# CLASSIFICATION OF RESPIRATORY PATHOLOGY FROM PULMONARY ACOUSTIC BASED ON RESPIRATORY CYCLE SEGMENTATION AND TWO – STAGE CLASSIFICATION

by

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## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| ANFIS | - | Adaptive Neuro-Fuzzy Inference System |
| ANN | - | Artificial Neural Network |
| ANOVA | - | Analysis of Variance |
| AR | - | Auto Regressive |
| API | - | Application Programming Interface |
| CC | - | Coarse Crackles |
| CD | - | Compact Disc |
| CDSS | - | Computerized Decision Support System |
| CHF | - | Congestive Heart Failure |
| CLS | - | Continuous Lung Sounds |
| COG | - | Center of Gravity |
| COPD | - | Chronic Obstructive Pulmonary Disease |
| CORSA | - | Computerized Respiratory Sound Analysis |
| CRF | - | Case Report Form |
| CT | - | Computer Tomography |
| DFT | - | Discrete Fourier Transform |
| DLS | - | Discontinuous Lung Sounds |
| F | - | Female |
| FC | - | Fine Crackles |
| FEV | - | Forced Expiratory Volume |

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| | | |
|---|---|---|
| FFT | - | Fast Fourier Transform |
| FIS | - | Fuzzy Inference System |
| GAL | - | Grow and Learn |
| GMM | - | Gaussian Mixture Model |
| HMM | - | Hidden Markov Model |
| ILD | - | Interstitial Lung Disease |
| IPF | - | Idiopathic Pulmonary Fibrosis |
| IPG | - | Impedance Plethysmography |
| *k* -nn | - | *k* -Nearest Neighbor |
| LVQ | - | Linear Vector Quantization |
| MARS | - | Marburg Respiratory Sounds |
| M | - | Male |
| MFCC | - | Mel Frequency Cepstral Coefficients |
| MLP | - | Multilayer Perceptron |
| N | - | Normal/Control |
| OP | - | Obstructive Pathology |
| PCA | - | Principal Component Analysis |
| R | - | Rhonchi |
| RBF | - | Radial Basis Function |
| RIP | - | Respiratory Inductive Plethysmography |
| RP | - | Restrictive Pathology |
| SD | - | Standard Deviation |
| SDK | - | Software Development Kits |

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| | | |
|---|---|---|
| SOM | - | Self Organization Maps |
| ST | - | Stockwell Transform |
| STFT | - | Short-Time Fourier Transform |
| SVM | - | Support Vector Machine |
| W | - | Wheeze |
| WA | - | Weighted Average |
| WHO | - | World Health Organization |
| WPT | - | Wavelet Packet Transform |
| WT | - | Wavelet Transform |

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# LIST OF SYMBOLS

| | | |
|---|---|---|
| Hz | - | Hertz (Unit of frequency) |
| % | - | Percentage |
| ± | - | Plus/minus |
| dB | - | Decibel (Unit of amplitude loss) |
| F - Value | - | Critical value for F - distribution |
| *p* - value | - | Probability of obtaining test statistical result |

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**Pengelasan Patologi Pernafasan daripada Isyarat Akustik Pulmonari Menggunakan Representasi berparameter dan bukan berparameter**

