Study of Getting Spectra of Doppler Signals Based on its Audio Signals

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Keywords: ultrasonic Doppler signal; bandpass filter; Hanning window; short-time Fourier transform;

Abstract: In general, the format of data produced by ultrasound Doppler is not open, and the data can not be obtained directly. As a result, the statistic and analysis to the data are impossible. There are two formats of the ultrasonic Doppler output signals, audio format and spectrum format. In order to get the monitoring data of ultrasound Doppler, especially to get the spectra of Doppler signals, a method of getting spectra of Doppler signals based on its audio signals is proposed in the paper. The audio signals produced by the ultrasound Doppler are filtered by a bandpass filter to get rid of some noises, and Hanning windowed short-time Fourier transform is used to get the spectra of ultrasound Doppler signals. The spectra are displayed in the computer. The simulation results show that using the method introduced in the paper can get clear and accurate spectra of Doppler signals. An open platform of acquiring ultrasound Doppler's data is established, which is the basis of studying Doppler pathological data and the pathogenesis of some diseases.

1. Introduction

When ultrasonic signal is used in Medical examination, the ultrasonic pulse wave get into the human body, and the Doppler effect is brought out due to the relative motion between sound source and acceptor, and this will produce series of complex phase frequency shift signals, after these signals are received and processed by the acceptor, through appropriate frequency analysis and display, the result can be applied to clinical diagnosis, so as to give the doctor's advice, and give patients the effective treatment[1,2]. TransCranial Doppler (TCD) is a non-invasive cerebrovascular disease detecting method by using the ultrasonic Doppler effect to test the hemodynamics parameters in intracranial cerebral main artery and the blood physiological parameters. TCD has the advantages of penetrating skull without hurting, simple operation and good repeatability[3]. TCD can be used to do continuous and long-term dynamical observation to the patient. More importantly, TCD can provide important hemodynamic information that can not be detected by imaging techniques such as MRI, DSA, CT, SPECT, meanwhile, Transcranial color Doppler monitor combined pulsed Doppler technique and 2MHz emission frequency which makes the ultrasonic beam can penetrate the thinner parts (head acoustic window) of the skull , tracing the Doppler signals of pavimentum Cerebral artery blood flow directly , and the blood flow velocity of ACA, MCA, PCA , VA , BA vessels is obtained, so as the hemodynamics and blood physiological parameters change of RI, PI, which provide important hemodynamic information for diagnostic and research for cerebrovascular disease[3]. Ultrasound Doppler flow spectrum shape can reflect the blood flowing condition in blood vessels, and output by audio and video ways, it is the main content transcranial Doppler (TCD) analyses, which has important clinical value. Among them, the spectrogram analysis of flow state is universally acknowledged, for the dynamic power spectrum of Doppler echo signal contains blood flow velocity, direction and other information.

Because of commercial reasons, Doppler ultrasound examination of the patient's data format is not open, and can not be obtained directly, so a statistical analysis of the data can not be done, and the disease pathogenesis can not be understood[4]. In order to obtain the monitoring data of Doppler ultrasound monitor, and the Doppler spectrum signal for statistical analysis , a method to obtain the Doppler spectrum based on the audio signal is proposed in this paper. Using Doppler monitor to

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get effective Doppler audio signals, according to the relationship between the Doppler signal and noise signal, the band pass filter is designed to remove noise. In order to reduce the spectrum leakage, in the filter design process, Hanning window is used for windowing process, Fast Fourier Transform on the signal obtained window function and the Doppler signal multiplied is established. The experiment results shows that, by choosing appropriate window function, using this method can obtain clear and correct Doppler spectrum signal from an audio signal.

2. The principle and method

2.1 Digital filter

In the analysis and processing of biomedical signals, there is always a problem that useful signal superpose with unwanted noise[5]. Some noise is generated in synchronization with the signal, and others are mixed in the process of signal transmission. The noise disturbs analysis of useful signal. In order to ensure the accuracy of signal, and provide a sTable, clear information for clinical diagnosis, eliminate or weaken the noise from the original signal components is a necessary prerequisite for the subsequent information analysis.

Digital filter has the function that let the useful signal with specific frequency get through, and suppress unwanted frequency signal, the input, output is digital signal, discrete system butterworth. is used to process and transform the input signal, the input sequence spectrum or signal waveform is changed, so the useful signal can be obtained. Method based on simulation performance of digital filter in digital signal processing technology is far superior to the traditional simulation method.

