TIME-FREQUENCY ANALYSIS AND CLASSIFICATION OF HEART SOUNDS AND MURMURS

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For my family, that special 'One' and friends...

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ABSTRACT

Heart sounds and murmurs are time-varying and non-stationary signals. It can show the difference between normal heart and pathological heart murmur. The signal gathered from heart auscultation and phonocardiogram do not provide permanent record of examination result for future evaluation. In addition, the auscultation needs a skilled physician to determine the heart condition correctly. Time-frequency distribution (TFD) is a method that can represent non-stationary and time-varying signals. Contrast to time-domain or frequency-domain, TFD is able to show the variation in the frequency content of the signal with time. In this study, the selected TFD for analysis purposes are the Wigner-Ville distribution (WVD), windowed Wigner-Ville distribution (WWVD) and smooth windowed Wigner-Ville distribution (SWWVD). The main contribution is to determine the distribution that accurately shows the time-frequency representation of heart sounds and murmurs. Comparison is made based on the mainlobe width (MLW), peak-to-sidelobe average ratio (PSAR) and signal-to-interference ratio (SIR). In general, the SWWVD shows the most accurate time-frequency representation based on the SIR which achieved 16.40 dB for normal heart compared to -4.82 dB using the WVD. From the time-frequency representation, a further operation of signal detection using the Moyal's formula can be applied. The Moyal's formula is used to classify the murmurs in the presence of noise. On the average, time-frequency classification performs better over the time-domain correlation by -9.94 dB of noise power added for all signal used. This is mainly due to the non-stationarity of the signal which is good to be analyzed in TFD.

ABSTRAK

Degupan dan desiran jantung merupakan isyarat berubah dengan masa dan tidak pegun. Isyarat ini mampu menunjukkan perbezaan di antara bunyi jantung yang normal dengan abnormal. Isyarat yang diambil melalui stetoskop ataupun mesin *phonocardiogram* tidak berupaya untuk disimpan bagi kegunaan masa depan. Tambahan pula, pendengaran melalui stetoskop memerlukan kepakaran yang tinggi dan pengalaman luas bagi menentukan penyakit jantung yang sebenar. Taburan masa-frekuensi merupakan satu kaedah bagi menganalisis isyarat yang berubah dengan masa dan tidak pegun. Bertentangan dengan domain masa atau domain frekuensi, taburan masa-frekuensi mampu menunjukkan variasi kandungan frekuensi mengikut perubahan masa. Kajian ini akan menggunakan teknik terpilih iaitu taburan *Wigner-Ville* (WVD), taburan *windowed Wigner-Ville* (WWVD) dan taburan *smooth windowed Wigner-Ville* (SWWVD). Asas penyelidikan ini adalah untuk menentukan teknik taburan yang paling tepat dalam memaparkan isyarat degupan dan desiran jantung dalam paparan masa-frekuensi. Perbandingan dilakukan berdasarkan kelebaran cuping utama, nisbah puncak cuping utama kepada purata ketinggian cuping sisi dan nisbah tenaga isyarat kepada tenaga hingar. Secara am, taburan SWWVD merupakan paparan masa-frekuensi yang paling tepat berdasarkan nisbah tenaga isyarat kepada tenaga hingar apabila mencapai 16.40 dB bagi degupan normal berbanding -4.82 dB dengan menggunakan WVD. Daripada paparan masa-frekuensi bagi isyarat tersebut, operasi selanjutnya melibatkan penggunaan formula Moyal untuk tujuan pengkelasan boleh diadaptasikan. Formula Moyal diguna untuk mengkelaskan isyarat desiran dengan kehadiran gangguan hingar. Secara purata, kaedah pengkelasan korelasi domain masa-frekuensi menunjukkan prestasi yang lebih baik berbanding pengkelasan korelasi domain masa dengan perbezaan kuasa hingar sebanyak –9.94 dB bagi semua isyarat yang digunakan. Ini disebabkan spesifikasi isyarat degupan dan desiran jantung yang tidak pegun lebih baik dianalisis menggunakan taburan masa-frekuensi.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

$\prod_{N_i}$	-	box function for individual component of signals
σ	-	controller parameter for EKD
σ^2	-	variance
α	-	frequency law
$a(n)$	-	amplitude of discrete-time signal
$\delta(t)$	-	delta function
$E(t_0)$	-	signal energy
f	-	frequency
$\|f_1 - f_0\|$	-	bandwidth of the signal
$g(\tau)$	-	lag window function
$g(m)$	-	lag-window function
$g(v,\tau)$	-	Doppler-lag kernel
$G(t,\tau)$	-	time-lag kernel function
$h(t)$	-	window or filter function
$H[\ldots]$	-	Hilbert transform
H_0	-	null hypothesis
H_1	-	alternative hypothesis
k	-	gain
$K(t,\tau)$	-	bilinear product function
$L(y)$	-	detection rule or likelihood ratio
$m(t)$	-	output of white noise
η	-	threshold
n	-	samples