**ABSTRAK**

Auskultasi adalah proses mendengar bunyi dalam badan dengan menggunakan stetoskop. Proses ini memberi maklumat penting mengenai keadaan semasa bagi organ-organ dalaman seperti jantung, paru-paru dan sistem pencernaan. Auskultasi adalah kaedah yang subjektif dan cenderung untuk menjadi kurang dipercayai. Analisis bunyi pernafasan berkomputer bagaimanapun adalah lebih berkesan dan boleh dipercayai. Tesis ini membincangkan pembangunan sistem sokongan keputusan berkomputer (CDSS) untuk mengesan patologi pernafasan menggunakan isyarat akustik paru-paru. Isyarat akustik pulmonari dikumpulkan daripada 72 subjek untuk membangunkan CDSS. Dalam usaha untuk membangunkan alat CDSS, tiga kerangka metodologi yang berbeza telah dicadangkan untuk menentukan klasifikasi patologi pernafasan yang paling berkesan. Isyarat akustik paru-paru telah ditapis untuk menyingkirkan bunyi dan artifak lain diikuti oleh segmentasi kitaran pernafasan. Dalam tesis ini, segmentasi kitaran pernafasan dilakukan dengan menggunakan sistem kesimpulan Fuzzy. Ciri-ciri representasi parametrik (Mel frekuensi pekali cepstral (MFCC) dan model Auto-regresif (AR)) dan representasi bukan parametrik (paket wavelet mengubah (WPT) dan transformasi Stockwell (ST)) kemudiannya diekstrak keluar. Ciri-ciri yang diekstrak telah dikurangkan dimensinya dengan menggunakan analisis komponen utama dan analisis statistik telah dilakukan untuk menentukan tahap kepentingan vektor ciri-ciri yang diekstrak dengan menggunakan analisa ANOVA sehala. Pemerhatian menunjukkan bahawa ciri-ciri yang diekstrak secara statistik signifikan dengan $p < 0.05$. Dalam peringkat kasifikasi pelbagai pengelas bukan linear seperti k-jiran terdekat (k-nn), mesin vektor sokongan (SVM) dan mesin pembelajaran melampau (ELM) telah dilaksanakan untuk mengklasifikasikan patologi pernafasan daripada bunyi pernafasan. Dalam peringkat klasifikasi, pengelas ELM menunjukkan prestasi yang terbaik daripada pengelas k-nn dan SVM untuk semua kerangka. Keputusan eksperimen menunjukkan bahawa pengekstrakan ciri-ciri berasaskan ST dengan pengelas ELM menunjukkan prestasi yang terbaik dengan kerangka ketiga. Penggunaan ciri-ciri berasaskan ST dan pengelas ELM dengan kerangka ketiga telah disahkan menggunakan satu set data yang terdiri daripada 48 subjek dan sistem itu didapati boleh dipercayai dengan purata ketepatan klasifikasi 96.63%, 97.57% dan 98.48% dalam mengklasifikasikan (bunyi normal, bunyi paru-paru berterusan dan bunyi paru-paru tidak berterusan), (bubar dan ronchi) dan (gemercik halus dan gemercik kasar). Selepas pengesahan berjaya dibuat alat CDSS dibangunkan menggunakan ciri-ciri berasaskan ST dan pengelas ELM dengan kerangka ketiga.

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**Classification of Respiratory Pathology from Pulmonary Acoustic Signals Using Parametric and Non-Parametric Representations**

## ABSRACT

Auscultation is the process of listening to the internal sounds of the body using a stethoscope. This process provides vital information on the present state of the internal organs, such as the heart, lungs and the gastrointestinal system. Auscultation is subjective and prone to be not reliable. However computerized respiratory sound analysis is more effective and reliable. This thesis discusses the development of a computerized decision support system (CDSS) to detect respiratory pathology using pulmonary acoustic signals. The pulmonary acoustics signals were collected from 72 subjects to develop the CDSS. In order to develop the CDSS tool, three different methodological frameworks were proposed to determine the most effective classification of respiratory pathology. The recorded pulmonary acoustics signals were filtered to remove noise and other artifacts followed by respiratory cycle segmentation. In this work, the respiratory cycle segmentation is performed by using Fuzzy Inference system. Parametric (Mel-frequency cepstral coefficients (MFCC) and Auto-regressive model (AR)) and Non-parametric (wavelet packet transform (WPT) and Stockwell transform (ST)) representations of features were extracted. The features extracted were dimensionally reduced using principal component analysis and a statistical analysis was performed to determine the significance level of the feature vector using One-way ANOVA. Observations showed that the extracted features were statistically significant with $p < 0.05$. In the classification stage various non-linear classifiers such as *k*-nearest neighbor (*k*-nn), support vector machines (SVM) and extreme learning machine (ELM) were implemented to classify the respiratory pathology from respiratory sounds. In the classification, extreme learning machine performed better than *k*-nn and support vector machine classifier for all the frameworks. Experimental results showed that ST based feature extraction performed well with ELM classifier with third framework. The ST based features and ELM classifier with third framework was validated using a new set of data comprising of 48 subjects and the system was found to be reliable with mean classification accuracy of 96.63%, 97.57% and 98.48% for classifying (normal, continuous lung sounds and discontinuous lung sounds), (wheeze and rhonchi) and (fine crackles and coarse crackles) respectively. After successful validation a CDSS tool was developed using the ST based features and ELM classifier with third framework.