Digital filter can be divided into lowpass, highpass, bandpass, bandstop filter from its function[6]. FIR filter and IIR filter are common used digital filter. IIR filter transfer function contains two groups of adjusTable factors , the zeros and poles, the only limit on the pole is in the unit circle. Therefore, higher selectivity can be obtained by lower order, and few storage unit, small amount of calculation are demanded with high efficiency. But this efficiency is at the price of a nonlinear phase. Therefore, the better the selectivity is, the more serious is the nonlinear phase. The FIR filter transfer function poles at the origin, only by changing the zero position can change its properties. So in order to achieve high selectivity, higher order must be used, for the same filter design indicators, the number of order FIR filter required may be 5-10 times higher than the IIR filter, it cost high and signal delay is large.

According to the characteristics of the Doppler signal, IIR filter bandpass filter is usedin this paper. Among Butterworth and Chebyshev filter IIR filter is in common. Butterworth digital bandpass filter has the advantages of simple designed, the pass band with maximally flat characteristics. Butterworth filter is selected based on the fast-non-stationarity of Doppler signals. The formula of Butterworth filter amplitude frequency response is[7,8]:

$$|H(w)| = \frac{1}{\sqrt{1+(\frac{w}{wc})^{2n}}} \tag{1}$$

whereω angular frequency,ω is cut-off frequency, N is the order of the filter.

The design procedure of digital bandpass filter: firstly, according to the actual needs to determine the performance index, and then seek the system function , the technical indicators are needed, finally implemented by using finite precision arithmetic. Doppler signal frequency shift generally below 4500Hz, but also vascular wall echo signal under 200Hz filter is needed, so the 200Hz~4500Hz band-pass filter can be designed to obtain Doppler frequency shift signal. The aim of the design is, the band edge frequency attenuation is not more than 0.1dB, below 100Hz and above 4600Hz attenuation is not less than 30dB, the sampling frequency is 9500. In Matlab, design filters by using butterworth. function and butter function, in which the butterworth. function is to determine the order of bandpass filter, butter function used to design the Butterworth digital bandpass filter. The band pass filter amplitude frequency corresponding is shown in Figure 1, the zero pole bandpass filter distribution diagram is shown in Figure 2

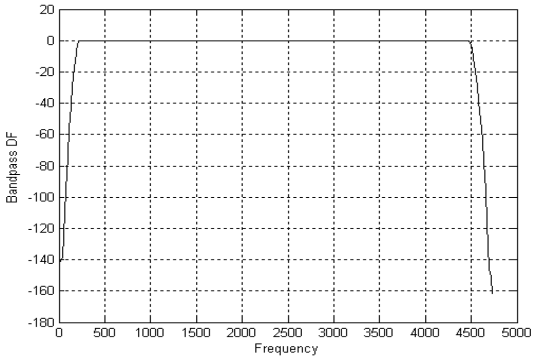


Figure.1 The band pass filter amplitude frequency corresponding

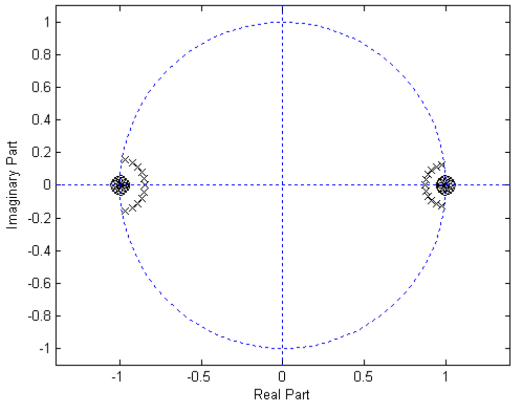


Figure.2 The Zero Pole Bandpass Filter Distribution Diagram

It can be seen from Figure 1, bandpass filter has characteristics of flat belt, this can satisfy the performance index; it can be seen from Figure 2, The system has poles and zeros, and respectively in the unit circle and on the unit circle, sTable 11 order passband filter can be obtained, passband and stopband attenuation is evenly distributed, with narrow transition band, to effectively filter out the noise, ensure the accuracy of the Doppler signal.

2.2 Short time Fourier transform(STFT)

In 1946, Gabor proposed the windowed Fourier transform [9]. The basic idea is: to the signal function $f(t) \in L^2(R)$, take the time function $g(t)$ of the window function, multiply them, then make Fu Liye transform, that is,

$$STFT_f(t,w) = \int_R f(\tau) g^*(\tau - t) e^{-jw\tau} d\tau = < f(\tau), g(\tau - t) e^{-jw\tau} > \quad (2)$$

