DICROTIC NOTCH DETECTION USING WAVELET TRANSFORM ANALYSIS

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ABSTRACT

The objective of this research was to devise a method of accurately and consistently extracting the dicrotic notch from the aortic blood pressure signal for various heart rates and arrhythmias. The aortic blood pressure signal has been analyzed by calculating the wavelet transform at several scales to consistently detect the temporal location of the dicrotic notch. The simultaneous locations of the peaks in the wavelet transforms of the first derivative of the aortic pressure waveform across 2 consecutive scales corresponds to the location of the dicrotic notch. A final algorithm analyzes the transform results and labels the notch point. Locating the dicrotic notch is critical for analyzing systolic time interval.

INTRODUCTION

The Fourier transform (FT), used for frequency analysis of stationary signals describes a signal as a decomposition of sinusoidal basis functions of infinite extent. Due to the infinite extent of the basis functions, any time-local (transient) information is spread over the entire frequency axis. Time-frequency information is obtained by applying the Fourier transform to a portion of the signal isolated using a time window function. This short time Fourier transform (STFT), is limited by a constant window width which does not adapt to changing signal frequencies.

The wavelet transform (WT) gives local frequency information, like the STFT, but utilizes "wavelet functions" h(t) as basis functions and allows adaptive window sizes with changing signal frequencies. The wavelet functions are generated from a single prototype wavelet by translation and dilatation/contraction of the form:

$$h_{a,b}(t)=1/\sqrt{a}\ h((t-b)/a) \qquad a \in \mathbb{R}+ \qquad b \in \mathbb{R}$$

The scale parameter (a) of the window function allows a dilatation or contraction in time. As the scale is increased, dilating the wavelet, the time resolution is decreased allowing higher frequency resolution. The translation parameter (b) is used to shift and localize the wavelet function in time.

Physiological signals, such as the blood pressure and electrocardiogram (ECG) are classified as nonstationary. Thus, the wavelet transform is more appropriate than the FT and the STFT for analyzing this time-varying signal. The dicrotic notch is observed in the aortic pressure signal as a consequence of the closing of the aortic valve. The detection of the dicrotic notch is non-trivial because the pressure signal may be corrupted by noise, or in sick patients, it may deviate greatly from the norm. It is possible to distinguish the dicrotic notch using the wavelet transform of the first derivative of the pressure waveform since the notch frequency can be identified and the signal's specific frequency bandwidths do not overlap.

METHODS

The wavelet functions and transform routine have been programmed on both a PC and UNIX workstation using Matlab 4.0. The aortic blood pressure signal is first smoothed using a lowpass filter to reduce extraneous noise. The algorithm then locates both the systolic peak and end diastole by locating the maximum and minimum of the pressure waveform respectively, using the zero crossing of the first derivative around the peaks, per cardiac cycle. The wavelet transform of the derivative is calculated using the dyadic wavelet ($a = 2^j$). We have used the Haar, Morlet, Shannon, and Spline wavelet functions [1], all of which provided notch disclosure. The dyadic wavelet transform is calculated by convolving the signal derivative with the opposite of the wavelet function scaled. The program continues to calculate the wavelet transform at increasing scales until the maximum in the wavelet transform, representing the notch location, occurs on the same point in time across 2 consecutive scales. The signal portion scanned for the notch is defined between the systolic peak and end diastole.

This wavelet transform dicrotic notch detection technique has been tested on human and pig experimental data as well as data on generated by the cardiovascular model of [2]. The test set included 12 aortic pressure signals including samples with constant heart rates and arrhythmias. Each pig data set was sampled at 200 Hz, while the human blood pressure data sets are stored at a sampling rate of 180 Hz. The first 1025 samples of each data set are used for signal processing.

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RESULTS

The algorithm has successfully recognized the dicrotic notch point in the aortic pressure waveforms. although various wavelet function were tested, more significant results were found using the cubic spline function. Figures 1a shows the original human arterial pressure signal with lines indicating where the dicrotic notch has been detected. Figures 1b indicates the signal derivative used in the wavelet transform analysis. Figures 1c and 1d present the result of the wavelet transform at the final two scales calculated to achieve successful notch recognition.

DISCUSSION

The example shown here indicates successful detection of the dicrotic notch for a relatively noise free waveform with an easily identifiable notch. This illustrates the analysis method while other waveforms, having more noise and various cardiac rhythms have also been tested with good results. This analysis method relates to the scheme presented by Mallat [3] for edge detection analysis, in which abrupt changes in a given waveform are discerned. Conventional methods of dicrotic notch detection look for the zero crossing of the signal derivative [4, 5]. The derivative is prone to error with noisy signals. This method of dicrotic notch detection is inherently better because noise is not correlated with wavelet transforms across several scales.

CONCLUSIONS

Reliable and consistent dicrotic notch detection of the aortic blood pressure signal has been accomplished by locating the consecutive maxima across 2 consecutive scales of the wavelet transform. A computer program has been written and implemented on a PC and workstation and has been tested on human, pig and computer model generated aortic blood pressure waveforms for both constant heart rates and arrhythmias.

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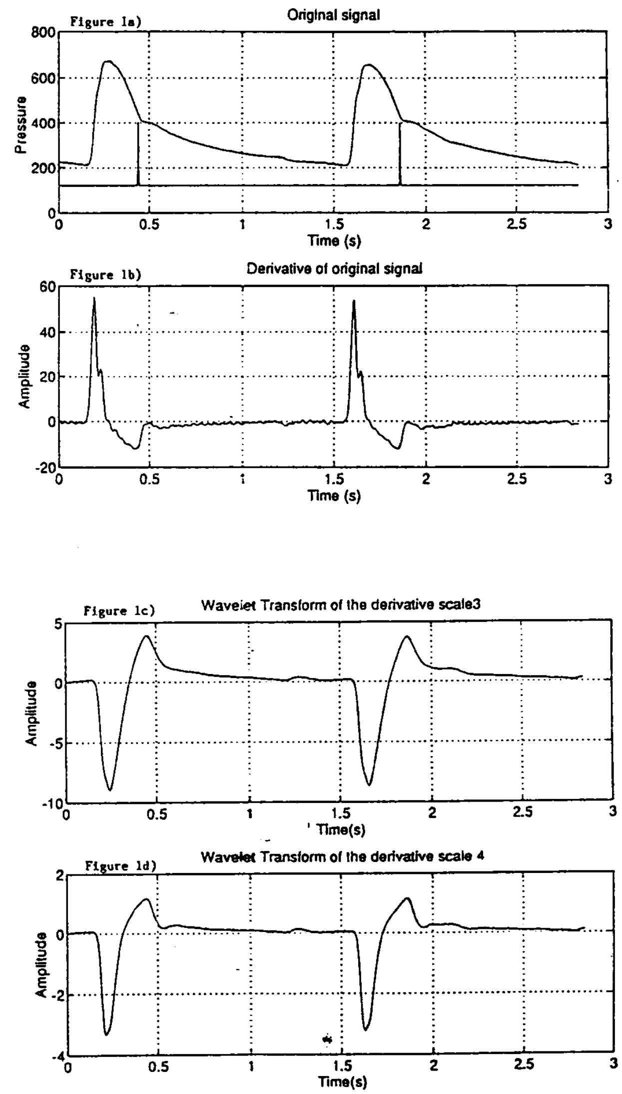

Figures 1a) Original human arterial blood pressure signal with dicrotic notch marked as determined from algorithm; 1b) Derivative of arterial pressure signal of figure 1a; 1c, d) 3rd and 4th scale wavelet transforms of signal derivative compared for maximum point corresponding to dicrotic notch location.