Comparison of Time-Frequency Analysis Performance on Hearts and Murmurs

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Abstract- Time-frequency analysis is one of the method to deal with non-stationary and time-varying signal such as heart sounds and murmurs. Wigner-Ville distribution (WVD) is a popular tool to obtain time-frequency representation of signal. Windowed Wigner-Ville distribution (WWVD) and smooth windowed Wigner-Ville distribution (SWWVD) are the improvement method to overcome the problem faced by WVD. Determination of parameter setting of WWVD and SWWVD will eliminate the cross-terms and improve time-frequency representation. The accuracy of time-frequency representation of simulated heart sounds and murmurs will be compared and determined based on the mainlobe width, peak-to-sidelobe average ratio and signal-to-interference ratio. It is found that the most accurate time-frequency representation can be obtained using the SWWVD.

Keywords
time-varying signal, simulated heart sounds and murmurs, time-frequency distribution, Wigner-Ville distribution.

I. INTRODUCTION

Heart auscultation is the standard procedure to diagnose heart problem. However, 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. Hence, it is an interest to develop a technique that can assist a trained physician to determine heart condition based on auscultation.

Variety of methods has been developed to study heart sounds and murmurs. Due to the non-stationarity of heart sounds, time-frequency analysis has been selected to analyze the heart signal in [3],[8,[9] and [11]. It was verified in [11] that time-frequency methods are capable of detecting heart murmurs and provide vital information in the classification of heart sounds and murmurs. Whilst [3] had discovered that the frequency resolution in the Wigner distribution is more accurately compared to the wavelet transform. Other research using techniques such as power spectral estimation techniques and time-scale analysis to analyze the heart sounds and murmurs [7],[8]. Wigner-Ville distribution have been applied in several researches such as in [1],[6],[9] and [10]. In general, fairly good estimation instantaneous frequency accuracy can be obtained from the time-frequency representation. The WVD and windowed WVD are used to analyze heart sounds and murmurs in [9]. The windowed WVD is necessary because the window function can be used to control the amount of interference present in the time-frequency representation.

II. SIGNAL MODEL

Heart sounds and murmurs can be model as a periodic signal where can be generally expressed as [9]

$$z(n)=\sum_{l=0}^{5} z_l(n) \qquad 0<n<N_p \qquad (1)$$

where N_p is the period of the signal and $z_l(n)$ is the individual component of heart sounds. This component is further defined as

$$z_l(n)=\prod_{N_l}(n-n_l)a_l(n)\cos(2\pi f_l(n-n_l)) \qquad (2)$$

where $a_l(n)$ is the amplitude, f_l is the frequency and the term $\prod_{N_l}$ is referred as a box function and defined as

$$\prod_{N_l}(n)=1 \qquad 0\le n\le (N_l-1)$$
$$=0 \qquad \text{elsewhere} \qquad (3)$$

where N_l indicates the length of the box function. The various components of heart sound can be shown graphically as in Figure 1.

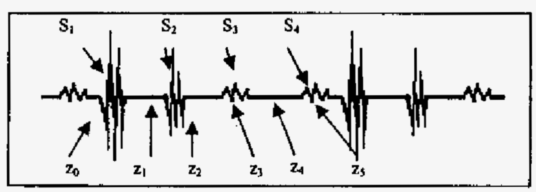


Figure 1 Diagram to illustrate the individual components of heart sounds.

Groups of simulated heart sound that shall be analyzed are listed as below

1 Normal S_1 and S_2 (NH)
2 Mitral Regurgitation (MR)
3 Mitral Stenosis (MS)
4 Aortic Regurgitation (AR)
5 Aortic Stenosis (MS)
6 Quadruple Rhythm (QR)
7 S_4 and S_3 Gallop (S4nS3G)
8 S_3 Gallop (S3G)
9 Mid-to-Late Systolic Click (MSC)
10 Patent Ductus Arteriosus (PDA)

III. TIME-FREQUENCY DISTRIBUTION

A. Generalized Bilinear Class Of Time-Frequency Distribution

The bilinear class of time-frequency distribution can be defined as follows [2]

$$\rho_z(t,f)=\int_{-\infty}^{\infty} G(t,\tau) \underset{(t)}{*} K_z(t,\tau)\exp(-j2\pi f\tau)d\tau \tag{4}$$

where $G(t,\tau)$ is the time-lag kernel function and $K_z(t,\tau)$ is the bilinear product of analytic signal $z(t)$. $K_z(t,\tau)$ can be defined as

$$K_z(t,f)=z\left(t+\frac{1}{2}\tau\right)z^*\left(t-\frac{1}{2}\tau\right) \tag{5}$$

where z^* denotes the complex conjugate of the analytical signal of interest.

