HEART MURMUR DETECTION AND ANALYSIS USING MULTIPOINT AUSCULTATION SYSTEM

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requirements for the award of the degree of
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Dedicated to my beloved wife Azlin Abd Jamil, my beloved children, Dania Sofea, Danny Iskandar, Daniel Akashah and Diana Maisara, and my beloved father, mother, brothers, sisters & friends.

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ABSTRACT

The study of phonocardiogram (PCG) in diagnosing valvular heart disease has gathered increasing attention over the past few years. Heart sound auscultation is performed at the primary care center by physician and the results are subjected to the skills and hearing ability. This has caused unnecessary referral and send home subject with potential heart disease. This issue has led to the establishment of standardized and computerized system to analyze the heart sound. This thesis investigates the optimal approach in establishing a reliable system to acquire and process heart sound to differentiate between normal and abnormal pattern. Previous studies are based on the analysis using heart sound that is recorded from single stethoscope which provides limited information regarding the heart disease. In this study, the recording based on four stethoscopes is used to record sound from four different valves with optimized analog instrumentation design. Beamforming algorithm is utilized to localize the actual source of the disease sound from all of the four recorded sound by focusing with respect to the angle of arrival of the desired disease signature. It is then followed by the implementation of Time Frequency (TF) algorithm with optimal Extended Modified B-Distribution (EMBD) kernel to suppress noises, analyze and represent the features. The experiments were conducted utilizing PCG signal that was recorded from real subject from Hospital Sultanah Aminah Johor Bahru. Each subject was screened by an echocardiogram machine. The disease was confirmed by cardiologist before the PCG recording procedure was performed. The result shows significant improvement in the quality of information that is preserved in the beamformed signal. The suggested framework is able to improve the heart murmur detection rate up to 95%. In conclusion, the localization of the exact location of the diseased sound has helped to improve the disease detection accuracy based on multi-point heart sound diagnostic system.

ABSTRAK

Kajian tentang bunyi degupan jantung untuk menganalisa penyakit jantung telah mendapat perhatian yang semakin meningkat sejak beberapa tahun yang lalu. Pengambilan bunyi jantung dilakukan di pusat penjagaan kesihatan oleh ahli fisiologi dan keputusan analisa adalah subjektif mengikut tahap kemahiran dan pendengaran ahli fisiologi tersebut. Keadaan ini menyebabkan pesakit yang tidak mempunyai penyakit dirujuk kepada pakar dan pesakit yang berpotensi berpenyakit dihantar pulang. Isu ini telah membawa kepada pengwujudan sistem berkomputer yang selaras untuk menganalisa isyarat bunyi jantung. Tesis ini mencari kaedah yang optima bagi mewujudkan sistem yang berkebolehpercayaan yang tinggi untuk memproses isyarat bunyi jantung untuk membezakan bunyi jantung normal dan tidak normal. Kajian sebelum ini menunjukkan pelbagai eksperimen telah dilakukan tetapi hanya berdasarkan bunyi yang dirakam dari satu lokasi dan mempunyai maklumat yang terhad. Kajian ini mencadangkan rakaman isyarat menggunakan sehingga empat stetoskop dengan rekabentuk instrumentasi yang optima. Kaedah pembentuk-rasuk digunakan untuk mengenalpasti sumber bunyi asal dengan memfokuskan kepada arah bunyi jantung. Ianya kemudian diikuti oleh penggunaan teknik frekuensi-masa menggunakan algoritma modifikasi *B-Distribution* lanjutan untuk mengurangkan hingar, menganalisa isyarat dan mewakilkan ciri penting isyarat. Eksperimen dijalankan menggunakan data dari Hospital Sultanah Aminah Johor Bahru. Setiap subjek diperiksa terlebih dahulu menggunakan mesin *echocardiograph*. Jenis penyakit disahkan dengan bantuan pakar jantung. Hasil kajian mendapati kualiti isyarat bunyi menjadi lebih baik selepas di proses oleh teknik pembentuk-rasuk. Keseluruhan rangka kerja ini mempu meningkatkan keupayaan mengecam bunyi desiran jantung sehingga 95%. Kesimpulannya, kebolehan menentukan sumber bunyi yang tepat telah membantu meningkatkan ketepatan pengesanan bunyi jantung berdasarkan sistem diagnostik isyarat jantung pelbagai titik.

