

FEATURES EXTRACTION OF HEART SOUNDS USING TIME-FREQUENCY  
DISTRIBUTION AND MEL-FREQUENCY CEPSTRUM COEFFICIENT

MASNANI BT MOHAMED

UNIVERSITI TEKNOLOGI MALAYSIA



PERPUSTAKAAN UTHM



\*3000001957569\*

## UNIVERSITI TEKNOLOGI MALAYSIA

**BORANG PENGESAHAN STATUS TESIS\*\*\***

JUDUL: FEATURES EXTRACTION OF HEART SOUNDS USING TIME-FREQUENCY  
DISTRIBUTION AND MEL-FREQUENCY CEPSTRUM COEFFICIENT

SESI PENGAJIAN : 2005/2006

Saya MASNANI BT MOHAMED  
(HURUF BESAR)

mengaku membenarkan tesis (~~PSM/Sarjana/Doktor Falsafah~~)\* ini disimpan di Perpustakaan Universiti Teknologi Malaysia dengan syarat-syarat kegunaannya seperti berikut:

1. Tesis adalah hak milik Universiti Teknologi Malaysia.
2. Perpustakaan Universiti Teknologi Malaysia dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. \*\* Sila tandakan ( ✓ )

SULIT

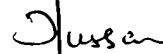
(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

TERHAD

(Mengandungi maklumat terhad yang telah ditentukan oleh organisasi / badan di mana penyelidikan dijalankan)

TIDAK TERHAD

Disahkan oleh



\_\_\_\_\_  
(TANDATANGAN PENULIS)

\_\_\_\_\_  
(TANDATANGAN PENYELIA)

Alamat Tetap:

LOT 530, KAMPUNG TENDONG,  
17030 PASIR MAS,  
KELANTAN

PROF. IR. DR. SHEIKH HUSSAIN  
BIN SHAIKH SALLEH

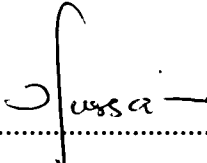
Nama Penyelia

Tarikh : 2 MAY 2006

Tarikh : 2 MAY 2006

- CATATAN :
- \* Potong yang tidak berkenaan
  - \*\* Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT atau TERHAD.
  - \*\*\* Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara penyelidikan, atau disertai bagi pengajian secara kerja kursus atau penyelidikan, atau Laporan Projek Sarjana Muda (PSM).

**“I/~~We~~\* hereby declare that I/~~we~~\* have read this thesis and in my/~~our~~\* opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Master of Engineering (Electrical-Electronic & Telecommunication)”**

Signature : .....  .....

Name of Supervisor : Prof. Ir. Dr. Sheikh Hussain Shaikh Salleh

Date : 2 May 2006

**FEATURES EXTRACTION OF HEART SOUNDS USING TIME-FREQUENCY  
DISTRIBUTION AND MEL-FREQUENCY CEPSTRUM COEFFICIENT**


**MASNANI BT MOHAMED**

**A thesis submitted in fulfillment of the  
requirements for the award of the degree of  
Master of Engineering (Electrical – Electronics & Telecommunications)**

**Faculty of Electrical Engineering  
Universiti Teknologi Malaysia**

**MAY 2006**

I declare that this thesis entitled "*Features Extraction of Heart Sounds using Time-Frequency Distribution and Mel-Frequency Cepstrum Coefficient*" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :  .....

Name : Masnani Bt. Mohamed

Date : 2 May 2006

To my beloved parents, Mohamed B. Shafie and Siti Zaharah Bt. Othman, my lovely  
brothers and sisters

## ACKNOWLEDGEMENTS

I would like to thank my supervisor, Prof. Ir. Dr. Sheikh Hussain B. Shaikh Salleh for giving me the opportunity to work on this project and always giving me lots of good advices. I would also like to thank En. Kamarulafizam B. Ismail for giving me the opportunity to cooperate with him. He has been a great source of information and his invaluable guidance and timely input has helped me throughout my Master's project. His good guidance has given me an exposure to learn a lot of new things.

