



**CLASSIFICATION OF ASTHMA SEVERITY LEVELS
USING PULMONARY ACOUSTIC SIGNALS BASED
ON WHEEZE SOUND**

by

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(In the name of Allah (S.W. T), the Most Gracious and the Most Merciful)

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LIST OF ABBREVIATIONS

AAP	-	Asthma Action Plan
ACT	-	Asthma Control Test
ANN	-	Artificial Neural Network
ANOVA	-	Analysis of Variance
AR	-	Auto-Regressive
ASAP	-	French Analyse des Sons Auscultatoires
BP	-	Back-Propagation
CDSS	-	Computerized Decision Support System
COPD	-	Chronic Obstructive Pulmonary Disease
CORSA	-	Computerized Respiratory Sound Analysis
CRC	-	Clinical Research Centre
DWT	-	Discrete Wavelet Transform
DTW	-	Dynamic Time Warping
ERS	-	European Respiratory Society
FEV ₁	-	Forced Expiratory Volume at 1 second
FIS	-	Fuzzy Inference System
FT	-	Fourier Transform
FFT	-	Fast Fourier Transform
FVC	-	Forced Vital Capacity
GINA	-	Global Initiative for Asthma
GMM	-	Gaussian Mixture Model

GUI	-	Graphical User Interface
HTF	-	Hospital Tuanku Fauziah
HMM	-	Hidden Markov Model
IQR	-	Inter-Quartile Range
KNN	-	K- Nearest Neighbor
LPC	-	Linear Predictive Coefficients
NIH	-	National Institute of Health
MREC	-	Medical Research Ethical Committee
PCA	-	Principal Component analysis
PEF	-	Peak Expiratory Flow
PEFR	-	Peak Expiratory Flow Rate
PEFRt	-	Peak Expiratory Flow Rate test
PFM	-	Peak Flow Meter
PSD	-	Power Spectral Density
MFCC	-	Mel-Frequency Cepstral Coefficients
MLP	-	Multilayer Perceptron
RBF	-	Radial Basis Function
RS	-	Respiratory Signal
SD	-	Standard Deviation
STE	-	Short Time Energy
STFT	-	Short Time Frequency Transform
STM	-	Short Time Magnitude
SVD	-	Singular Value Decomposition

SVM	-	Support Vector Machine
TFDA	-	Time-Frequency Detection Analysis
TVAR	-	Time-variant Autoregressive
USA	-	United States of America
VC	-	Vital Capacity
WHO	-	World Health Organization

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Klasifikasi Paras Keparahan Asma Menggunakan Isyarat Akustik Pulmonari Berasaskan Bunyi Bubar