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# CHAPTER 1

# INTRODCTION

This chapter presents an introduction to respiratory pathology, discussion on conventional methods used for the diagnosis of respiratory pathology, drawbacks of the existing methods and the advantages of using computerized respiratory sound analysis. The main objectives of the proposed research and the organization of the thesis are also described in the following section.

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## 1.1 Research Background

Auscultation is the process of listening to the internal sounds of the body using a stethoscope. This process provides vital information on the present state of the internal organs, such as the heart, lungs and the gastrointestinal system (Chauhan et al., 2008; J. Earis, 1992). The stethoscope, which was invented by a French physician named René Théophile Hyacinth Laennec in 1816, has been used to perform auscultation for several years now (Welsby et al., 2003). The medical professionals auscultate the heart to indentify presence of heart murmurs, gallop and also to monitor the heart rate (Leatham, 1958). When listening to the lung sounds, medical professional listen for vital signs such as wheeze, rhonchi and crackles (Murphy, 1981). In auscultating the gastrointestinal system, medical professional listen for signs of bowel sounds (Craine et al., 1999). The stethoscope remains the most widely used instrument in clinical medicine. In addition, it has been an effective tool for the diagnosis of respiratory pathology for a number of years now. The auscultation process using stethoscope is inexpensive, non-invasive, and less time-consuming. This process mainly relies on the medical professional and hence requires well-trained medical professional to recognise respiratory pathology from sounds. In addition, it also depends on the hearing perception of the medical professionals for accurate diagnosis. To overcome these drawbacks computerized respiratory sound analysis was proposed in the early 1980's (Nissan et al., 1993). Computerized respiratory sound analysis deals with the analysis of respiratory sounds by applying various signal processing and machine learning algorithms.

## 1.2 Motivations of the Work

According to the World Health Organization (WHO), respiratory disorders such as chronic obstructive pulmonary disease (COPD), Asthma, pneumonia, pulmonary fibrosis and other respiratory related illness stands third as the cause of fatality throughout the world. WHO has reported 3 million fatalities due to COPD in the year 2012 (WHO, 2012). WHO also has reported that 235 million people were suffering from Asthma in 2011 (WHO, 2013a). In the case of pneumonia, 935,000 fatalities were reported by WHO in the year 2013 (WHO, 2013b). The major cause of respiratory related illness are smoking, prolonged exposure to certain toxic agents, air pollution and hereditary. Often, patients neglect consulting medical professionals at the early stages of the pathology and only seek medical attentions when the respiratory system is affected badly. By the time the respiratory abnormality is diagnosed, the damage might be irreversible. Early diagnosis and treatment can reduce the number of fatalities drastically and improve the patient's quality of life. Few major cause for fatalities due to respiratory related illness are the lack of treatment facilities and lack of medical professional in the rural areas. The methods for diagnosing respiratory related illness include auscultation, radiography techniques and pulmonary function test are very expensive and also time-consuming. Radiography techniques such as X-rays and Computer Tomography (CT) scans causes serious side effects on human body when exposed for a longer duration (Kandaswamy et al., 2004).