A great thank to Mr. Asasul Islam for providing me the heart sounds data for my analysis. I would also like to thank all my colleagues in UTM & KUITTHO for their supports and helping me to complete this project successfully. Last but not least, a special thanks to my family especially my beloved parents, brothers and sisters who have supported me all through their life and provided constant encouragement.



## ABSTRACT

Heart sounds analysis can provide lots of information about heart condition whether it is normal or abnormal. Heart sounds signals are time-varying signals where they exhibit some degree of non-stationary. Due to these characteristics, therefore, two techniques have been proposed to analyze them. The first technique is the Time-Frequency Distribution using B-Distribution, used to resolve signal's components in the time-frequency domain and specifies the frequency components of the signal that changing over time. Another proposed technique is the Mel-Frequency Cepstrum Coefficient, used to obtain the cepstrums coefficients by resolving signal's components in the frequency domain. An experiment is presented to extract features of heart sounds using both mentioned techniques and compare their performances. Both techniques are discussed in details and tested against ideal simulations of 50 heart sound signals including normal and abnormal signals. All simulations are done using Matlab software except for MFCC where it has used the Microsoft Visual C++ software. A brief description of SVD is included to the technique using time-frequency distribution. Also, a brief description of Neural Network is used to verify and to compare the performances results of the two techniques with regard to the values of hidden node, learning rate and momentum coefficient. The results showed that performance of the TFD can be achieved up to 90% whereas MFCC is only 80%. Therefore, the TFD technique is chosen as the best technique to analyze and to extract features of the non-stationary signals such as the heart sounds signals.

## ABSTRAK

Analysis degupan jantung dapat memberikan banyak maklumat tentang keadaan jantung sama ada ia normal atau tidak. Isyarat degupan jantung sentiasa berubah-ubah, menunjukkan bahawa ia adalah isyarat yang tidak pegun. Disebabkan oleh ciri-ciri tersebut, maka dua teknik khas telah disarankan untuk menganalisisnya. Teknik yang pertama adalah menggunakan taburan masa-frekuensi (TFD) dengan jenis taburan-B (B-Distribution) untuk merungkaikan komponen-komponen isyarat dalam domain masa-frekuensi. Satu lagi teknik yang disarankan adalah menggunakan pekali Mel-Frekuensi Sepstrum (MFCC) bagi mendapatkan pekali sepstrum dengan merungkaikan komponen-komponen isyarat dalam domain frekuensi. Satu eksperimen telah dilakukan bagi mengekstrak ciri-ciri yang ada pada bunyi degupan jantung menggunakan dua teknik tersebut dan membandingkan tahap pencapaian yang diperolehi. Kedua-dua teknik telah dibincangkan dengan terperinci dan telah diuji dengan mensimulasi sebanyak 50 isyarat degupan jantung yang terdiri daripada isyarat normal dan abnormal. Kesemua teknik simulasi tersebut telah dilakukan menggunakan perisian Matlab kecuali MFCC menggunakan perisian Microsoft Visual C++. Terdapat penerangan ringkas tentang penguraian nilai tunggal (SVD) yang digunakan bersama teknik TFD. Juga disertakan huraian mengenai rangkaian saraf tiruan (ANN) untuk menentukan pencapaian kedua-dua teknik tersebut berdasarkan kepada jumlah lapisan tersembunyi, kadar latihan dan kadar momentum. Keputusan telah menunjukkan bahawa pencapaian teknik TFD telah mencecah 90% manakala teknik MFCC pula hanya 80%. Jadi, teknik TFD merupakan teknik yang terbaik untuk menganalisa dan mengekstrak ciri-ciri yang ada pada isyarat yang tidak pegun seperti isyarat degupan jantung.

## TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	<b>DECLARATION</b>	<b>ii</b>
	<b>DEDICATION</b>	<b>iii</b>
	<b>ACKNOWLEDGEMENTS</b>	<b>iv</b>
	<b>ABSTRACT</b>	<b>v</b>
	<b>ABSTRAK</b>	<b>vi</b>
	<b>TABLE OF CONTENTS</b>	<b>vii</b>
	<b>LIST OF FIGURES</b>	<b>xi</b>
	<b>LIST OF TABLE</b>	<b>xiii</b>
	<b>LIST OF ABBREVIATIONS</b>	<b>xiv</b>
	<b>LIST OF SYMBOLS</b>	<b>xvi</b>
<b>1</b>	<b>INTRODUCTION</b>	<b>1</b>
	1.1 Project Background	1
	1.2 Project Objectives	2
	1.3 Scope of Work	2
	1.4 Heart Sounds	3
	1.5 Time-Frequency Distributions	5
	1.6 Mel-Frequency Cepstrum Coefficient	6
	1.7 Thesis Outline	8

<b>2</b>	<b>LITERATURE REVIEW</b>	<b>8</b>
	2.1 Time-Frequency Representations/Distributions	8
	2.2 Cross-terms Elimination (Signal-to-Interference Ratio)	11
	2.3 B-Distribution	12
	2.4 Singular Value Decomposition	14
	2.5 Mel-Frequency Cepstrum Coefficient	14
	2.6 Neural Network	16
<b>3</b>	<b>TIME-FREQUENCY DISTRIBUTION TECHNIQUE</b>	<b>18</b>
	3.1 Introduction	18
	3.1.1 Time-Frequency Transforms	19
	3.2 General Signal Representations	20
	3.3 General Form of Time-Frequency Distributions	21
	3.3.1 Properties of the Cohen Class of Distributions	22
	3.3.2 Reduced Interference Distributions	24
	3.3.2.1 The B-Distribution	25
	3.3.2.2 The B-Distribution Kernel	26
	3.3.2.3 The B-Distribution Properties	27
	3.4 Singular Value Decomposition	28
	3.4.1 Theories	29
	3.4.2 Define Items	30
	3.4.3 Formula and Criteria	30
	3.4.4 Benefits of using SVD	31
<b>4</b>	<b>MEL-FREQUENCY CEPSTRUM COEFFICIENT TECHNIQUE</b>	<b>33</b>
	4.1 Introduction	33
	4.1.1 Discrete Fourier Transform	34
	4.1.2 Convolution	36
	4.2 Short-Term Analysis	37
	4.3 Cepstrum	38
	4.4 Mel-Frequency Cepstrum Coefficient	40

<b>5</b>	<b>NEURAL NETWORK</b>	<b>43</b>
5.1	Introduction	43
5.2	The Multilayer Perceptron	44
5.3	The Logistic Activation (Sigmoid) Function	45
5.4	The Backpropagation (BP) Algorithm	46
5.4.1	Learning Mode	47
5.4.2	The Generalized Delta Rule (G.D.R)	47
5.5	Summary of the BP Algorithm	49
5.6	Parameters for Neural Network	50
<b>6</b>	<b>METHODOLOGY</b>	<b>52</b>
6.1	Introduction	52
6.2	Methodology	53
6.2.1	Time-Frequency Distribution Technique	54
6.2.2	SVD Implementation	57
6.2.3	Mel-Frequency Cepstrum Coefficient	60
6.2.4	Verification Technique	63
<b>7</b>	<b>RESULTS AND DISCUSSION</b>	<b>65</b>
7.1	Introduction	65
7.2	Time-Frequency Distribution	66
7.2.1	B-Distribution of Normal Heart Sounds	66
7.2.2	B-Distribution of Abnormal Heart Sounds	68
7.2.3	SVD of Normal Heart Sounds	70
7.2.4	SVD of Abnormal Hart Sounds	71
7.3	Mel-Frequency Cepstrum Coefficient	73
7.3.1	MFCC of Normal Heart Sounds	73
7.3.2	MFCC of Abnormal Heart Sounds	75
7.4	Neural Network	77
7.4.1	Verification of TFD	78
7.4.2	Verification of MFCC	80
7.5	Discussion	82