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LIST OF ABBREVIATIONS

A2	-	Aortic Valve Closure Sound
ADC	-	Analog to Digital Converter
AI	-	Aortic Insufficiency
ANN	-	Artificial Neural Network
CHF	-	Coronary Heart Failure
CI	-	Cochlear Implant
CMRR	-	Common Mode Rejection Ratio
CWT	-	Continuous Wavelet Transform
DFT	-	Discrete Fourier Transform
DSBF	-	Delay and Sum Beamforming
DTW	-	Dynamic Time Warping
E	-	Energy
ECG	-	Electrocardiogram
EMD	-	Empirical Mode Decomposition
EMBD	-	Extended Modified B-Distribution
FFT	-	Fast Fourier Transform
GP	-	General Practitioner
HA	-	Hearing Aid
HMM	-	Hidden Markov Models
ICS	-	Intercostal Space
IDFT	-	Inverse Discrete Fourier Transform
LPC	-	Linear Predictive Coding
LPCC	-	Linear Predictive Coding Cepstrum
LSB	-	Left Sternal Border
M1	-	Mitral Valve Closure Sound
MR	-	Mitral Regurgitation

MS	-	Mitral Stenosis
MBD	-	Modified B-Distribution
MCE	-	Minimum classification error
MFCC	-	Mel-Frequency Cepstral Coefficients
MFPC	-	Mel-Frequency Power Cepstrum
MLP	-	Multi-Layer Perceptron
MVP	-	Mitral Valve Prolapse
NN	-	Neural Network
OS	-	Opening Snap
P2	-	Pulmonic valve closure sound
PCG	-	Phonocardiogram
PLP	-	Perceptual Linear Prediction
PR	-	Pulmonary Regurgitation
PS	-	Pulmonary Stenosis
PVWD	-	Pseudo Wigner Ville Distribution
RSB	-	Right Sternal Border
S1	-	First Heart Sound
S2	-	Second Heart Sound
S3	-	Third Heart Sound
S4	-	Fourth Heart Sound
SA	-	Sinus Atria
SNR	-	Signal to Noise Ratio
STFT	-	Short Time Fourier Transform
SVM	-	Support Vector Machine
T1	-	Tricuspid Valve Closure Sound
TF	-	Time-Frequency
TFD	-	Time-Frequency Distribution
TR	-	Tricuspid Regurgitation
USB	-	Universal Serial Bus
VSD	-	Ventricular Septal Defect
WT	-	Wavelet Transform

LIST OF SYMBOLS

Δ_m	-	Delay of the m[th] sthethoscope
$\gamma_m(i)$	-	Scalar representation of stethoscope amplitude
τ	-	Signal delay
$S(\omega)$	-	Source signal from stethoscope
$Z(\omega,\theta)$	-	Signal mixture of all stethoscopes
$H(\omega,\theta)$	-	Transfer function for source signal
$z(t)$	-	Time domain representative of signal
$E(t)$	-	Energy representative of signal
$S(f)$	-	Frequency domain representation of signal
$\rho(t, f)$	-	Time frequency representation of signal
$G(t,\tau)$	-	Time lag kernel
$g(v, \tau)$	-	Doppler lag kernel function
β	-	Smoothing variable for time-frequency

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CHAPTER 1

INTRODUCTION

1.1 Introduction.

Heart disease is the number one killer disease in most countries in the world (Nichols M., 2014). The statistic shows significant increment in mortality rate each year. Regardless of the causes, most fatality is caused by the inability to detect this disease at the early stage (Michael S., 2006). Detection at the earlier stage could save many lives and able to reduce the treatment cost tremendously.

Human heart exhibits a plethora of information regarding its health status and working condition via its electrical signal known as electrocardiogram (ECG). The acoustic signal generated is known as phonocardiogram (PCG) or heart sound. The ECG is an electrical impulse originating from Sinoatrial (SA) node as an effect of polarization and depolarization of heart tissue (Pipberger *et al.*, 1962). This electrical impulse initiates the working mechanism of blood pumping activity, which open and close four valves in the heart and produces the PCG.