where $g_{t,w}(\tau) = g(\tau - t)e^{-jw\tau}$, $\| g(\tau) \| = 1$, $\| g_{t,w}(\tau) \| = 1$ .From(1),we can see, In the time domain use $g(\tau)$ to cut $x(\tau)$, make Fu Liye transform on the intercepted signals, Fu Liye transform of the signal in time t can be obtained ,it can reflect the characteristics of the signal in time t , constantly move t , that is move window function's center position, can be obtained Fu Liye transform in different time, and reflected signal feature information in different time. $STFT_f(t,w)$ means the spectrum characteristic of $f(t)$,where τ is the center,around the time of $\Delta\tau$ .Window width $\Delta\tau$ determines the resolution of time domain,the frequency window $2\Delta w$ of window function $g(t)$ determines the frequency resolution of Short-term Fu Liye transform. The time-frequency resolution of short-time Fu Liye transform is directly determined by the window function of time-frequency window size, once the window function $g(t)$ is selected, the time-frequency resolution is determined, and does not vary with frequency w and time t change. Therefore, a suitable window function should be selected based on the STFT time-frequency processing method, in order to achieve the aim of best performance and real-time.

For fast time-varying non-stationary signal, using traditional Fu Liye transform can obtain better time resolution, meanwhile, it will reduce the frequency resolution of high frequency signals; on the contrary, when it comes to slowly-varying signal, to get better low frequency signal frequency resolution, signal time resolution will have to be lowered. Short term Fu Li ye transform can overcome these shortcomings. Doppler signal is a non-stationary signal, of which frequency is changing with time. For this kind of signal, if Fu Liye transform is used for analysis, complete information can not be obtained. That is to say, via traditional Fu Liye transform, frequency information of the signal can be known, but the frequency information can not be known it appears in what in what time. If the frequency feature information of a period of time has to be extracted, traditional Fu Liye transform can't meet this demand. In order to study the frequency characteristics information of Doppler signal in a period of time and describe the changes of signal spectrum by time, representing the energy or intensity variable information of signal, the short Fu Liye transform is proposed in this paperfor processing the Doppler signal.

2.3 The application of window function

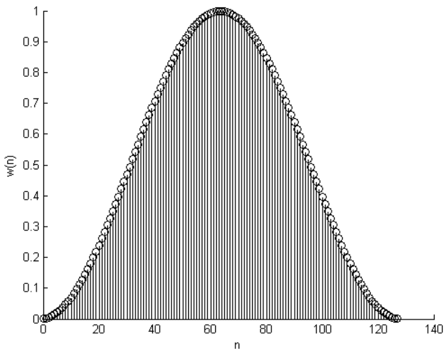
In simple, window function is the “weighting”. The ideal window function should have narrow main lobe width, the minimum peak side lobe and the maximum rate of decay, but in practice it is difficult to satisfy the three conditions. Rectangular window and Hanning window are commonly used Window function, rectangular window has narrow main lobe, but has large peak side lobe level side lobe and slower peak attenuation speed, severe boundary effect will result in the leakage of spectrum energy, in the case of low SNR, it is difficult to obtain higher accuracy. Hanning window has a smaller sidelobe peak and higher sidelobe peak attenuation speed, although the main lobe slightly wider than the rectangular window, but good for frequency energy accumulation, higher frequency measurement accuracy can be gained in case of low SNR. Compared with the rectangular window, Hanning window has larger bandwidth and higher stopband attenuation speed, smaller distortion of the input signal. Therefore, this paper selects the Hanning window function for Doppler signal processing[10]. Frequency response window can be obtained by using short time Fu Liye operation to window function. The window is designed to suppress the sidelobes, but also make the main valve with different degree of broadening. Hanning window is a widely used window function, the time domain formula[10,11] is :

$$w(t) = \{ \begin{matrix} \frac{1}{T}(\frac{1}{2} + \frac{1}{2}\cos\frac{\pi t}{T}) & |t| < T \\ 0 & |t| > T \end{matrix} \tag{3}$$

The window spectrum is:

$$W(w) = \frac{\sin wT}{wT} + \frac{1}{2}[\frac{\sin(wT+\pi)}{wT+\pi} + \frac{\sin(wT-\pi)}{wT-\pi}] \tag{4}$$

It can be seen from formula(3),Hanning window can be regarded as the sum of the frequency spectrum of 3 rectangular window, or the sum of 3 $\sin e(t)$ formula, the two term in the parenthesis relative to the first spectral window, each mobile π / T right and left, so that the sidelobe cancel each other out, eliminate the high frequency interference and leakage. According to the characteristics of the Doppler signal, this paper selects 128 as the Hanning window’s size, then the signal-to-noise ratio and peak width can be better obtained. The effect of window function width selection on time and frequency is restricted by the uncertainty principle, the time resolution and frequency resolution can only take a compromise, one raise, the other is bound to be lower, and vice versa. Hanning window function and the window function spectrum used in this paper are as shown in Figure 3 and Figure 4.