ABSTRAK

Asma adalah penyakit paru-paru umum yang menjejaskan kira-kira 300 juta orang di seluruh dunia. Kini, tiada penawar untuk asma, oleh itu, asas pengurusan asma adalah untuk mencapai kawalan asma yang optimum. Setiap pesakit yang terkawal perlu mempunyai 'Asthma Action Plan' (AAP). Ia melibatkan satu kertas bertulis untuk memantau dan merekodkan gejala harian asma berdasarkan 'Peak Expiratory Flow Rate' (PEFR) yang diukur menggunakan 'Peak Flow Meter' (PFM). PFM bagaimanapun tidak digunakan secara meluas kerana beberapa limitasi seperti kegunaannya yang terbatas kepada pesakit asma yang kritikal dan pesakit asma bayi, sekaligus mengurangkan keberkesanan AAP itu sendiri. Selain dari PFM, stetoskop juga digunakan dalam mendiagnosis paras keparahan asma. Walau bagaimanapun, kakitangan perubatan sahaja yang dapat mentafsir bunyi pernafasan yang diperolehi, iaitu bunyi bubar. Oleh itu, tesis ini membincangkan pembangunan 'Computerized Decision Support System' (CDSS) untuk mengklasifikasikan tahap keparahan asma menggunakan isyarat akustik pulmonari berdasarkan bunyi bubar. Sistem ini dibangunkan berdasarkan hubungan antara PEFR dan juga bunyi bubar yang telah dilaporkan oleh beberapa penyelidik terdahulu. Dalam usaha untuk membangunkan alat CDSS, dua rangka kerja telah dicadangkan untuk menentukan rangka kerja yang paling berkesan. Kedua-dua rangka kerja dibangunkan adalah berdasarkan kaedah umum dalam pemprosesan gambar/signal yang melibatkan proses pra-proses, proses pengekstrakan ciri-ciri, dan proses klasifikasi. Bagaimanapun, rangka kerja dua terdapat satu lagi proses tambahan iaitu proses segmentasi bubar. Proses segmentasi bubar yang dicadangkan mengadaptasikan kaedah 'Short Time Energy' (STE) dan 'Fuzzy Inference System' (FIS). Data yang dikumpul terlebih dahulu diproses mengikut kepada garis panduan 'Computerized Respiratory Sound Analysis' (CORSA). Ciri-ciri seperti 'Mel Frequency Cepstral Coefficients' (MFCC), 'Auto-regressive' (AR) model, ciri-ciri statistik dan ciri-ciri statistik berdasarkan STE akan diekstrak daripada data. Pengurangan dimensi ciri-ciri dengan menggunakan 'Principal Component Analysis' (PCA) dan analisis statistik ciri-ciri dilakukan dengan menggunakan ANOVA satu hala untuk menentukan aras signifikan vektor ciri-ciri tersebut. $p < 0.05$ diperolehi bagi semua ciri-ciri yang diuji dengan itu membuktikan bahawa kesemua ciri-ciri yang diekstrak adalah statistik signifikan dan dengan itu sedia untuk digunakan untuk proses pengelasan. Diperingkat klasifikasi, 'K-nearest neighbor' (KNN), 'Artificial Neural Network' (ANN) dan 'Support Vector Machine' (SVM) digunakan untuk kajian ini. Dari pemerhatian secara keseluruhan, keputusan yang diperolehi daripada rangka kerja dua menggunakan MFCC bersama KNN menunjukkan prestasi yang paling tinggi berbanding dengan model lain yang diuji dengan memperoleh 97.71% purata ketepatan. CDSS kemudiannya dibangunkan dengan menggunakan ciri MFCC bersama pengelas KNN mengikut rangka kerja dua. Alat CDSS yang dibangunkan ini boleh menjadi kaedah pilihan bagi ujian PEFR yang sangat berguna bagi pelbagai organisasi. Di hospital contohnya, ianya dapat dijadikan sebagai alat pilihan untuk mendiagnosis asma, sekaligus dapat membantu para doktor dan jururawat. Akhir sekali, bagi pesakit asma sendiri, ia boleh digunakan sebagai alat pengurusan dan diagnosis asma sendiri yang juga selamat digunakan oleh pesakit asma tahap kritikal.

Classification of Asthma Severity Levels Using Pulmonary Acoustic Signals Based On Wheeze Sound

ABSTRACT