ECG has been used for more than a century in diagnosing heart disease (Pipberger *et al.*, 1962). The information contain in ECG signal is more related to the heart tissue conduction issues and the pumping regulations of the valves. However it does not describe the pumping capability of each valve, the condition of each valve and the overall efficiency of the heart. Since heart sound is capable in providing such information, it has been used as a primary screening tool together with ECG when diagnosing patients with suspected heart disease. In general practice, a physician will perform heart sound auscultation before recommending ECG screening. This procedure makes complete sense to examine the valve first then ECG on the basis that ECG is the one which regulates the valves operation. Any discrepancy on the valve operation may possibly be caused by the ECG.

1.2 The Organization of the Thesis.

This thesis is divided into 6 chapters. Chapter 1 introduces the issues and related motivational element, which drives the need to perform this research. It also covers the research objectives as well as outlining the research limitation, bridging the research gap and scope. Chapter 2 describes the literature review on anatomy of heart sound and it's relation to heart disease. The significant heart sound signatures of each disease are explained which is important in extracting unique features. It is then followed by a review of heart sound analysis. A number of heart disease detection methods are elaborated in terms of its strength and weakness and how the proposed method emerged. Chapter 3 describes the design and development of 5 channels acquisition apparatus that is used in this research. Chapter 4 describes the processing procedure using beamforming and time-frequency analysis. In chapter 5, the results are presented with related discussions. In chapter 6, the conclusions are presented.

1.3 Problem Background

Developing the skill of listening to the heart sound or also known as auscultation requires years of training. This ability is different from one physician to another. The outcome of interpretation is also subjective. A physician is required to be trained regularly in order to maintain the auscultation skill (Tavel, 1996 and Cheitlin *et al.*, 1997). The traditional acoustic bell shape stethoscope is capable in delivering sound from 100Hz to 200Hz. However, most of the heart sounds frequency content lies at the lower frequency band, which is as low as 50Hz to 500Hz (Abbas, 2009). This provides limited heart sound information and led to many false diagnoses resulting in numerous unnecessary referrals. The subject with heart disease is sent back when the disease is still undetected. Many studies have proven that as many as 87% of patients that are referred to cardiologists are as a result of false alarms (Pease, 2001).

Since the introduction of echocardiography technology which is based on ultrasound imaging, it has become a gold standard in heart disease verification. Here the heart sound and ECG are only used as pre-screening tools. However, the implementation is restricted by the availability of this tool due to high acquisition cost. A typical machine would cost up to 1.5 million ringgit. Only big hospitals can afford the cost and only a few units can be made available. This limited number of machine could not be a solution to help the large number of the population. As a result, the patients have to wait for the disease to be diagnosed before it is confirmed and treated. Such machine has been around for more than a decades and heart disease still remain as the number one killer disease. Therefore, echocardiogram seems not to be the solution to current scenario. A much cheaper machine with the capability to detect heart disease from the very earlier stage is critically needed. This is the main subject of this thesis in order to address the issue raised earlier in heart related disease.

Diagnosing heart disease based on heart sound will require an ECG signal to be recorded together and displayed side by side. This will help the physician to determine the beginning of a cardiac cycle. However, it is rather difficult to find a system that records heart sound and ECG simultaneously. A typical system that is available in the medical field is either to record the heart sound or just ECG. Even if there is, the principle behind the design is just for the sake of monitoring and not tailored for heart disease diagnosis. Diagnosing bio-signal requires high precision data with specialized design of analog and digital circuitry that preserve not only the information but also remove the unwanted noise which is one of the concerns of this study.

Since the heart is operated by four valves, and typically diagnosed down to each valve, it makes perfect sense to listen to all of the sound that is produced by each of these valves. Manual diagnosis performed by physician usually moves the stethoscope around the chest area to find abnormal sound produced by the valves. Once the location is identified, the physician listens closely and starts to list down several suspected diagnosis based on the sound. Automated diagnosis would require all four locations of heart sound in order to be able to locate the actual source of the problem. Recording one after another will not help to locate the problem in real-time, thus simultaneous recording is suggested in this thesis.

1.4 Problem Statement

The study is motivated by the need of solutions from the following problems:

- Lack of fast and reliable screening tool to aid the general practitioner (GP) in the primary care center (echocardiogram machine cannot be place in all the clinics).