<b>8</b>	<b>CONCLUSIONS AND RECOMMENDATION</b>	<b>84</b>
	8.1 Conclusions	84
	8.2 Recommendation	86
	8.2.1 Modified MFCC	87
	<b>REFERENCES</b>	<b>89</b>

## LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1	Heart sounds components	3
4.1	Discrete Fourier Transform	35
4.2	Short-term analysis	38
4.3	Example of signal magnitude spectrum	39
4.4	Cepstrum	39
4.5	Computing of Mel Cepstrum	40
4.6	Triangular filter used to compute Mel Cepstrum	41
5.1	A two-layer network	44
5.2	The architecture of a typical MLP network	44
5.3	Sigmoid activation function with different values of $c$	46
5.4	Configuration for training ANN using BP algorithm	47
5.5	Typical ANN model	48
6.1	Feature extraction techniques and verification	53
6.2	Technique using TFD/SVD	55
6.3	Technique using MFCC	60
6.4	Steps of computing MFCC	61
6.5	Steps of backpropagation algorithm	64
7.1	Normal heart sound; e.g. 1	66
7.2	Normal heart sound; e.g. 2	67
7.3	Abnormal heart sound; e.g. 1	68
7.4	Abnormal heart sound; e.g. 2	68
7.5	Abnormal heart sound; e.g. 3	69
7.6	Abnormal heart sound; e.g. 4	69

7.7	SVD of normal heart sound; e.g.1	70
7.8	SVD of normal heart sound; e.g.2	71
7.9	SVD of abnormal heart sound; e.g.1	71
7.10	SVD of abnormal heart sound; e.g.2	72
7.11	MFCC of normal heart sound; e.g.1	73
7.12	MFCC of normal heart sound; e.g.2	74
7.13	MFCC of normal heart sound; e.g.3	74
7.14	MFCC of abnormal heart sound; e.g.1	75
7.15	MFCC of abnormal heart sound; e.g.2	76
7.16	MFCC of abnormal heart sound; e.g.3	76
7.17	Verification of TFD (number of hidden neurons)	78
7.18	Verification of TFD ( learning rate )	78
7.19	Verification of TFD ( momentum coefficient )	79
7.20	Verification of MFCC ( number of hidden neurons )	80
7.21	Verification of MFCC ( learning rate )	80
7.22	Verification of MFCC ( momentum coefficient )	81
8.1	Basic structure of modified MFCC	87

**LIST OF TABLE**

<b>TABLE NO.</b>	<b>TITLE</b>	<b>PAGE</b>
7.1	Performance comparison between the TFD and MFCC	82

## ACKNOWLEDGEMENTS

I would like to thank my supervisor, Prof. Ir. Dr. Sheikh Hussain B. Shaikh Salleh for giving me the opportunity to work on this project and always giving me lots of good advices. I would also like to thank En. Kamarulafizam B. Ismail for giving me the opportunity to cooperate with him. He has been a great source of information and his invaluable guidance and timely input has helped me throughout my Master's project. His good guidance has given me an exposure to learn a lot of new things.

A great thank to Mr. Asasul Islam for providing me the heart sounds data for my analysis. I would also like to thank all my colleagues in UTM & KUITTHO for their supports and helping me to complete this project successfully. Last but not least, a special thanks to my family especially my beloved parents, brothers and sisters who have supported me all through their life and provided constant encouragement.



