UNIVERSITI PUTRA MALAYSIA

REGIONAL CONTRAST ENHANCEMENT AND FOUR-DIRECTIONAL THRESHOLDING TECHNIQUES FOR PULMONARY NODULE EXTRACTION AND DISCRIMINATION

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By

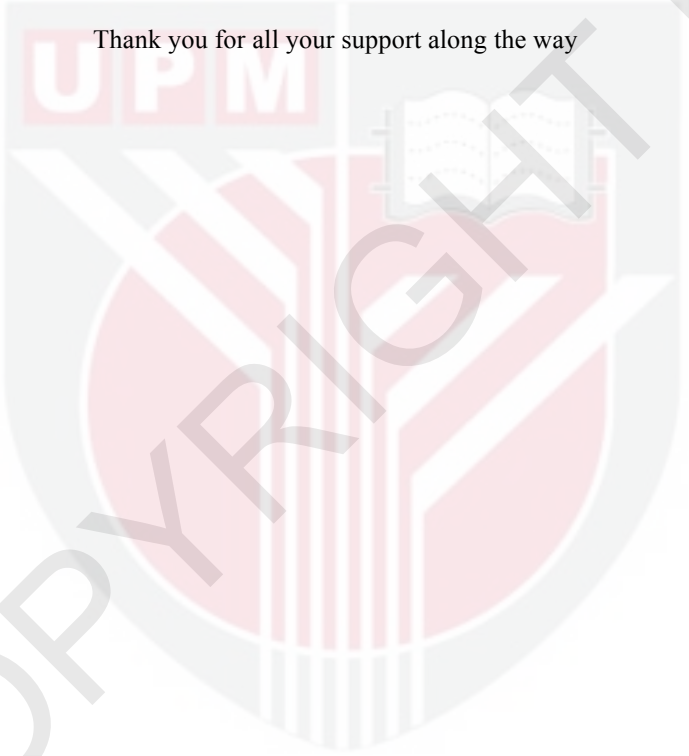
SALEHEH HEIDARI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

July 2015

A special dedication to my loving family

Thank you for all your support along the way



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

REGIONAL CONTRAST ENHANCEMENT AND FOUR DIRECTIONAL THRESHOLDING TECHNIQUES FOR PULMONARY NODULE EXTRACTION AND DISCRIMINATION

By

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July 2015

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Faculty: Computer Science And Information Technology

Automated pulmonary nodules extraction and lung disease diagnosis by Computer Aided Diagnosis (CAD) systems is a challenging task. Generally, the CAD system utilizes the Computed-Tomography (CT) images to diagnose tumor and observe its condition during the treatment process. Due to extensive similarity between pulmonary vessels, bronchus and arteries in lung region and the low contrast of Computed-Tomography (CT) images the accuracy of lung tumor diagnosis is highly dependent on image's contrast and the precision of segmentation. Contrast enhancement and image segmentation are the most prominent image preprocessing techniques that are utilized as a primary and essential steps of almost every pathological applications. Thus, a particular contrast enhancement and image thresholding techniques are required to enhance the contrast of lung CT image by refining their pixels' intensity value and overcome the difficulties of precise segmentation as well as facilitating the accurate pulmonary nodule extraction.

Accordingly, in this research Regional Contrast Enhancement (RCE) and Four-Directional Thresholding (FDT) techniques are introduced followed by nodule extraction and their discrimination based on their respective size and circularity measurements.
Regional Contrast Enhancement (RCE) technique aims to improve the CT image's visual quality by boosting the contrast of lung CT images and modifying the image histogram by implementing the proposed algorithm on every individual pixel based on their intensity value and their regional variations.

The proposed FDT technique also aims to augment the precision of lung CT image's segmentation by implementing a specific thresholding approach from four different directions in which the determination of pixels' value as being either on foreground or background is highly dependent on its adjacent pixel's intensity value and the final decision is made based on all four directions' thresholding results. Finally, pulmonary nodules are extracted from thresholded CT images by several morphological techniques and then extracted candidates are discriminated based on their eccentricity and corresponding size as benign and malignant nodules.

