Abstract

The complete analysis of the pulse wave is in the collection of the pulse wave signal in the signal containing a small amount of noise and more clear, however vulnerable to a variety of the influence of interference, so that the extracted pulse wave contains a lot of noise, thus lowering noise handling is particularly necessary. At the same time, pulse wave contains human physiological and pathological information, different people will exhibit different characteristics, can be seen to determine the characteristic point of the pulse wave analysis of human physiological health makes sense. Method for signal denoising with wavelet transform and multi-resolution analysis, the method in the time domain and frequency domain can characterize the local signal information, and has a self-adaptive signal. The use of the extremum method to determine the peak point of the pulse wave, then determined based on the peak point out the location of the other features, the experiment proved that this method can increase the detection rate of feature points.

Key words: Pulse Wave, Wavelet Transform, Signal Denoising, Feature Point Extraction

0. Introduction

The contraction and relaxation of the heart periodically so that the blood of the heart chamber starting from the root of the aorta launched into the aorta to the form of waves along the arterial various piping propagation, such a wave is called pulse wave[1]. External reflection of the pulse of the heart and vascular status and other important information, and the body of any one system state changes will affect the pulse system, and that these changes will be apparent in some way in the pulse, the physician may be based on tactile pressure sensation to understand the human pulse frequency, rhythm, depth, strong or weak, to know that some of the body's physiological function of the system is good or bad. The pulse measurement in the multiple of the body surface of the body, such as the wrist, foot wrist, chest, etc., depending on the pulse pressure, the pulse signal will be collected by showing a waveform (pulse). Pulse wave propagation in the arterial piping, not only by the heart itself, but also by the impact of the piping system and the various branches of the physiological factor, such as the elasticity of the blood vessel wall, blood viscosity, the waveform will exhibit different characteristics. As can be seen, the pulse wave contains a large number of physiological and disease information, the correct extraction of the pulse wave and the noise reduction will play an important role in the information for analysis of physiological disease [2].

The wavelet transform is the rapid development of a mathematical method in recent years, an important feature is time window and frequency window can change the time-frequency localization analysis[3], wavelet transform has a self-adaptive to signal, compared to other mathematical method, wavelet transform is very suitable for processing non-stationary signals like pulse wave.

1. Theoretical basis

1.1. Wavelet transform and Mallat algorithm

Non-stationary signals of the pulse wave, non-stationary signals requires the local time-frequency analysis, wavelet analysis method can be used. Wavelet analysis is a time window and the frequency window may be changed in time domain localized analysis method, its window size is fixed, but the
shape can be changed, that is in the signal low-frequency portion having a higher frequency resolution and lower the time resolution, in the signal frequency portion having a lower frequency resolution and higher time resolution, known mathematical microscope [3]. It is this feature of wavelet transform has a self-adaptive signal.

Wavelet Transform definition:

\[ W_T(a, \tau) = \frac{1}{\sqrt{a}} \int f(t) \psi\left(\frac{t - \tau}{a}\right) dt \]  

\( f(t) \) is a function of the space of arbitrary real number, \( \psi_{(a, \tau)}(t) \) wavelet basis function, \( \psi^* \left(\frac{t - \tau}{a}\right) \) is conjugate of wavelet basis function, \( a \) is scale, \( \tau \) is the amount of shift, \( W_T(a, \tau) \) is the wavelet transform coefficient. The wavelet transform has the scale and the amount of shift of two parameters, Therefore, the function for performing wavelet transform means a function of time of the one-dimensional projected onto a two-dimensional time-scale plane, so that is conducive to the essential characteristics of the extracted signal.

Mallat proposed the concept of multi-resolution analysis (Multi-Resolution-Analysis, MRA) build Orthogonal wavelets, multi-resolution analysis of the signal is to be processed with the orthogonal transformation decomposition in different resolutions for the approximation signal and detail signal [4].

Wavelet transform multiscale analysis theory: Let \( \{V_j\}_{j \in \mathbb{Z}} \) be a multi-scale analysis of the space \( L^2(R) \), then there is a scaling function \( \phi(t) \) and the wavelet function \( \psi(t) \) and they pan and telescopic function system \( \{\phi_{j,k}, j, k \in \mathbb{Z}\} \) and \( \{\psi_{j,k}, j, k \in \mathbb{Z}\} \), respectively, constitute the \( V_j \) and \( W_j \) orthonormal basis, in which A is a B orthogonal sub space.

\[ V_{j+1} = V_j \oplus W_j \]  

\( W_1 \) is the orthogonal complement of \( V_1 \) in \( V_0 \) space, rescaled continue split down there is

\[ V_0 = V_1 \oplus W_1 = V_2 \oplus W_2 \oplus W_1 = \cdots \]  

For any function \( f(x) \in V_0 \) can be broken down into the details of some of the \( W_i \) and the large-scale part of the \( V_j \) part of large-scale re-decomposed. Generally, the noise portion included in the details of the section, its coefficient of use of the threshold processing can achieve the purpose of the removal of signal noise.

