TIME-FREQUENCY ANALYSIS OF HEART SOUNDS USING WINDOWED AND SMOOTH WINDOWED WIGNER-VILLE DISTRIBUTION

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ABSTRACT

Heart sounds and murmurs are time-varying signals that would best be analyzed using time-frequency analysis. Windowed Wigner-Ville distribution (WWVD) and smooth windowed Wigner-Ville distribution (SWWVD) are used to obtain the time-frequency representation (TFR) of the signal. Determination of parameter setting of WWVD and SWWVD will eliminate the cross-terms and improve TFR. The accuracy of TFR will be determined based on the mainlobe width and signal-to-interference ratio. It is found that the most accurate TFR can be achieved using SWWVD.

1. INTRODUCTION

Heart sounds and murmurs are the important parameter used in diagnosing the heart condition and it can be captured by using phonocardiogram or heart auscultation [1]. However, heart auscultation has its own disadvantage as it doesn't provide permanent record of the examination result and the technique is very subjective due to listening skills, experiences and hearing ability of the physicians. Thus, a technique that can assist a trained physician is required to differentiate the heart sounds and murmurs. Time-frequency analysis methods are capable of detecting heart murmurs and vital information to the classification of heart sounds and murmurs [2]. WVD and WWVD are used to analyze heart sounds and murmurs in [3]. The WWVD is necessary because the window function can be used to control the amount of interference present in TFR. The study on the characteristic of the second heart sound (S_2) was performed in [4]. The component of S_2 is modeled as a narrow-band non-linear chirp signal having a fast decreasing instantaneous frequency with time.

2. SIGNAL MODEL

Based on [3], the heart sounds and murmurs can be model as a periodic signal where can be generally expressed as

$$z(t) = \sum_{i=0}^{5} z_i(t) \qquad 0<t<T_p$$
$$= \sum_{i=0}^{5} \Pi_{T_i}(t-t_i)a_i(t)\cos(2\pi f_i(t-t_i)) \qquad (1)$$

where T_p is the period of the signal, $z_i(t)$ is the individual component of heart sounds, $a_i(t)$ is the amplitude, f_i is the frequency and the term Π_{T_i} is refer to a box function equal to 1 in $0 \le t \le (T_i - 1)$. Based on [4], the individual components of S_2 can be defined as

$$z_{2,i}(t) = \Pi_{T_{2,i}}(t-t_{2,i})a_{2,i}(t)\cos(2\pi f_{2,i}(t-t_{2,i})) \qquad (2)$$

where i is 0 and 1 corresponding to the individual components of S_2. The quadratic frequency law will define the $f_{2,i}(t)$ as follows

$$f_{2,i}(t) = f_1 + \alpha(t-T)^2 \qquad (3)$$

where f_1 is the high starting frequency of the signal and α is the quadratic FM frequency law expressed as

$$\alpha = \frac{f_0 - f_1}{T^2} \qquad \text{where } f_0 > f_1 \qquad (4)$$

In conclusion, heart sound can be model as time-varying signal with characteristics of quadratic FM signal.

3. TIME-FREQUENCY DISTRIBUTION

The bilinear class of time-frequency distribution can be defined as follows [5]

$$\rho_z(t,f) = \int_{-\infty}^{\infty} G(t,\tau) \underset{(t)}{*} z(t+\tfrac{1}{2}\tau)z^*(t-\tfrac{1}{2}\tau)\exp(-j2\pi f\tau)d\tau \quad (5)$$

where $G(t,\tau)$ is the time-lag kernel function and $z(t+\frac{1}{2}\tau)z^*(t-\frac{1}{2}\tau)$ is the bilinear product of $z(t)$. Setting the time-lag kernel equal to 1, WVD will be defined as

$$W_z(t,f) = \int_{-\infty}^{\infty} z(t+\tfrac{1}{2}\tau)z^*(t-\tfrac{1}{2}\tau)\exp(-j2\pi f\tau)d\tau \qquad (6)$$

The unity kernel of WVD preserves both the auto-terms and cross-terms of the signal. Setting the time-lag kernel as

$$G(t,\tau) = \delta(t)g(\tau) \qquad (7)$$

resulting the windowed WVD

$$W_{z,w}(t,f) = \int_{-\infty}^{\infty} g(\tau)\cdot z(t+\tfrac{1}{2}\tau)z^*(t-\tfrac{1}{2}\tau)\exp(-j2\pi f\tau)d\tau \quad (8)$$

where window $g(\tau)$ will be nonzero for $-\frac{T_w}{2} < \tau < \frac{T_w}{2}$ and T_w is the window width in lag. Setting the kernel function as

$$G(t,\tau) = g(t)g(\tau) \qquad (9)$$

where $g(t)$ is the time-smooth function and $g(\tau)$ is similar to the window in WWVD. The $g(t)$ is defined as

$$g(t) = 1 - \cos(\tfrac{\pi t}{T_{sm}}) \qquad 0<t<T_{sm}$$
$$= 0 \qquad \text{elsewhere} \qquad (10)$$

where T_{sm} is the time spread that controls the suppression of the cross-terms [6]. Substituting (9) into (5) will result in the SWWVD

$$W_{z,sw}(t,f) = \int_{-\infty}^{\infty} g(t) \underset{(t)}{*} [g(\tau)z(t+\tfrac{1}{2}\tau)z^*(t-\tfrac{1}{2}\tau)\exp(-j2\pi f\tau)]d\tau \qquad (11)$$