B. Wigner-Ville Distribution

Setting the time-lag kernel equal to 1, the time-frequency distribution will be recognized as Wigner-Ville distribution (WVD), $W_z(t,f)$

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

where τ is lag in time. The unity kernel of Wigner-Ville distribution preserves both the auto-terms and cross-terms of the signal.

C. Windowed Wigner-Ville Distribution

Defining the kernel function a separable kernel, $G(t,\tau)$

$$G(t,\tau)=h(t)g(\tau) \tag{7}$$

where $h(t)$ defined as a delta function and Equation (7) will be

$$G(t,\tau)=\delta(t)g(\tau) \tag{8}$$

Thus, the time-frequency distribution of windowed WVD will be define as

$$W_{z,w}(t,f)=\int_{-\infty}^{\infty} g(\tau)\cdot z\left(t+\frac{1}{2}\tau\right)z^*\left(t-\frac{1}{2}\tau\right)\exp(-j2\pi f\tau)d\tau \tag{9}$$

where $g(\tau)$ is defined as

$$\begin{aligned} g(\tau)&\neq 0 \qquad \text{for } -\frac{T_w}{2}<\tau<\frac{T_w}{2} \\ &=0 \qquad \text{elsewhere} \end{aligned} \tag{10}$$

where T_w is the window width in the time-lag domain. Any recognized window function such as the rectangular, Hamming or Hanning window can be applied in this WWVD.

D. Smooth Windowed Wigner-Ville Distribution

In order to generate the smooth windowed WVD (SWWVD), the kernel function will be defined as

$$G(t,\tau)=g(t)g(\tau) \tag{11}$$

where $g(t)$ is the smooth function. In this research, the raised-cosine pulse has been chosen to be the smooth function, where $g(t)$ is defined as

$$\begin{aligned} g(t)&=1-\cos\left(\frac{\pi t}{T_{sm}}\right) \qquad 0<t<T_{sm} \\ &=0 \qquad \text{elsewhere} \end{aligned} \tag{12}$$

where T_{sm} is the time spread that controls the suppression of the cross-terms [10]. Thus, the time-frequency distribution of SWWVD is shown as below

$$\begin{aligned} W_{z,sw}(t,f)=\int_{-\infty}^{\infty} g(t)\underset{(t)}{*}\left[g(\tau)z\left(t+\frac{1}{2}\tau\right)z^*\left(t-\frac{1}{2}\tau\right)\right. \\ \left.\times\exp(-j2\pi f\tau)\right]d\tau \end{aligned} \tag{13}$$

In conclusion, this study focused on improving the Wigner-Ville distribution by modifying the kernel function in order to suppress the cross-terms while maintaining the time-frequency resolution in time-frequency representation.

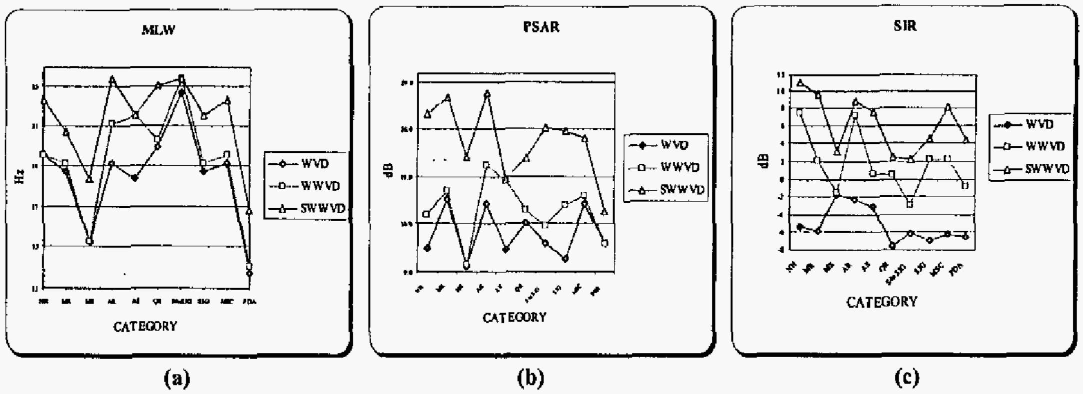


Figure 2 Comparison of performance measure (a) mainlobe width (MLW) (b) peak-to-sidelobe average ratio (PSAR) (c) signal-to-interference ratio (SIR) using WVD, WWVD and SWWVD based on ten groups of simulated heart sound.

E. Parameter Determination of WWVD and SWWVD

Since WVD had poor performance when applied to multi component signals by generating cross-terms in time-frequency plane, thus WWVD and SWWVD have to adjust their parameter to eliminate the cross-terms and improve time-frequency representation [10]. In WWVD, the parameter of T_w needs to be adjusted to remove the time oscillation that generates the cross-term in time-frequency plane. The T_w can be calculated by using the smallest time duration of signal S_1 or S_2 in time-domain based on Equation (2).