- The use of single stethoscope to acquire heart sound provides limited information. A tool that is able to maximize the information acquisition from the beating heart, down to each and individual valve is critically needed. The multi-point auscultation device which records four sounds from four valves simultaneously with lead II ECG provides massive advantages.

- The correct information has to be extracted from the heart sound from the right location on the chest. Recording four heart sound simultaneously provides localization advantage. An efficient algorithm to pin point the exact location of murmur is necessary to improve detection.

- The general practitioner needs support in making decision. A reliable and accurate scientific presentation and visualization would be of a great advantage in deciding whether a subject should be referred or otherwise.

1.5 Objectives.

In this thesis, the research objective is concerned with identifying murmurs based on heart auscultation. In particular, the thesis focuses in the improvement of system hardware design by specific development of the multi-point bio-signal input. Various performance measures are used to evaluate the beamforming auscultation system for different aspect of performance. The results presented reflect the acceptable level of initial performance of the system. The research objectives of this study are as follows:

- To design and develop a 5 channel data acquisition system for the heart sound and ECG.
- To perform multi-point auscultation to acquire four heart sound simultaneously.
- To enhance the beamforming auscultation system for heart murmur analysis.
- To evaluate the performance of time-frequency analysis of heart murmurs.

1.6 Scope.

The main concern of this study is to design a new five channel data acquisition system for multi-point auscultation of the heart sound. The primary focus is on the design of the new hardware for signal acquisition as the available data processing system are only capable of monitoring of the heart sound. A special emphasis is placed on the evaluation methods with real microphone recording involving simultaneous heart sound signals, as opposed to computer-generated simulation.

This new design will be followed by an introduction to a new procedure to process the multi-channel heart sound which enables the localization of heart murmurs utilizing beamforming algorithm. As the beamforming is usually used in communication, this is the first time to utilize the approach in biomedical signal particularly in heart sound.

There are several approaches to time frequency analysis (Cohen *et al.*, 2001) which can be used to tackle this problem, but this does not come to focus as the extended modified B-distribution algorithm is used here. The modification is necessary to fit the nature of heart sound signal model, which is generated by vibration collected by microphone.

The scope of the study is limited on these specific issues:

- Ensure the proposed 5 channels design is capable of acquiring high quality bio-signal data, which correlates the ECG and heart sound signal.

- Utilization the beamforming algorithm to localize heart murmurs based on multi-point auscultation system.

- Utilize the extended modified B-distribution algorithm to visualize the presence of murmurs.

1.7 The Contribution of the Study.

In this research, an optimal method of accessing cardiac abnormalities is deployed. There are several major contributions that have been achieved from this research as follows:

- A new 5-channel analog front-end system is developed to ensure optimal signal quality is acquired. The consideration started from the selection of proper transducer which is sufficiently sensitive to capture the vibration of beating heart from the human chest. The instrumentation stage is carefully designed to ensure all possible information is preserved with the most minimum information losses. The selection of operational amplifier, filter, analog to digital converter, the operating voltage is discussed in detail in chapter 3.

- This study proposes multi-point auscultation technique in acquiring the heart sound. Typically, heart sound is acquired at one location and disease is determined using that information. As the acquired sound originated from four locations namely aortic valve, pulmonic valve, tricuspid valve and mitral valve, and the disease is also associated to each and individual valve, it makes perfect sense to acquire all the four sound at the same time and use the combination of all the sound as input to the processing stage. This could provide more information about the dynamic operation of all valves especially when it comes to diseases.

- A physician usually start listening to heart sound at a position and move the stethoscope around until the desired diseased sound is audible. This justify that disease sound is not always present at the location where it is originally produced which are the valves. The sound has to be mapped out around the valves. To adapt this approach, beamforming technique is used to identify the actual source of the sound. It is hypothesized that beamforming method is able to highlight the important sound from all the given four valves sound and to pin point the location that heart sound should be acquired.

- Time-frequency analysis is a popular tool to visualize signal content in term of energy, time and frequency. It is usually derived from communication research and application. Time frequency analysis utilizing B-distribution algorithm is modified to fit medical application. This could provide an improved presentation of heart sound and murmur.

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