DETERMINATION OF MITRAL OR AORTIC VALVE STENOSIS OR INSUFFICIENCY VIA POLE-ZERO MAP ANALYSIS OF HEART SOUND SIGNALS

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Abstract

Heart sound signals were recorded, both for healthy subjects and for patients with mitral or aortic valve stenosis or insufficiency. Sounds were recorded by electronic stethoscope and then analyzed. Firstly, these signals were modeled with a fourth-order AR process. A pole-zero map of each signal was created with the help of the transfer function of this process. On the basis of the evaluations made of these maps, it can be concluded that pole-zero maps can be used as an auxiliary element in diagnosing mitral or aortic valve stenosis or insufficiency.

Keywords: heart sounds; AR Model; pole-zero maps

1. Introduction

Biological signal processing is widely used, as it provides researchers with the opportunity to undertake studies without the need for invasive surgery. The heart, which enables blood circulation, is the main source of sound within the body, due to its mechanical movement. The sound signals produced by the heart are quite variable, low-frequency vibrations. Mitral valve stands between the left atrium and left ventricle of the heart and aortic valve stands between the end of the left ventricle and the start of the aorta which is the largest artery in the body and comes out of the heart. Anomalies due to various factors are often observed in the functions of these valves. These anomalies develop as stenosis or insufficiency and result in irregularities in blood flow. This can lead to some serious illnesses that significantly affect the lives of individuals [1].

One of the non-invasive methods of diagnosing such disturbances is by analyzing the sounds of the body (termed auscultation). A special microphone (phonocardiograph) is used to monitor and record heart sounds and murmurs, thereby providing important evidence about the condition of the heart. This data is recorded in a graphical format (Phonocardiogram (PCG)) for subsequent evaluation [2].

The signals are then evaluated using classical and modern parametric methods such as FFT (Fast Fourier Transform), periodogram, spectrogram, STFT (Short Time Fourier Transform), AR (Autoregressive), MA (Moving Average), ARMA (Autoregressive Moving Average), wavelet transform etc. and presented in a form that will facilitate clinical evaluations [3].

Modern parametric methods such as AR, MA, ARMA and wavelet transform are based on the selection of a model appropriate to the signal to be examined and on the estimation of the model parameters. These parameters that model the signal are used in obtaining the power spectrum. Indirect use of the signal eliminates any potential negative result that can occur due to assigning the value “0” to the data excluded from the window during the windowing process. Depending on the features of the signal; modeling method, modeling order and the measurement intervals of the model application gain importance in parametric methods [4,5].

2. Method

Heart-sound signals of healthy individuals and of patients with mitral valve stenosis, mitral valve insufficiency, aorta valve stenosis or aorta valve insufficiency were recorded with the help of a digital electronic stethoscope [6]. All the signals were sampled with the same sampling frequency (11025 Hz). Signals were modeled using the MATLAB computer program. In discrete time systems encountered in practical applications, AR models can be applied when the only data available to model the system are outlet values [7].

Figure 1 assumes that the heart is a linear dynamic system with single outlet and white noise in the inlet; y(n) refers to outlet signal heart sound signal and v(n) refers to white noise inlet.

![Figure 1. AR Model: Heart Sound Signal (Synthesis Model)](Image)

\[
y(n) = b_1 y(n-1) + b_2 y(n-2) + \ldots + b_M y(n-M) + v(n) \quad (1)
\]

This is an AR process of M order. The value of the process at that specific time "y(n)" will be equal to the sum of the finite linear combination of past values of the process \(y(n-1), y(n-2), \ldots, y(n-M)\" and an error term "v(n)". \(b_1, b_2, \ldots, b_M\) are constants and AR parameter v(n) is a white noise process.

If we generalize statement (1):

As long as

\[
B(z) = 1 + b_1 z^{-1} + \ldots + b_M z^{-M} \quad (2)
\]

\[
B(z)Y(z) = V(z) \quad (3)
\]

can be valid.