## ABSTRACT

Heart sounds analysis can provide lots of information about heart condition whether it is normal or abnormal. Heart sounds signals are time-varying signals where they exhibit some degree of non-stationary. Due to these characteristics, therefore, two techniques have been proposed to analyze them. The first technique is the Time-Frequency Distribution using B-Distribution, used to resolve signal's components in the time-frequency domain and specifies the frequency components of the signal that changing over time. Another proposed technique is the Mel-Frequency Cepstrum Coefficient, used to obtain the cepstrums coefficients by resolving signal's components in the frequency domain. An experiment is presented to extract features of heart sounds using both mentioned techniques and compare their performances. Both techniques are discussed in details and tested against ideal simulations of 50 heart sound signals including normal and abnormal signals. All simulations are done using Matlab software except for MFCC where it has used the Microsoft Visual C++ software. A brief description of SVD is included to the technique using time-frequency distribution. Also, a brief description of Neural Network is used to verify and to compare the performances results of the two techniques with regard to the values of hidden node, learning rate and momentum coefficient. The results showed that performance of the TFD can be achieved up to 90% whereas MFCC is only 80%. Therefore, the TFD technique is chosen as the best technique to analyze and to extract features of the non-stationary signals such as the heart sounds signals.

## ABSTRAK

Analysis degupan jantung dapat memberikan banyak maklumat tentang keadaan jantung sama ada ia normal atau tidak. Isyarat degupan jantung sentiasa berubah-ubah, menunjukkan bahawa ia adalah isyarat yang tidak pegun. Disebabkan oleh ciri-ciri tersebut, maka dua teknik khas telah disarankan untuk menganalisisnya. Teknik yang pertama adalah menggunakan taburan masa-frekuensi (TFD) dengan jenis taburan-B (B-Distribution) untuk merungkaikan komponen-komponen isyarat dalam domain masa-frekuensi. Satu lagi teknik yang disarankan adalah menggunakan pekali Mel-Frekuensi Sepstrum (MFCC) bagi mendapatkan pekali sepstrum dengan merungkaikan komponen-komponen isyarat dalam domain frekuensi. Satu eksperimen telah dilakukan bagi mengekstrak ciri-ciri yang ada pada bunyi degupan jantung menggunakan dua teknik tersebut dan membandingkan tahap pencapaian yang diperolehi. Kedua-dua teknik telah dibincangkan dengan terperinci dan telah diuji dengan mensimulasi sebanyak 50 isyarat degupan jantung yang terdiri daripada isyarat normal dan abnormal. Kesemua teknik simulasi tersebut telah dilakukan menggunakan perisian Matlab kecuali MFCC menggunakan perisian Microsoft Visual C++. Terdapat penerangan ringkas tentang penguraian nilai tunggal (SVD) yang digunakan bersama teknik TFD. Juga disertakan huraian mengenai rangkaian saraf tiruan (ANN) untuk menentukan pencapaian kedua-dua teknik tersebut berdasarkan kepada jumlah lapisan tersembunyi, kadar latihan dan kadar momentum. Keputusan telah menunjukkan bahawa pencapaian teknik TFD telah mencecah 90% manakala teknik MFCC pula hanya 80%. Jadi, teknik TFD merupakan teknik yang terbaik untuk menganalisa dan mengekstrak ciri-ciri yang ada pada isyarat yang tidak pegun seperti isyarat degupan jantung.

## TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	<b>DECLARATION</b>	<b>ii</b>
	<b>DEDICATION</b>	<b>iii</b>
	<b>ACKNOWLEDGEMENTS</b>	<b>iv</b>
	<b>ABSTRACT</b>	<b>v</b>
	<b>ABSTRAK</b>	<b>vi</b>
	<b>TABLE OF CONTENTS</b>	<b>vii</b>
	<b>LIST OF FIGURES</b>	<b>xi</b>
	<b>LIST OF TABLE</b>	<b>xiii</b>
	<b>LIST OF ABBREVIATIONS</b>	<b>xiv</b>
	<b>LIST OF SYMBOLS</b>	<b>xvi</b>
<b>1</b>	<b>INTRODUCTION</b>	<b>1</b>
	1.1 Project Background	1
	1.2 Project Objectives	2
	1.3 Scope of Work	2
	1.4 Heart Sounds	3
	1.5 Time-Frequency Distributions	5
	1.6 Mel-Frequency Cepstrum Coefficient	6
	1.7 Thesis Outline	8