Asthma is a common pulmonary disease that affects approximately 300 million people worldwide each year. At present, there are no cures for asthma, and therefore, the cornerstone of asthma management is to achieve optimal asthma control. Every well-controlled patient should have an asthma action plan (AAP). It involves a paper written asthma diary to monitor and record the daily symptoms of asthma based on the Peak Expiratory Flow Rate (PEFR) measured using a Peak Flow Meter (PFM). The PFM however not been implemented due to some limitations such as it restrictions to be used by severe asthma patients and also asthmatic babies does hinders the effectiveness of the AAP itself. Other than PFM, stethoscope is also used in diagnosing asthma severity. Even though it is reliable, only medical personnel can interpret the respiratory pathology from the pulmonary acoustic signals. Therefore, this thesis discussed on the development of a computerized decision support system (CDSS) to classify asthma severity using pulmonary acoustics signals based on wheeze sound. This system is designed based on the relationship between PEFR and also wheeze sound that have been reported by some of the previous researcher. In order to develop the CDSS tool, two frameworks were proposed and the most effective framework was used to implement for the development of the CDSS for classification of asthma severity levels. Both of the suggested frameworks were proposed based on the standard frameworks for image/signal processing which involved pre-processing, feature extraction and classification process. However for framework two, there is an additional process of wheeze segmentation method. The proposed wheeze segmentation method adapted Short Time Energy (STE) and Fuzzy Inference System (FIS). The data collected were pre-processed in accordance to the Computerized Respiratory Sound Analysis (CORSA) guidelines. Features such as Mel-frequency Cepstral Coefficients (MFCC), Auto-regressive (AR) model, statistical features and STE based statistical features were extracted from the pulmonary acoustic signals. The features were dimensionally reduced using Principal Component Analysis (PCA) and a statistical analysis of the features was performed using One-way ANOVA in order to determine the significance level of the feature vector. The statistical significance test for all the extracted features were found to be significant with $p < 0.05$ and thus ready to be used for the classification process. In the classification stage, K- Nearest Neighbor (KNN), Multilayer Perceptron (MLP) and Support Vector Machine (SVM) were implemented to classify the asthma severity levels. From the overall observation, result obtained from framework two implementing MFCC with KNN shows the highest performance compared to other model tested with 97.71% average accuracy obtained. CDSS tool were then developed using MFCC features and KNN classifier following framework two. This CDSS tool can be a very good optional method for PEFR test that can be very beneficial to many organizations. In the hospital for instance, as an optional tool for asthma diagnosis that can assist the doctors and also nurses. And finally for asthma patients itself, it can be an easy self management and self diagnosis tool that is also safe to be used by a severe asthma patient.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Asthma is a common pulmonary disease that affects approximately 300 million people worldwide (Bumatay et al., 2012; Al-Dowaihi et al., 2013). Death due to asthma are uncommon but are of serious concern. Asthma contributes to less than 1% of all deaths in most countries worldwide. Rates of death from asthma rise from mid-childhood to old age, so the majority of asthma deaths occur after middle age. Figure 1.1 compares the mortality rates for asthma among countries. Avoidable asthma death are still occurring due to inappropriate management of asthma (Asher & Ellwood, 2014).