To demonstrate the superiority of proposed RCE technique the minimum Absolute Mean Brightness Error (AMBE), the highest Peak Signal to Noise Ratio and structural Similarity Measurement Index obtained by RCE technique are compared with the other advanced contrast enhancement by histogram equalization methods. The effectiveness and high exactitude of proposed FDT method also has been evaluated on different CT images by correlation and regional non-uniformity measurement criteria. Ultimately, the performance of nodule extraction and discrimination were evaluated and 93.33% of sensitivity, 93.90% of accuracy and 94.59% of specificity have been obtained.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia Sebagai memenuhi keperluan untuk ijazah Master Sains

PENINGKATAN KONTRAS SEKAWASAN DAN TEKNIK-TEKNIK PENGAMBANGAN EMPAT-ARAH BAGI PENGEKSTRAKAN DAN DISKRIMINASI NODUL PULMONARI

Oleh

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Pengekstrakan nodul Pulmonal automatik dan diagnosis penyakit paru-paru menggunakan Sistem Diagnosis Berbantukan Komputer (CAD) merupakan satu tugas yang mencabar. Secara umumnya, sistem CAD menggunakan imej-imej Tomografi-Berkomputer (CT) untuk mendiagnosis tumor dan memerhatikan keadaannya semasa proses rawatan. Oleh kerana persamaan yang banyak di antara pembuluh pulmonari, bronkus dan arteri di kawasan paru-paru dan kontras yang rendah pada imej-imej Tomografi-Berkomputer (CT), ketepatan diagnosis tumor paru-paru adalah sangat bergantung kepada kontras imej tersebut dan ketepatan segmentasinya. Peningkatan Kontras dan segmentasi imej adalah teknik pra pemprosesan imej paling menonjol yang digunakan sebagai langkah utama dan penting bagi hampir setiap aplikasi patologi. Oleh itu, teknik peningkatan kontras dan teknik pengambangan imej tertentu diperlukan untuk meningkatkan kontras imej CT paru-paru dengan memperhalusi nilai keamatan pikselnya dan mengatasi kesukaran mendapatkan segmentasi yang tepat serta memudahkan pengekstrakan nodul pulmonari yang jitu.

Sehubungan itu, dalam kajian ini, Peningkatan Kontras Sekawasan (RCE) dan teknik Pengambangan Empat-arah (FDT) diperkenalkan dan diikuti dengan pengekstrakan dan diskriminasi nodul berdasarkan saiz dan ukuran bundaran masing-masing.

Teknik Peningkatan Kontras Sekawasan (RCE) bertujuan untuk meningkatkan kualiti visual imej CT dengan meningkatkan kontras imej CT paru-paru dan mengubah-suai histogram imej dengan melaksanakan algoritma yang dicadangkan pada setiap piksel individu berdasarkan nilai keamatan mereka dan variasi kawasannya.

Teknik FDT yang dicadangkan juga bertujuan untuk membantu dalam menyokong ketepatan segmentasi imej CT paru-paru dengan melaksanakan pendekatan pengambangan tertentu dari empat arah yang berbeza di mana penentuan nilai piksel sama ada berada di latar depan atau latar belakang adalah sangat bergantung kepada nilai keamatan piksel bersebelahan ini dan keputusan akhir adalah dibuat berdasarkan semua keputusan pengambangan empat arah tersebut. Akhir sekali, nodul pulmonari diekstrak dari imej CT yang telah diambangkan melalui beberapa teknik morfologi dan

kemudiannya imej-imej yang telah diekstrak itu didiskriminasikan berdasarkan keeksentrikan serta saiz padanannya sebagai nodul-nodul tidak merbahaya atau merbahaya.