Whilst in SWWVD, the raised-cosine pulse has been chosen as the time-smooth function to smooth and remove time oscillations in the bilinear product by setting the parameter of T_{sm}. The time-smooth function will acts as a time-domain filter and remove the cross-terms in time-frequency plane by setting the T_{sm} as

$$T_{sm} \geq \frac{3}{2|f_1 - f_0|} \qquad (14)$$

where f_1 and f_0 is the highest and lowest frequency component exist in signal respectively. Thus, the SWWVD can further eliminate the cross-terms by setting the most applicable T_{sm}.

III. PERFORMANCE MEASURE

In order to determine the accuracy of time-frequency representation, a set of performance measures were designed. This can be done by analyzing the representation of the signal using mainlobe width (MLW), peak-to-sidelobe average ratio (PSAR) and signal-to-interference ratio (SIR).

Parameter MLW represents the sharpness of the time-frequency representation that is measured at 50% of the highest peak at S_1 spectrum energy. The lower value is desired since it shows the sharpness of representation. It can quantify the smearing effects of time-frequency distribution for the heart sounds and murmurs.

Whilst parameter PSAR and SIR determines level of interference due to cross-terms exist in time-frequency representation. A high ratio means less interference such as presence of cross-terms. The ratios is as follows

$$\text{PSAR (dB)} = 10 \log_{10} \frac{\text{Peak of the energy spectrum}}{\text{Average sidelobe level}} \qquad (15)$$

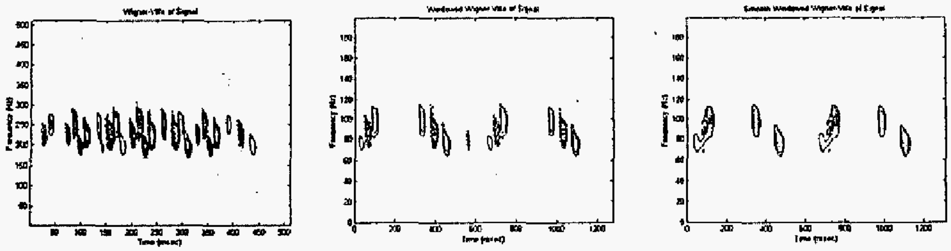
$$\text{SIR (dB)} = 10 \log_{10} \frac{\text{Total energy of } S_1, S_2, S_3, S_4}{\text{Total energy of interferences (others than } S_1, S_2, S_3, S_4)} \qquad (16)$$

Parameter SIR is the most important comparison measure compared to MLW and PSAR as it can determine the techniques which best suppressed the cross-terms. 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 the inaccurate interpretation of the true signal characteristic.

IV. RESULTS

A set of simulated heart sounds and murmurs consists of ten groups define in Section II are tested using Wigner-Ville distribution (WVD), windowed Wigner-Ville distribution (WWVD) and smooth windowed Wigner-Ville distribution (SWWVD). The performance of applied methods is measured by analyzing the representation of selected signals using mainlobe width (MLW), peak-to-sidelobe average ratio (PSAR) and signal-to-interference ratio (SIR).

The result is summarized in Figure 2 where the performance for each method is shown. The lower MLW determines the sharpness of the signal while the higher



(a) (b) (c)

Figure 3 Time-frequency representation using (a) WVD (b) WWVD (c) SWWVD of quadruple rhythm heart sound.

PSAR and SIR showing higher elimination of cross-terms and interference sidelobes. Based on the result, the correct setting of T_{sm} and T_w will perform the best of time-frequency representation.

Even though SWWVD shown the best performance by having the least interference occurred based on PSAR and SIR, the signal may have some smearing effect by having a higher MLW for most of the signal. However, the main interest of research is to represent the signals in the most accurate time-frequency representation. 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.

The example of time-frequency representation using WVD, WWVD and SWWVD for quadruple rhythm is shown in Figure 3. It is clearly shown that SWWVD provide the least interference existed due to cross-terms based on this worst case of heart sound signal. The time-smooth function successfully eliminates the amount of interference by setting the correct parameter. The analysis on simulated heart sound is important as a guidance to predetermine the characteristic of real heart sound.

V. CONCLUSIONS

Due to its time-varying characteristics of heart sounds and murmurs, time-frequency distribution is the most appropriate method to be chosen. The interference due to existence of cross-terms in WVD makes the distribution unable to display the correct time-frequency representation of heart sound. Thus, WWVD and SWWVD is the enhancement to overcome the problem faced by WVD; by setting the suitable parameter. The accuracy of time-frequency representation has been measured and compared based on MLW, PSAR and SIR; resulting SWWVD proved to be the most accurate time-frequency representation based on PSAR and SIR.

VI. REFERENCES

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