The wavelet decomposition of tower algorithm shown in Figure 1

![Mallat tower algorithm](image)

Among of this, \( A^d_{j+1} f = \tilde{H} * A^d_j f \), \( D^d_{j+1} f = \tilde{G} D^d_j f \),  \( j = J, J - 1, \cdots , -1 \), Corresponding Mallat reconstruction algorithm is \( A^d_{j-1} f = \tilde{H} * A^d_j f + \tilde{G} * D^d_j f \),  \( j = J, J - 1, \cdots , -1 \).

1.2. Feature points of the pulse wave
The pulse wave feature points are closely linked to their corresponding physiological factors, to analyze physiological disease information for health care workers, and lay a solid foundation, but also affects the cardiovascular indicators parameter correctly extract has an important medical value.

2. Pulse wave denoising

2.1. Pulse wave signal wavelet decomposition

Mutations portion of the signal, the performance of certain wavelet components amplitude large, just stark contrast it with the uniform performance of the noise in the high frequency portion, orthogonal wavelet decomposition can effectively distinguish the mutant portion and a noise in the signal. Noisy pulse signal decomposition by wavelet decomposition high frequency detail signal and low-frequency approximation signal is very important in the process of wavelet bases wavelet transform signal processing functions select different wavelet basis function of signal decomposition can high light characteristics of the different characteristics of the signal[6]. After several tests, using the db3 wavelet basis function, 5 layer decomposition (Figure 4) on the the noisy pulse of signal, Figure 3 shows the original noisy signal.

![Fig3. Original signal](image)

Figure from the bottom up as a pulse signal on a 1-5 scale wavelet transform result, from the figure it can be seen, the high-frequency noise of the signal is mainly concentrated in the $S = 2^1$ and $S = 2^2$ scale, low frequency components are mainly concentrated in the $S= 2^{2-4}$ scale.

2.2. Threshold Denoising

The signal denoising actual inhabit the unwanted part of the signal, to restore the signal in the useful part of the process. Based on experience, corresponding to the noise signal and the low frequency of the high frequency details approximation signal parts removed and reconstructed to obtain a useful signal[7]. The wavelet transform coefficient signal wavelet transform coefficient increases with increasing scale, noise is decreased with increasing scale. Door and thus can be used to limit the form of the threshold of wavelet coefficients for processing, then to reconstruct the signal that you can
achieve the purpose of noise cancellation. Using wavelet analysis of one-dimensional signal the threshold denoising following steps:

(1) a one-dimensional signal wavelet decomposition: select the wavelet basis function and to determine the decomposition level N, then the signal N layer wavelet decomposition;

(2) high-frequency coefficient threshold selection: each layer from the first layer to layer N, the high-frequency coefficients to select a threshold quantification processing;

(3) one-dimension wavelet reconstruction:According to the low-frequency coefficients of wavelet decomposition of the N layer and high-frequency coefficients through quantization processing of the first layer to the N layer, and signal reconstruction.

In the threshold denoising 3 steps, the most critical in step 2, how to choose the threshold quantization thresholds and how it is directly related to the quality of the signal denoising. There are three common threshold denoising method: Forced the threshold denoising, default threshold denoising, given the soft (or hard) threshold denoising. Where in the force threshold denoising is to the high frequency coefficients in the wavelet decomposition structure of all set to zero, this method, although simple, the reconstructed signal is also relatively smooth, but it’s easy a useful component of the signal is lost. Given soft (or hard) threshold denoising with empirical and human subjectivity, but also very tedious and time-consuming, so the final choice to the default threshold denoising this method, it is generated by the system fixed threshold, the coefficient deletion is less than the threshold then the signal reconstruction and the results shown in Figure 5.

As can be seen, the denoising threshold value method, not only can almost completely suppress the noise, and can be well preserved to reflect the characteristics of the original signal peak point, has good denoising effects. Jus cogens filter out the high-frequency part of all, but the loss of useful components likely to cause The peak deformation: default threshold is generated by the system fixed threshold, the coefficient is less than the threshold value to delete and then reconstructed by filtering noise signal; given threshold method to set the threshold of each layer wavelet coefficients based on experience, and then reconstructed signal. Given threshold method can theoretically achieve the results of two kinds of methods, but it is the threshold, with the empirical and human subjectivity, tedious and time-consuming, and attempt to go through for each experimental system manual and each layer wavelet decomposition, optimal threshold than the default threshold method is simple and convenient. As can be seen by comparing the default thresholds law can better noise filtering effect, and greatly reduce the workload, adaptability, filtering on the pulse of the analysis signal processing, to achieve a satisfactory result.