$n(t)$	-	noise function
N	-	discrete sample length
N_0	-	spectral density of white noise
N_p	-	duration period of discrete-time signal
N_{sm}	-	discrete length of time-smooth function
N_w	-	discrete window width
$\rho(.....)$	-	joint density function
$\rho_z(t,f)$	-	continuous time-frequency distribution function
$P(...)$	-	joint probability mass function
P_I	-	type I error
P_{II}	-	type II error
P_e	-	probability of error
P_F	-	probability of error – false alarm
P_M	-	probability of error – miss
$S_{xx}(f)$	-	continuous-time power spectrum
$S_{xx}(k)$	-	discrete-time power spectrum
t_0	-	time to be selected
T	-	continuous sample length
T_s	-	sampling duration
T_{sm}	-	continuous length of time-smooth function
T_w	-	continuous window width
$W(n,k)$	-	discrete-time distribution function
$\bar{x}$	-	sample mean
$\overline{X}$	-	function mean
$x(t)$	-	sample function
$X(t)$	-	random signal
$y(t)$	-	output or observed signal function
$Y_0......Y_n$	-	regions in observation space
$z(n)$	-	discrete-time complex signal
$z(t)$	-	continuous-time complex signal
$z^*(t)$	-	complex conjugate of continuous-time complex signal

LIST OF ABBREVIATIONS

AR	-	Autoregressive model
AV	-	Atrioventricular node
CW	-	Continuous-wave
DFT	-	Discrete Fourier Transform
ECG	-	Electrocardiogram
EKD	-	Exponential Kernel Distribution
FFT	-	Fast Fourier Transform
FM	-	Frequency Modulation
Hz	-	Hertz
HUKM	-	Hospital Universiti Kebangsaan Malaysia
mm Hg	-	millimetre mercury (pressure measurement)
ms	-	millisecond
ms^{-1}	-	meter per second
MA	-	Moving Average model
MAP	-	Maximum *a* posteriori probability
MLW	-	Mainlobe Width
PCG	-	Phonocardiogram
PSAR	-	Peak-to-Sidelobe Average Ratio
PW	-	Pulsed-wave
S_1	-	First heart sound
S_2	-	Second heart sound
S_3	-	Third heart sound
S_4	-	Fourth heart sound
SA	-	Sinoatrial node
SIR	-	Signal-to-Interference Ratio

SNR	-	Signal-to-Noise Ratio
SWWVD	-	Smooth Windowed Wigner-Ville Distribution
WD	-	Wigner Distribution
WVD	-	Wigner-Ville Distribution
WWVD	-	Windowed Wigner-Ville Distribution

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

1.1 Introduction

Auscultation is one of the techniques to determine the condition of heart by using the stethoscope. However, interpretation and diagnosis based on auscultation is subjective due to the listening skills, experiences and hearing ability of the physicians. Thus, it is essential to develop a heart diagnostic system to assist a physician and to be used as a fundamental tool before referring patients to a specialist.

Various techniques have been developed to analyze the heart sounds and murmurs. However, this study will explore the time-frequency distribution to analyze the temporal behavior of the signal. Presently, there is no standard method to classify the heart sounds and murmurs [Chung-Hsien Wu *et al*, 1995]. Classical detection and classification proves to be optimal achievement if the *a* priori information of the signals is available. Thus, time-frequency correlations are evaluated as an alternative to the time-domain classification for heart sounds and murmurs.

1.2 Objectives

There are several features of the research that should be considered and the main objectives are

i) To understand the variability of heart sound and murmurs.

ii) To evaluate time-frequency distribution as an analysis method with a focus on Wigner-Ville distribution (WVD), windowed Wigner-Ville distribution (WWVD) and smooth windowed Wigner-Ville distribution (SWWVD).

iii) To compare the time-frequency representation of heart sounds and murmurs using various time-frequency distributions based on a set of performance measures.

iv) To classify the obtained time-frequency representation of heart sounds and murmurs using the classical detection and classification of matched filter and time-frequency correlation.

1.3 Scope of Work

Heart sounds and murmurs will be analyzed and classified using time-frequency analysis and classification methodology. However, there exist numerous methods that can be used in analyzing and classifying heart sounds. This research focuses on several points as follows

i) Analyzing the various pattern of heart sounds and murmurs with a selection of ten groups of heart sounds. This selection is considerably adequate for analysis purposes ranging from normal heart to heart murmurs. These selective groups of heart sounds are able to show the heart disease pattern based on heart sounds and murmurs. Besides that, detection of starting point of first heart sound (S_1) and second heart sound (S_2) in real data of heart sounds and murmurs is difficult to accomplish. This is due to lack of the electrocardiogram (ECG) implementation which the QRS peak can determine the existence of S_1 in heart sounds. Even medical diagnosis will refer to ECG for determination of S_1 and S_2. On the other hand, the detection of S_1 and S_2 existence real data of heart sounds and murmurs are not the objective of this research. This research just required to represent the heart sounds and murmurs in time-frequency representation accurately. Thus, the S_1 and S_2 existence will be determined based on general practice since the duration of diastolic cycle shows a longer period than systolic.