Untuk menunjukkan keunggulan teknik RCE yang telah dicadangkan, Ralat Kecerahan purata Mutlak (AMBE) minimum, Isyarat Puncak tertinggi kepada Nisbah Bunyi dan Indeks Pengukuran Persamaan struktur yang diperolehi menerusi teknik RCE telah dibandingkan dengan peningkatan kontras termaju lain menerusi kaedah penyamaan histogram. Keberkesanan dan kejituan tinggi yang dipamerkan oleh kaedah FDT yang dicadangkan juga telah dinilai pada imej-imej CT berbeza melalui kaedah korelasi dan kriteria pengukuran bukan keseragaman serantau. Akhirnya, prestasi pengekstrakan dan diskriminasi nodul telah dinilai dan 93.33% sensitiviti, 93.90% kejituan dan 94.59% kespesifikan telah diperolehi.

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I certify that a Thesis Examination Committee has met on 1 July 2015 to conduct the final examination of Saleheh Heidari on her thesis entitled "Regional Contrast Enhancement and Four Directional Thresholding Techniques For Pulmonary Nodule Extraction and Discrimination" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

ACO	Ant Colony Optimization
AMBE	Absolute Mean Brightness Error
BBHE	Brightness Bi-Histogram Equalization
BW	Black and White image, binary image
CAD	Computer Aided Diagnosis
CAT	Computerized Axial Tomography
CDF	Cumulative Density Function
CLAHE	Contrast Limited Adaptive Histogram Equalization
CT	Computed Tomography
DBS	Discontinuity-Based Segmentation
DICOM	Digital Imaging and Communication in Medicine
DSIHE	Dualistic Sub-Image Histogram Equalization
FDT	Four-Directional Thresholding
FN	False Negative
FP	False Positive
GUI	Graphic User Interface
HE	Histogram Equalization
LCE	Linear Contrast Enhancement
LHE	Local Histogram Equalization
NSCLC	Non-Small Cell Lung Cancer
PDF	Probability Distribution Function
PIV	Pixel's Intensity Value
PNE	Pulmonary Nodule Extraction
PSNR	Peak Signal to Noise Ratio
PSO	Particle Swarm Optimization
RCE	Regional Contrast Enhancement
RMSHE	Recursive Mean Separate Histogram Equalization
RNU	Region Non-Uniformity
ROC	Receiver Operating Characteristic
ROI	Region Of Interest
SBS	Similarity-Based Segmentation
SCLC	Small Cell Lung Cancer
SPN	Solitary Pulmonary Nodule
SSIM	Structural Similarity Index Measurement
T	Thresholding Value
TN	True Negative
TP	True Positive

CHAPTER 1

INTRODUCTION

1.1 Background

Lung is the most vital and complex bilateral organ in human body. It is enclosed by musculoskeletal chest wall and carries out the task of intrathoracic air-exchange by expanding and contracting up to 20 times per minute (Apar K. et al., 2013). Lung is divided into lobes and provides capillaries by supplying oxygen to be diffused to tissue and oxygenate blood all over the body. The healthiness of this respiratory organ is vitally important for human life. Thus it should be retained from any respiratory disorders (American Thoracic Society, 2014).

Recently, many industrialized countries suffer from air pollution that can be the common cause of respiratory diseases such as Acute bronchitic, Lung cancer, Pneumonia, Asthma and Tuberculosis (G. Krucik, 2013). Among all types of lung diseases, Interstitial Lung Diseases (ILD) and Diffuse Parenchymal Lung Disease (DPLD) are generally recognized as the most common and prevalent lung disorders (Guo J. et al., 2002; Helen et al., 2011).

Generally, lung cancer is a type of pulmonary disease that occurs when the anomalous cells grow and proliferated in lung lobes uncontrollably. The nominated abnormal cells usually are divided rapidly and forming the lung pulmonary tumors which diminish the lung's ability to oxygenate the vessels (Peter C., 2009).

