Design and Function Implementation of Pulse Collection System

The software part of the pulse acquisition system is based on the LabVIEW development platform of National Instruments in the United States, combined with the hardware acquisition system functions of pulse signals and the requirements of "three parts and nine periods" for design. LabVIEW is a powerful and easy-to-use graphical programming virtual software that allows users to complete functional design by dragging and dropping controls and connecting lines. The pulse collection upper computer designed in this article includes functions such as real-time wristband pressure measurement, optimal pulse pressure search, pulse waveform display, data storage, and classification result calculation. The upper computer serves as the interactive interface of the system, and works in conjunction with the hardware acquisition system and wristband pressure control module to measure pulse signals. The main interface of the software is responsible for sending instructions to the hardware system, obtaining the optimal pulse pressure value, receiving and displaying pulse waveforms, performing algorithm processing, and displaying classification results. The specific functions include sending commands, obtaining the optimal pulse pressure value, displaying pulse waveforms, and data storage. The system transfers data through USB 2.0 and uses VISA driver software provided by NI company to achieve data exchange between the upper computer and hardware. The USB firmware program was designed using Cypress' CY7C68013A chip and developed using Keil μ Vision4. The workflow of pulse collection software includes device initialization, instruction sending, data reading and storage, and obtaining the optimal pulse pressure. MathScript node is used to realize the optimal pulse pressure algorithm, and the "floating", "middle" and "sinking" pressure ratios are set according to the standard of traditional Chinese pulse pressure. After testing, all modules of the pulse acquisition system can achieve the expected results, meet the requirements of traditional Chinese medicine pulse acquisition, and ensure the accuracy and reliability of the data.

4. Results and discussion

4.1 Application of Improved EMD Algorithm in Removing Pseudo Baseline of Pulse Signal

Pulse signals are physiological signals of the human body, characterized by small amplitude and low frequency, and belong to nonlinear and non-stationary weak signals. Although notch filter circuits are used in hardware design to remove high-frequency and partially low-frequency noise, in practical applications, they are still affected by pseudo baseline caused by factors such as human respiration and limb movement. Therefore, software filtering processing is particularly important before analyzing pulse signals. This article proposes an improved EMD algorithm to remove pseudo baselines in pulse signals by combining single cycle comparison and empirical mode decomposition (EMD) algorithm. The algorithm first uses correlation coefficient analysis to remove pseudo components in each order IMF (Intrinsic Mode Function), and identifies pseudo components by calculating the correlation coefficient between the original signal and each IMF component and setting a threshold. Then, the IMF component is selected using the single period comparison method, and the maximum and minimum values of the local single period are defined. In theory, the period of the lowest frequency IMF component should be equal to the length of one pulse cycle. Next, the steps include identifying periodic feature points of the pulse signal, performing EMD decomposition on the signal, calculating the minimum single period of each IMF component, and removing IMF components greater than the maximum single period. Finally, the remaining IMF components are added to obtain the pulse signal with pseudo baseline noise removed.

4.2 Model experiment

Pulse signals are weak physiological signals characterized by small amplitudes and low frequencies, classified as nonlinear and non-stationary. Despite hardware efforts like notch and filtering circuits to eliminate noise, they are still affected by factors like respiration and limb movement, necessitating software filtering. This article presents an improved method that combines single period comparison and empirical mode decomposition (EMD) to effectively remove pseudo baselines in pulse signals.

The proposed EMD-based algorithm uses correlation coefficient analysis to identify pseudo components. By calculating the correlation coefficients between the original signal and each Intrinsic Mode Function (IMF), a threshold of 10% of the maximum coefficient is set to distinguish pseudo from effective components. Additionally, the single period comparison method helps select suitable IMF components based on local periodicity.The algorithm involves identifying periodic features, performing EMD decomposition, selecting the minimum single period, and reconstructing the signal by removing components linked to pseudo baselines. Results indicate that the improved algorithm stabilizes pulse signals, effectively filters out noise, and preserves feature information. Quantitative evaluations show a twofold increase in signal-to-noise ratio and a significant reduction in root mean square error compared to traditional methods.

As pulse signals exhibit quasi-periodic characteristics, segmenting them into cycles is crucial for accurate feature extraction. This process involves determining the starting point and peak of each pulse cycle through waveform derivative analysis and zero-crossing point identification. Time-domain features include key points like starting and ending points, main peaks, and troughs, while frequency-domain features are extracted using Welch's method for power spectrum estimation. Using the Nektar 1D model, this study generated 384 sets of pulse signals under varying cardiovascular states and age groups, facilitating subsequent pattern recognition by analyzing average thresholds and extracting waveforms for different pulse locations.

4.3 Effect analysis

In this study, the classification results of pulse signals were detected. A pulse acquisition system was used to collect signals from 30 male subjects, all of whom were school students, approximately 25 ± 1 years old, and had not consumed alcohol or stayed up late in the three days before collection. To reduce external interference, participants need to sit quietly for 1 to 3 minutes before collection, and the entire collection process should be kept quiet. Signal acquisition is divided into two stages: first, single pulse acquisition is performed on the three parts of the left hand, namely the inch, guan, and chi, with each part lasting for 45 seconds. Then, simultaneous acquisition of three pulse signals is performed. The collected pulse signals are filtered and preprocessed using an improved Empirical Mode Decomposition (EMD) algorithm, and segmented according to pulse pressure (floating, medium, and sinking) to extract features for input into the Self Organizing Map (SOM) algorithm for classification and recognition. In order to compare the effectiveness of different algorithms, this article also uses decision tree algorithm for comparative analysis. The results show that in the classification and recognition of single pulse data, the accuracy of SOM algorithm is generally better than that of decision tree algorithm, especially in the classification of left hand inch, guan and right hand inch, and the recognition effect is particularly outstanding when the pulse pressure is taken as "medium". In the classification and recognition of the three pulse signals, the classification accuracy of each collected part is similar to that of a single part signal, with the highest accuracy in the left hand inch, which verifies the "left inch heart syndrome" in traditional Chinese medicine theory. By combining data analysis and chart comparison, the effectiveness of SOM algorithm in pulse signal pattern recognition is determined. This chapter mainly proposes an improved EMD algorithm for removing pseudo baselines in pulse signals, and conducts research on feature extraction and classification recognition, verifying the potential application of this algorithm in cardiovascular related information extraction.

5. Conclusion

This article presents a wristband-style pulse signal acquisition device based on the "Three Parts and Nine Symptoms" method of traditional Chinese medicine. The device utilizes PVDF pressure sensors, which are soft and reduce discomfort during use. Its separated collection structure allows for adjustable positioning and variable pulse pressure, simulating traditional pulse diagnosis techniques.To address weak pulse signals and noise, the design includes impedance conversion circuits, bandpass filters, and amplification circuits. A six-channel digital acquisition system with a user-friendly interface was developed for effective pulse signal collection. An improved EMD algorithm is employed to remove pseudo baselines, extracting temporal and frequency domain features and reducing dimensionality through preprocessing.The classification research, using the Nektar 1D model and methods like the Self-Organizing Map (SOM) and decision trees, shows higher accuracy with the SOM algorithm for pattern recognition of pulse signals. The thesis includes simulating the sensitivity of PVDF films, designing a wristband pressure regulating device, creating a digital acquisition system with FPGA control[8], and developing software on the LabVIEW platform for data management.Future improvements will focus on reducing hardware bulkiness, enhancing processing capabilities, and building a more comprehensive database for traditional Chinese medicine pulse diagnosis, emphasizing the need for further exploration of its characteristics to enhance the objectivity of pulse diagnostics.

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