ii) Time-frequency analysis using the generalized bilinear class of time-frequency distribution will be discussed. Even though spectrogram is one of the popular tool to analyze time-varying and non-stationary signal, this method is proved to be low in time-frequency resolution [Boashash, 1992]. In addition, heart sounds analysis using spectrogram has already been done by Zaiton Sharif (2001). Thus, WVD has been selected since its distribution is high in time-frequency resolution. However, application of Wigner-Ville distribution suffers from the cross-terms problem. This can be overcome by using exponential kernel distribution, WWVD and SWWVD.

iii) Usually research analysis will be resolved by a set of parameter of features extraction. However, this research only focused on determining the most suitable time-frequency distribution to accurately represent the heart sounds and murmurs in time-frequency representation by using mainlobe width, peak-to-sidelobe average ratio and signal-to-interference ratio.

iv) Since signal estimation is not the interest of this research, popular classification tools that needs feature extraction such as neural network and ruled-based method are excluded from this research. This study will only focus on the classical classification methodology approved to achieve optimal performance.

1.4 Problem Statement

The study of cardiac signal processing has a long history but the majority of interest has centered on the electrocardiography (ECG). However this study would focus on the analysis of phonocardiography (PCG) signals, i.e. heart sounds and murmurs using time-frequency distribution.

Heart sound can be heard physically by auscultation using a stethoscope when the main heart valves closed. However, the auscultation is a very subjective technique because the records provided could be interpreted in several ways depending on how the physicians interpret the sounds. Thus, it is important to capture the signal of heart sounds and murmurs and analyze it using time-frequency method. This is mainly because the heart sounds and murmurs are non-stationary and time-varying signals [Cohen, 1995]. If a direct application of Fourier transforms being used, some of the frequency content of the heart sounds may be lost. In addition, any abnormal sounds in heart sounds and murmurs will indicate a percentage having valvular heart problems.

1.6 Research Methodology

This research consists of several steps to achieve the objectives of the research

i) Literature review

Understanding the behavior of heart sounds and murmurs will give an overview explanatory to the time-frequency representation of heart sounds and murmurs. A review on the fundamental and current analysis on heart sounds and murmurs will specify which method is applicable for analysis purposes to heart sounds and murmurs. The methodology and contribution of time-frequency analysis and classification will show current work using these methods. This procedure will help in justifying the correct path of analysis using the applied methods. Thus, this research would be a contribution to the heart sounds and murmurs analysis and gives a broader view to the application of time-frequency distribution.

ii) Data collection

A database of 102 types of simulated heart sounds and murmurs is used for this study. This database was used to train the medical practitioner. Real data of heart sounds and murmurs were collected from Hospital Universiti Kebangsaan Malaysia (HUKM). However, the variation of collected signals is limited. Nevertheless, this research only desired to determine which distribution will represent real heart sounds accurately in time-frequency plane. Thus, a small amount of data is sufficient enough to do the analysis on them. To differentiate between simulated and real data, 'x…' will represent the simulated heart sounds whilst 'p…' will represent the real data of heart sounds.

iii) Data analysis

Time-frequency distribution of Wigner-Ville distribution, windowed Wigner-Ville distribution and smooth windowed Wigner-Ville distribution will be used for signal analysis. In addition, the exponential kernel distribution will be additional method to be compared with these selective methods. The exponential kernel distribution has been chosen due to its popularity and capability to overcome the weaknesses in Wigner-Ville distribution. Whilst for classification based on time-frequency correlation will only be implemented on the smooth windowed Wigner-Ville distribution since this method achieve the most accurate representation of heart sounds and murmurs.

iv) Computation platform

All computation and analysis are done based on MATLAB software package running on a personal computer with Windows 98 and XP operating system.

(v) Thesis writing

Writing up a report based on the results and explanations will be the final task in this research. This task will give the overall view of the research background, outcomes and contributions for heart sounds and murmurs signals specializing in time-frequency analysis.

1.5 Research Contribution

There are many other researcher works on the heart sounds and murmurs signal using time-frequency distribution such as White *et al*, (1996), El-Asir *et al*, (1996) and Noponen *et al*, (2000) . However, they did not focus on one method and improve it to be a suitable method to analyze the heart sounds and murmurs. As for this research, WVD has been selected to analyze the heart sounds and murmurs signals. The cross-term problem in WVD can be overcome using WWVD and SWWVD. From the time-frequency representation, a further operation of signal detection using the Moyal's formula can be applied and compared to the classical time-domain correlation classification.

1.6 Organisation of Thesis

The overall view of the research will be covered in Chapter I. Chapter II will review on heart anatomy and terminology used in heart diseases and followed by a further description on the background and recent development involve with heart sounds and murmurs corresponding with time-frequency analysis and classification methodology. The analysis and classification providing the theory of each application, parameter justification and results with its explanation will be presented in Chapter III and IV. This thesis will be concluded in Chapter V with some recommendations for future research.

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