At present, there are no cures for asthma, and therefore, the cornerstone of asthma management is to achieve optimal asthma control (Jia et al., 2013). Every well-controlled patient should have an asthma action plan (AAP). It involves a paper written asthma diary to monitor and record the daily symptoms of asthma (if present) based on the PEFr measured using a Peak Flow Meter (Oletic, 2011).

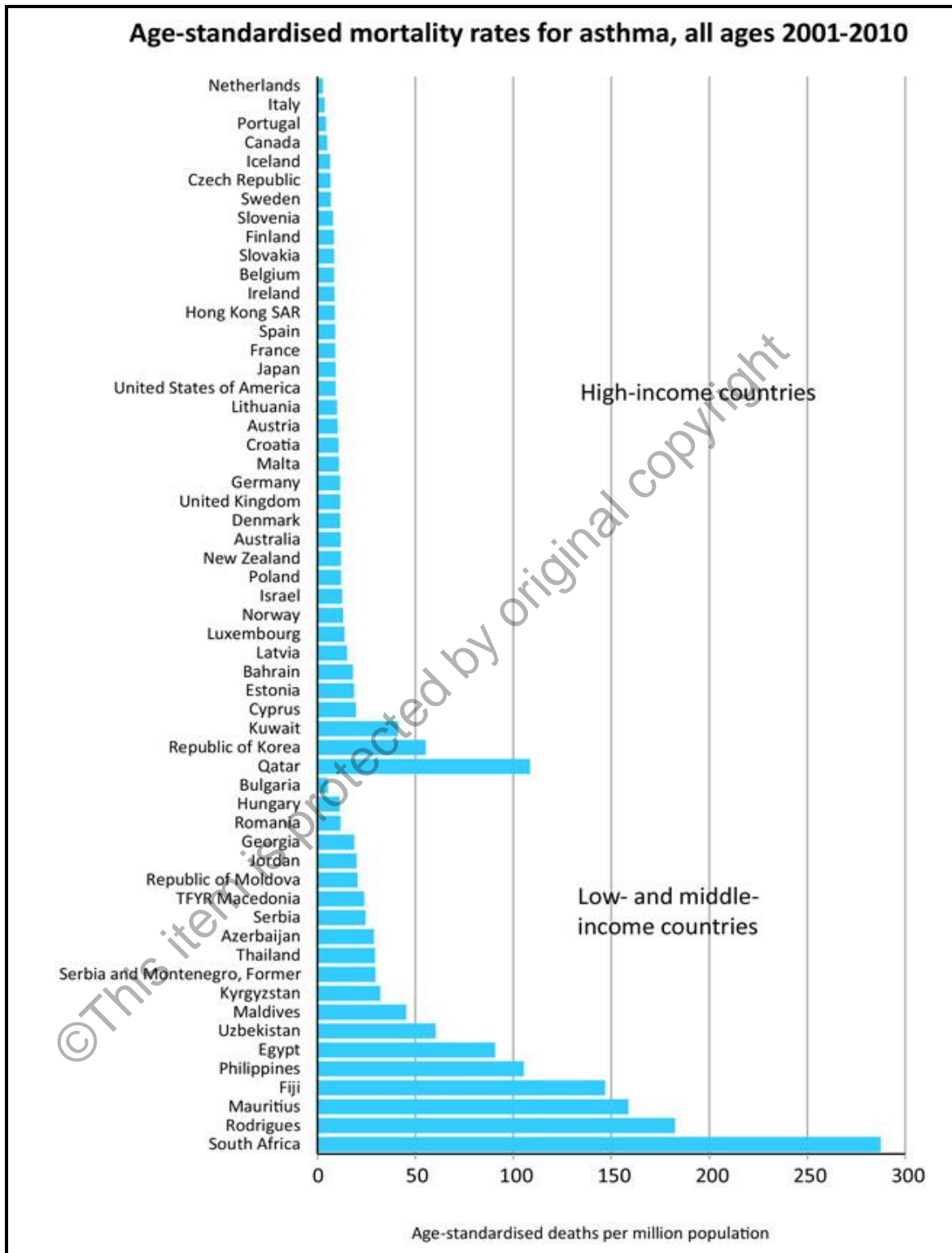


Figure 1.1 Age-standardized mortality rates for asthma for all ages in 2001 to 2010 (Asher & Ellwood, 2014).

AAP is an international standard procedure that is recommended in the Global Initiative for Asthma (GINA) and it has been reported that AAP can decrease the numbers of hospitalisations and deaths resulting from asthma (Gupta et al., 2012).

PEFR is obtained using Peak Flow Meter (PFM) in a PEFr test. PFM provides a simple, quantitative, and reproducible measure of the degree of airflow limitation to risk stratify asthmatic presentations (Clark et al., 2012). An asthmatic patient that can be considered as healthy or might have mild asthma would have a higher PEFr reading than a severely asthmatic patient. The information gathered from PEFr will help health care professionals to determine a patient's lung functionality, asthma severity (mild, moderate or severe), and treatment options (Bumatay et al., 2012). Although the existence of AAP and PEFr test for asthma control and management has been demonstrated, they have not been implemented either at home or at the hospital, due to the reasons explained below.

This problem is first due to the AAP itself. Regardless of the usefulness of the AAP, there are some limitations that lead to patients not following the AAP. One of the limitations is the fact that the hand-written diary method is very insufficient and burdensome such as for older patients who may have difficulties in learning and understanding the procedures and may be very inconvenient in many more situations. Moreover, this problem is also due to the PEFr test, which is an effort-dependent test that requires the patient to exhale as forcefully as possible into the PFM to obtain a good and accurate reading. Moreover, it is very tiresome to continuously reach the maximum expiratory effort (Gannon et al., 1999). For cases such as infant and toddler, it is impossible for them to do the PEFr test. It is also impossible to carry out the PEFr for infant because; the wrong placement of mouth on the mouthpiece of the PFM may obtain inaccurate result.

Other than that, for people with severe asthma, PEFr is not very suitable for them as

by doing the test, might cause them to have a worst breathing difficulty as the deep breathing procedure can worsen their asthma. Other than PFM, auscultation of the sound from the human body using a stethoscope to diagnosed abnormalities in asthma patients is commonly used by doctors. Although auscultation with a conventional stethoscope is popular, rapid, safe, convenient and non-invasive method for diagnosing, stethoscope is not an ideal means for the continuous monitoring of a respiratory condition (Zhang et al., 2009). Moreover, it also depends on the hearing perception of the medical professionals for accurate diagnosis. Due to the usefulness of the stethoscope, research studies on the development of a CDSS for respiratory sound auscultation have been actively performed by researchers around the world to overcome the limitations of the stethoscope, and many have succeeded. The CDSS deal with the analysis of the respiratory sounds by applying various signal processing and machine learning algorithm. The advantages of using the CDSS include fast diagnosis, simple, not expensive, non-invasive and can be very accurate. It can serve as an optional tool for medical personal. Even though there are studies that have proven the high relationship between PEFr and wheeze present for every asthma severity levels such as work done by Shim and Williams in 1983, CDSS for wheeze recognition exist nowadays only focuses in classifying wheeze and no wheeze sound. There are no studies reported earlier to detect different severity of asthma.