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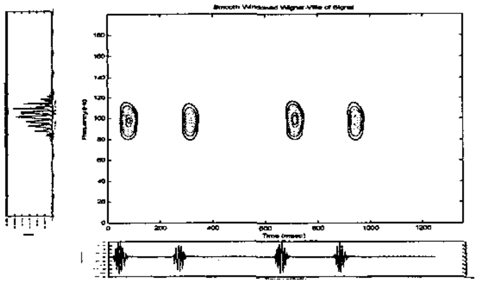

Figure 1 SWWVD representation for normal heart.

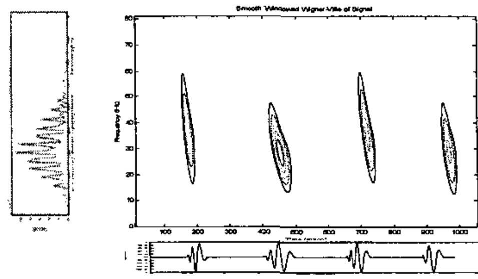

Figure 2 SWWVD for quadratic FM model heart sound.

This study focused on improving WVD by modifying the kernel function in order to suppress the cross-terms while maintaining high time-frequency resolution in TFR. Interference problem in WVD can be minimized by adjusting the appropriate parameters in the WWVD and SWWVD [6]. In WWVD, T_w needs to be adjusted to remove the cross-term in TFR and can be calculated by using the smallest time duration of signal S_1 or S_2 in time-domain based on Equation (1). Whilst in SWWVD, the raised-cosine pulse has been chosen as the time-smooth function to smooth and remove time oscillations in bilinear product by setting parameter T_{sm} as

$$T_{sm} \geq \frac{3}{2|f_1 - f_0|} \tag{12}$$

where $|f_1 - f_0|$ is the bandwidth of the signal.

4. PERFORMANCE MEASURE

A set of performance measures were design to determine the accuracy of TFR. This can be done by analyzing the representation using mainlobe width (MLW) and signal-to-interference ratio (SIR). MLW represents the sharpness of the TFR that is measured at 50% of the highest peak at S_1 spectrum energy. The lower value is desired since it can quantify the smearing effects of TFR for heart sounds and murmurs. Whilst, SIR determine the ratio of signal power to the interference power in TFR. The ratio is as follows

$$\text{SIR (dB)} = 10 \log_{10} \frac{\text{Total energy of } S_1, S_2, S_3, S_4}{\text{Total energy of interferences (others than } S_1, S_2, S_3, S_4)} \tag{13}$$

Ideally, the SIR should be as high as possible. For unknown signal, the presence of interference introduce by the analysis is undesirable as it will lead to inaccurate interpretation of the true signal characteristic.

5. RESULTS

The result is shown in Table 1 for simulated normal heart (NH), simulated quadruple rhythm (QR), real late systolic murmurs (LSM) and quadratic FM model heart sound (Model HS). Lower MLW indicates the sharpness of the signal while higher SIR showing higher elimination of cross-terms. Even though MLW is higher for SWWVD, this method is considered the appropriate since SIR of SWWVD is the highest compared to the WVD and WWVD. The most important task is to overcome the existence of cross-terms present in the time-frequency representation; due to signals in practice have unknown characteristics. Model HS shows the highest SIR since the model is noise-free signal. Example of TFR using SWWVD for normal heart and quadratic FM modeling heart sound is shown in Figure 1 and 2 respectively.

Table 1 Results for MLW and SIR.

Type of heart sounds	MLW (Hz)			SIR (dB)		
	WVD	WWVD	SWWVD	WVD	WWVD	SWWVD
NH	19.53	19.53	22.27	-5.41	7.46	11.03
QR	19.92	20.31	23.05	-7.59	0.7	1.13
LSM	3.55	2.37	2.37	-0.11	9.66	10.83
Model HS	4.85	4.85	5.33	-2.19	12.33	14.3

6. CONCLUSIONS

Time-frequency analysis of heart sounds and murmurs is needed due to its time-varying characteristics of signal. The existence of cross-terms in WVD presented poor performance of TFR. Thus, the WWVD and SWWVD have been selected to overcome this problem. The parameter setting of WWVD and SWWVD is calculated based on the characteristic of the signals. The accuracy of TFR is compared using MLW and SIR. As a result, the TFR obtained from the SWWVD is the most accurate compared to WVD and WWVD based on parameter SIR.

7. REFERENCES

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