3. Identification of feature points

3.1. Recognition of the pulse wave period

The pulse wave is very complex, even if the same person's pulse wave does not have the same in one cycle, so it is necessary to first identify the cycle of the pulse wave, which is actually the point b, and c, of identifying feature a large number of the pulse wave analysis shows; points b and c are a pair
of minimum and maximum point; amplitude difference of b and c are two points in one period than the other extrema on the amplitude of a large difference (Figure 3). The recognition process in the cycle, if individually compare each point to find a maximum value of the minimum point is obviously very time-consuming, in general, the pulse wave period is 700-1200ms, and b and c of the feature point interval typically 70-120ms, approximately one tenth of the entire cycle, therefore, the first order differential signal after selecting a suitable $L = \lambda T$, wherein $\lambda$ is a constant, T is the time interval between points b and c, and looking in the appropriate L time interval maximum value of the minimum value b and c points can be identified. Meanwhile, the in identified peak point out may contain noise point, then the time difference between two points can be used at greater than a certain range, such a method to filter out the noise point. The program diagram is shown in Figure 8, and its effect is in Figure 6.

3.2. Other features point recognition

D, e, f, g on the positional relationship is such a sequence arranged according to Figure 2 Observe that, but first identify the points f and g is more appropriate, and identified after two longer identify d and e two o'clock will easier, since f and g are local extreme points of the cycle, can be detected by the method of pulse wave and the first order differential; d and point e is the inflection point of the partial cycle for the point d by the pulse wave the second-order differential detection of local maxima point e, it is located between the d and f slow decline to a sharp decline in the turning point of the waveform, can be identified using the differential threshold method.

Fig6. Defined feature points b and c  
Fig7. Other characteristics point to identify
Specific recognition process is:

1. Start
   - Pre-processing
   - Note of the characteristic point $b, c$
   - Find max and min value in a set of waveforms
   - Determine the identification cycle threshold $P$
   - Search waveform decline edge $i$
   - Looking for extreme points $b, c$
   - Note of the feature point $b, c$
   - Number of cycles $N = 10$
   - Plus $L$ re-search $i$
   - $y_{c+1} - y_{b+1} > p$
   - Note of the feature point $b_{N+1}, c_{N+1}$
   - Extreme on the codes within $(T_{e_k}, T_{m})$
   - Extreme value of the number 1
   - The extreme value is the point $f_N, g_N$
   - Identify the point $d$ in $(T_{d_k}, T_{f})$
   - Recognition point $e$ in $(T_{d_k}, T_{f})$ within the $N = N + 1$

Fig8. Program flow diagram
(1) of the pulse wave after denoising seeking first-order differential and the position of the point c as a starting point, backward detecting two zero crossings, respectively corresponding to f and g points; 
(2) pulse wave the second-order differential, still as a starting point the position of the point c, rearwardly detecting maxima, corresponding to the point d;

(3) Assuming that p-1, p, p +1 is the adjacent inner waveform \( df \) three points, and the difference is divided into: 

\[
\Delta_p = \Delta_{p-1} - \Delta_p, \quad \Delta_{p+1} = \Delta_p - \Delta_{p+1},
\]

if the \( \Delta_p \leq H_1 \), \( \Delta_{p+1} \geq H_2 \), as a feature point e to the point p. Wherein the threshold 

\[
H_1 = (1.0 \sim 1.5) \Delta_{\text{min}},
\]

\[
H_2 = (0.5 \sim 0.8) \Delta_{\text{max}},
\]

\( \Delta_{\text{min}} \) and \( \Delta_{\text{max}} \) are between the minimum and the maximum differential in the \( df \). As shown in Figure 7.

4. Conclusion

Use multi-resolution analysis of wavelet decomposition of the original pulse wave, de-noising and reconstruction of the ideal pulse wave signal periodically determine the main peak and trough, Minimax Principle and pulse wave detected, and as a basis for other feature points using Matlab program implementing the method. Experimental results show that the method can be more accurate extracted their respective feature points, to achieve the effect of positioning.

5. References


Study on Pulse Wave Signal Noise Reduction and Feature Point Identification
ZHAO Zhi-qiang, ZHENG Guo-wei, PANG Yu, SHENG wei, LIAO cheng, LIN Jin-zhao