An abnormal respiratory sound (RS) that is commonly heard during an asthma attack is wheezing that is resulting from the narrowing of the bronchi, which causes whistling sounds in the airways. Wheeze detection is a coherent and inexpensive method to monitor asthma (Yu et al., 2013), and wheezing is an indicator of the progress of an asthmatic attack because it is usually present in mild to severe asthma patients (Oletic, 2011). Wheezing present during unforced breathing has been related to the severity of airway obstruction (Riella et al., 2009).

The severity of airway obstruction has also been related to the duration, intensity and pitch of the wheeze sound. Therefore, wheeze measurement may be a very useful tool in analysing the asthma severity (Le Cam et al., 2009). Shim and Williams, (1983) have found a relationship between the characteristics of wheezing and the severity of airway obstruction. Patient with more severe asthma are reported to have a high-pitched wheezes compared to a mild and moderate asthma patient. A progressive decreased in PEFV reading were also observed with a more severe asthma patient (Shim & Williams, 1983). Moreover, adventitious sound such as wheeze also have been found to be more sensitive indicator, detecting and characterising the severity of the respiratory diseases before any other measure (Marques et al., 2013).

1.2 Problem Statements

The problems that motivate this study are as follows:-

a) There are still absent of previous CDSS researches opted wheezes in classifying severity levels of asthma.

A relationship between the degrees of airway obstruction together with the presence of wheezes in asthma has been demonstrated in several studies. However, most studies on respiratory sound analysis have only concentrated on the comparison of normal respiratory sounds and wheeze sounds obtained from patients (Guler et al, 2005). No study has been reported to analyse the various severity level of asthma with respect to its wheeze signal characteristics.

b) There are still absent of wheeze databases that is developed from different severity of asthma.

Due to the above problem in (a), there are no such study have been done before by the

previous researcher thus no available database that can be used in this study.

c) So little data acquisition techniques that comply with the CORSA standard.

The European community has sponsored a BIOMED Concerted Action project entitled Computerized Respiratory Sound Analysis (CORSA). CORSA have provided a guidelines for research and clinical practice in the respiratory sound analysis field, however most of the researcher have not developed the studies accordingly. The variation in data acquisition between researchers has a large effect on the current research. Hence following CORSA guidelines is suggested.

It is found that most of asthma related research in developing a CDSS does not follow the CORSA standard for their research and also uses some provocative drugs in obtaining data from the patient. Forkheim et. al, (1995) mentioned that it may not always be possible to observe a patient during an asthmatic attack to confirm the diagnosis. Therefore, it may be necessary to use a provocative test such as methalcholine challenge. During a methalcholine challenge, the patient breaths a small amount of metahcholine which may cause wheezes to occur if the patients have asthma. Methacholine challenge can cause discomfort to the patient and can also trigger an unwanted asthma attack that may be fatal.

d) There is an absent of wheeze segmentation methods that are reliable to be used for this work.

In previous work, there are various types of automated segmentation have been done. Although the previous methods produce a very competent result, however the existence segmentation methods were designed only to differentiate between normal and wheeze sound. The method designed however reduced quality of the wheeze sound and sometimes causing

the high and the low pitch wheeze to be excluded.

e) The previous researchers only apply feature extraction and classification method to classify wheeze and no wheeze signal.

Previous researchers have only extracted features to classify no wheeze and wheeze signal. However, there is no study reported in the literature which extracts feature for classifying severity level of asthma according to its wheeze sound.

f) Subjects of various age groups were used for the system development in the previous study.

In determining the severity of asthma using the standard procedure of the PEFR test, children and adult are measured differently according to the outcomes of the PEFR measurement. Therefore in designing a system for asthma severity levels classification, the age group also needed to be taken into consideration. Some of the previous researcher does not differentiate their subject to children and also adult. Even though a good performance result is obtained, those studies however are not reliable.

1.3 Objectives of Research

The main objective for this project is to develop a CDSS for the classification of asthma severity levels based on wheeze sound. This CDSS can also act as an optional method apart from PEFR test. The sub-objectives of this project also includes:-

- a) To develop a database with wheeze from different severity level of asthma using data acquisition protocol based on the CORSA.