Transfer function of the synthesis model:
\[ H(z) = \frac{Y(z)}{V(z)} = \frac{1}{\sum_{n=0}^{M} b_n z^{-n}} \]  

4 

Roots of

\[ 1 + h_1 z^{-1} + h_2 z^{-2} + \ldots + h_M z^{-M} = 0 \]  

Characteristic equations are \( H(z) \) \( p_1, p_2, \ldots, p_M \) poles [4,5].

\[ H(z) = \frac{1}{[1 - p_1 z^{-1}][1 - p_2 z^{-1}] \ldots [1 - p_M z^{-1}]} \]  

The current value of the \( y(n) \) heart signal in the AR model can be explained by using the previous values of \( y(n) \) signal and linear combination of white noise. The signal is modeled using the AR method as causal, whole-pole and the outlet of a discrete filter (e inlet, which is composed of white noise).

As in the linear filter statement (6) based on the equation (1) above, it is determined as a transfer function composed of the poles in \( Z \) domain. The output power of the filter evaluated on unit/square is driven by the white noise with an average value of zero and variance of \([8,9,10]\).

3. Clinical Application

3.1. Normal Heart

A normal heart sound signal in Figure 3 is expressed in the fourth-order AR model as follows:

\[ (1 - 1.302 z^{-1} - 0.1679 z^{-3} + 0.2787 z^{-3} + 0.1937 z^{-4}) Y(z) = V(z) \]

3.2. Mitral Stenosis

\[ (1 - 1.278 z^{-1} - 0.0877 z^{-3} + 0.06935 z^{-3} + 0.2989 z^{-4}) Y(z) = V(z) \]

In Figure 4, an opening snap and a mid-diastolic murmur are observed just after S2. Two poles that are quite close to each other develop in the left segment of the pole-zero map. Figure 5 gives pole-zero maps of the heart sound signals of six patients suffering from mitral stenosis.
3.3. Mitral Insufficiency

Fourth-order AR model expression:

\[
(1 - 3.074z^{-1} + 3.547z^{-2} - 1.842z^{-3} + 0.3697z^{-4})Y(z) = V(z)
\]

In Figure 6, the time-amplitude diagram shows a holosystolic murmur is observed during systole as a finding for mitral insufficiency. In the case of mitral insufficiency, unlike the normal case, the poles are located in the right semi-circle of the pole-zero diagram.

Figure 7 shows the pole-zero maps of heart sound signals of nine patients suffering from mitral valve insufficiency.

3.4. Aortic Valve Stenosis

Fourth-order AR model expression:

\[
(1 - 2.258z^{-1} + 1.592z^{-2} - 0.403z^{-3} + 0.06973z^{-4})Y(z) = V(z)
\]

In Figure 8, a late systolic murmur is recorded, which is observed in aortic stenosis during systole. The pole-zero map shows two poles quite close to each other in the left semi-circle.

Figure 9 shows the pole-zero maps of heart sound signals of seven patients suffering from aortic valve stenosis.

3.5. Aortic Valve Insufficiency

Fourth-order AR model expression:

\[
(1 - 0.6973z^{-1} + 0.403z^{-2} - 0.592z^{-3} + 1.258z^{-4})Y(z) = V(z)
\]

In Figure 10, a decrescendo murmur during diastole in addition to S1 and S2. The pole-zero map shows poles accumulated in the right semi-circle.

Figure 11 shows the pole-zero maps of heart sound signals of four patients suffering from aortic valve insufficiency.
4. Conclusion

The following conclusions are presented, after evaluation of the pole-zero maps of heart sound signals:
1) Both healthy individuals and patients with heart conditions have sound signals which show two (of four) poles located on the radius edge of the right semi-circle.
2) The other two poles are located on the left semi-circle in mitral and aortic valve stenosis.
3) These two poles are located in the right semi-circle in mitral and aortic valve insufficiency. These findings demonstrate that, in addition to other diagnostic methods, pole-zero maps can be useful in diagnosing mitral and aortic valve stenosis and insufficiency.

References

[6] Littmann Electronic Stethoscope Model 4100, This is available online at <http://www.3M.com/Littmann3M>, 1/12/08.