<b>2</b>	<b>LITERATURE REVIEW</b>	<b>8</b>
	2.1 Time-Frequency Representations/Distributions	8
	2.2 Cross-terms Elimination (Signal-to-Interference Ratio)	11
	2.3 B-Distribution	12
	2.4 Singular Value Decomposition	14
	2.5 Mel-Frequency Cepstrum Coefficient	14
	2.6 Neural Network	16
<b>3</b>	<b>TIME-FREQUENCY DISTRIBUTION TECHNIQUE</b>	<b>18</b>
	3.1 Introduction	18
	3.1.1 Time-Frequency Transforms	19
	3.2 General Signal Representations	20
	3.3 General Form of Time-Frequency Distributions	21
	3.3.1 Properties of the Cohen Class of Distributions	22
	3.3.2 Reduced Interference Distributions	24
	3.3.2.1 The B-Distribution	25
	3.3.2.2 The B-Distribution Kernel	26
	3.3.2.3 The B-Distribution Properties	27
	3.4 Singular Value Decomposition	28
	3.4.1 Theories	29
	3.4.2 Define Items	30
	3.4.3 Formula and Criteria	30
	3.4.4 Benefits of using SVD	31
<b>4</b>	<b>MEL-FREQUENCY CEPSTRUM COEFFICIENT TECHNIQUE</b>	<b>33</b>
	4.1 Introduction	33
	4.1.1 Discrete Fourier Transform	34
	4.1.2 Convolution	36
	4.2 Short-Term Analysis	37
	4.3 Cepstrum	38
	4.4 Mel-Frequency Cepstrum Coefficient	40

<b>5</b>	<b>NEURAL NETWORK</b>	<b>43</b>
	5.1 Introduction	43
	5.2 The Multilayer Perceptron	44
	5.3 The Logistic Activation (Sigmoid) Function	45
	5.4 The Backpropagation (BP) Algorithm	46
	5.4.1 Learning Mode	47
	5.4.2 The Generalized Delta Rule (G.D.R)	47
	5.5 Summary of the BP Algorithm	49
	5.6 Parameters for Neural Network	50
<b>6</b>	<b>METHODOLOGY</b>	<b>52</b>
	6.1 Introduction	52
	6.2 Methodology	53
	6.2.1 Time-Frequency Distribution Technique	54
	6.2.2 SVD Implementation	57
	6.2.3 Mel-Frequency Cepstrum Coefficient	60
	6.2.4 Verification Technique	63
<b>7</b>	<b>RESULTS AND DISCUSSION</b>	<b>65</b>
	7.1 Introduction	65
	7.2 Time-Frequency Distribution	66
	7.2.1 B-Distribution of Normal Heart Sounds	66
	7.2.2 B-Distribution of Abnormal Heart Sounds	68
	7.2.3 SVD of Normal Heart Sounds	70
	7.2.4 SVD of Abnormal Hart Sounds	71
	7.3 Mel-Frequency Cepstrum Coefficient	73
	7.3.1 MFCC of Normal Heart Sounds	73
	7.3.2 MFCC of Abnormal Heart Sounds	75
	7.4 Neural Network	77
	7.4.1 Verification of TFD	78
	7.4.2 Verification of MFCC	80
	7.5 Discussion	82



<b>8</b>	<b>CONCLUSIONS AND RECOMMENDATION</b>	<b>84</b>
	8.1 Conclusions	84
	8.2 Recommendation	86
	8.2.1 Modified MFCC	87
	<b>REFERENCES</b>	<b>89</b>