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Obstructive pathology cannot be easily diagnosed using the radiography technique. The pulmonary function test does not cause any serious effects however it is time-consuming, expensive and the patients need to put extra effort in some tests such as spirometry and hence it is an invasive procedure. The pulmonary function test provides additional information's such as lung volume, respiratory flow estimation and also the severity level of the pathology (Shephard et al., 1959). In spite of its advantages, the drawbacks of pulmonary function test are invasive method, expensive and time consuming method. To overcome these drawbacks, an alternative method should be developed using respiratory sound analysis to recognize the respiratory pathology. The advantages of using the computerised respiratory sound analysis include non-invasive based approach, fast diagnosis, not expensive and are more accurate. It can additionally serve as a differential diagnosis tool for medical professionals. Differential diagnosis is a process to distinguish specific disease or condition suffered by a patient or to at least eliminate any other disease or condition. This research aims to develop a Computerized Decision Support System (CDSS) to detect respiratory pathology using the respiratory sounds.

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## 1.3 Problem Statement

There are several issues related to the classification of respiratory pathology from respiratory sounds. The previous researchers have formulated unrecognized protocols and have not followed the standard computerized respiratory sound analysis (CORSA) guidelines in the data acquisition and filtering process. In the respiratory cycle segmentation, the researchers have implemented both non-acoustic approach and acoustic approach. However, the non-acoustic approaches are considered to affect the natural breathing process and hence the acoustic approaches have been implemented by the previous researcher. In the acoustic approaches, researchers have focused on particular lung auscultation point and not developed a general method which can segment the respiratory cycles of any auscultation point. The accuracy reported by the previous researcher in segmenting the respiratory cycle was also found to be low which will have an effect on the classification of respiratory pathology. In the feature extraction stage, various parametric and non-parametric algorithms were implemented by previous researcher. However the sample size also comes into consideration and hence the reported accuracies are unreliable to predict the quality of features in categorizing the respiratory pathology. In the respiratory pathology classification stage, only few previous researchers have classified most of the respiratory pathology (Wheeze, Rhoinchi, Fine Crackles, and Coarse Crackles) categories. The previous research also shows that clinical validation was not performed in any study reported earlier. The development of CDSS tool is also not reported earlier.

## 1.4 Research Objectives

This research aims to develop a CDSS tool for respiratory pathology detection using respiratory sounds, signal processing algorithms and artificial intelligence techniques. Despite the presence of various studies in literature, this work focuses on various parametric and non-parametric characteristics of respiratory sound signals in an effort to identify suitable parameters to capture the minute and hidden information from the respiratory sounds for the detection of respiratory pathology. The objectives formulated for the successful implementation of the system are as follows.

i. **To design an experimental protocol for collecting respiratory sounds using Computerized Respiratory Sound Analysis (CORSA) standard.**

   One of the main challenges in computerized respiratory sound analysis research is the acquisition of proper respiratory sound data. To develop an effective

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computerized respiratory sound analysis system, reliable data is needed. There are two prominent databases used by previous researchers: Marburg Respiratory Sounds (MARS), and R.A.L.E repository. However, the R.A.L.E repository is the only commercially available database. The MARS database was compiled using lung sound CDs that are commercially available for the training of medical professionals in auscultation. R.A.L.E repository comprises of only 70 respiratory sound recordings. However, an artificial intelligence technique requires more number of samples to train and validate the model. In this research, we intend to formulate the data acquisition protocol by the guidelines of CORSA. CORSA is the only standard guideline available for respiratory sound acquisition. CORSA is a standard developed by the European Respiratory Society which provides extensive information on respiratory sound data acquisition and processing of respiratory sounds.

ii. **To develop suitable preprocessing and respiratory cycle segmentation algorithm.**

Respiratory sounds comprises of heart sounds and other artifacts. In order to eradicate these noises suitable preprocessing technique was implemented. The preprocessing algorithm was able to effectively remove the unwanted noise while retaining the respiratory sound signals. By carefully analyzing the frequency components of the data, and removing the unnecessary spectral information, an artifact free dataset was formed. The segmentation of respiratory cycle is essential for the reason that the presence of adventitious sounds is in the inspiratory phase or the expiratory phase. The filtering technique proposed in this research will be followed as per the guidelines in CORSA. It is proposed that the segmentation of

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