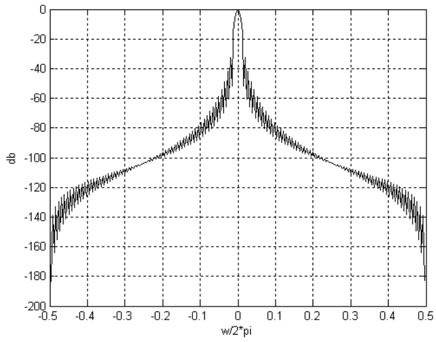


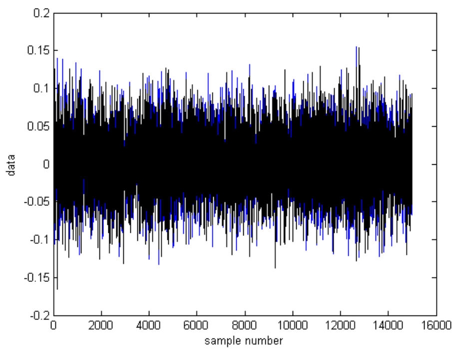
Figure 3 Hanning window function; Figure 4 Hanning window function spectrum

It can be seen from Figure 3 and Figure 4, the Hanning window mainlobe widening and reduce, side lobe decreased significantly, from the point of view of reducing the leakage point, Hanning window is better than the rectangular window, which has good frequency resolution. Effect of different window function to signal spectrum is not the same, this is because different window functions generate different leakage, and so is the frequency resolution. Signal truncation generates energy leakage, and spectrum will have a picket fence effect by using the Fu Liye algorithm, these two kinds of errors cannot be eliminated from the principle, but can be suppressed by affecting the choice of different window function on them.

The selection of window function is very important, if the window is shorter, the spectral width will be more serious, and the accuracy of spectral estimation will be lower. If the long window is selected, time accuracy spectrum will become poor, and also the signal spectrum broadening can be caused by non smooth.

3. The experimental simulation results

First, read the Doppler audio signal, select 15000 signal from it, use the Butterworth digital bandpass filter to filter the noise outside the 200Hz~4500Hz, get the Doppler ultrasound signal useful; then, use the Hanning window, to suppress the side lobe, broaden the mainlobe, reduce the energy leakage, inhibit the picket fence effect. Use the Short term Fu Liye transform Hanning window on the signal to obtain the Doppler signal spectrum. Doppler audio signal is shown in Figure 5, the spectrum before filtering is shown in Figure 6, the application of spectrum filter is shown in figure 7.



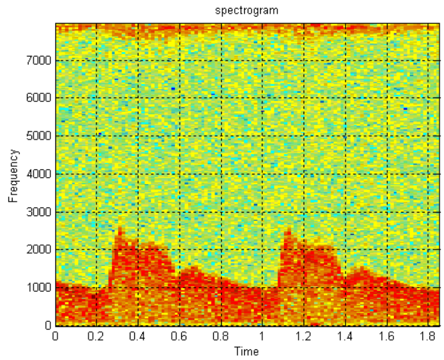


Figure.5 Doppler signal spectrum. Doppler audio signal; Figure.6 the spectrum before filtering

Figure 5 is a dual channel Doppler audio signal, it can be seen from the figure, the signal is non-stationary signal, transforms faster, has higher frequency. It can be seen from figure 6 and figure 7, the use of the band-pass filter that designed in this paper effectively filtered the noise signal, did not lead to distortion of useful signal, and achieved the anticipated design effect. Simulation results show that, using this algorithm can get Doppler audio signal spectrum.

4. Conclusions

Using audio signal signal of blood flow Doppler ultrasound detector, extract the time series data that reflects flow signals, obtain the Doppler signals' spectrum information by using digital signal processing technology. The experimental results show that, the method has the advantages of small signal distortion, good stability, and can accurately process signals by using nonlinear analysis. It can not only observe the original blood flow signal, but also can real-time test the changes in time series information in experiment, observe the changes in signal. By using this method, the Doppler test data can be statistically analyzed, and the pathogenesis of disease can be further understood, which plays an important role in further study of cardiovascular and cerebrovascular disease and its prevention and control.

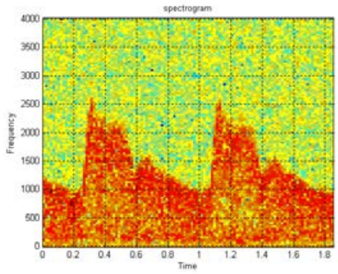


Figure 7 The Application Of Spectrum Filter

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