Regarding the lung cancer related mortality; National Cancer Institute revealed that there were 226160 new lung cancers diagnosed and 160340 related death by the end of 2012. Accordingly, World Health Organization (WHO) broadcast that the 7.6 million deaths are caused by cancer and by far the lung cancer with 1,370,000 deaths per year is the worst cancer killer worldwide (Peter C., 2009). Studies done in United State manifest that the lifetime risk of invasive lung cancer for women is approximately about 5.5 percent and 5.9 percent for men. It is argued that approximately about 80 percent of lung cancer could be treated if it is diagnosed in incipient phase of disease (Peter J. et al., 2013). Therefore, due to the importance of early disease-diagnosis, the identification of pathological feature and types of pulmonary tumors in lung cancer could impact on accurate prognosis (Russell C. et al., 2008; Rina D. et al., 2013).

Tumors' location variation and their characteristics may differ in specific period of time. Based upon these characteristics and the tumors' traits they are classified into two different types, which determine whether they are cancerous or non-cancerous. The tumors that have not been propagated in specific time and their characteristics remain

identical are known as benign tumors (non-cancerous). Otherwise, they are categorized as malignant tumors as they behave like cancerous nodules that spread to other parts of body through lymphatic system (Peter C., 2009; Robert M. et al., 2014).

It is noticeable that the treatment of lung malignant nodules is much harder and in some case it is impossible. Thus, recognizing pulmonary nodules in early phase of disease has significant impacts on all stages of treatment process (Chaudhary, 2012). Inspection of lung pulmonary disease and identification of tumors' type could be done by scrutinizing Computed-Tomography (CT) images and morphological analysis of extracted nodules.

Lung Computed Tomography (CT) image is a standard instrument, which is utilized for lung disease diagnosis. But due to the specific gray-level distribution among CT images, they have a very low contrast. Although overwhelming minor lung diseases could be observable in CT images, the paucity of information that they provide is often insufficient to identify the type of nodules and hampers the task of pulmonary nodule extraction in Computer Aided Diagnosis (CAD) systems (Guo J. 2002). Lung nodules extraction and malignant tumor detection through Lung CT images investigation by CAD systems has always been a challenging task which is associated with some difficulties. Tackling with these difficulties would not be possible without using image-processing techniques.

1.2 Problem Statement

Although body possess natural defenses to protect lung from any germs and large particles such as dust and pollen, air pollutants usually harm the lung tissues directly and undermine those important defenses. Thus, due to the complexity and substantial functioning of lung, the healthiness of this respiratory organ is vitally important for human life and helps the human body to work properly.

Retention of lung from any aforementioned factors is often inevitable. But restraining the development of lung disease like pulmonary malignant and benign nodules and repelling their progression could always prevent lung disease mortality. Consequently, lung Computed-Tomography (CT) image is used to observe lung pulmonary nodules' abnormality (William E. Brant, 2012). Pulmonary nodules are usually emerged as the primary sign of lung cancer, which could be observable in CT images. CT image is the most fundamental tool used in Computer Aided Diagnosis (CAD) system to evaluate the various types of lung lesion (Li Y. et al., 2011). But usually due to narrow dynamic range (poor quality) of CT images, inspection of lung disease and examination of nodules' types become awkward (Guodong Z. et al., 2008; Agarwal, T.K. et al., 2014).

Thus, the low quality of lung CT images is one of the most important obstacles in pulmonary nodule investigation thorough CT images. The poor quality provided by CT image is due to the dynamic range of gray level, the distribution of gray pixels and

their frequency of occurrence throughout the image. This characteristic always causes the lack of contrast in CT image and leads the image to provide paucity of information that makes the nodule examination and their interpretation tedious and difficult.

Additionally, low contrast of lung CT images usually leads to omission of pulmonary nodule recognition by human radiologist. Beside the fact that low contrast of lung CT image make the lung disease diagnosis abstruse for human, it also leads to a high False-Negative (FN) rate for small nodules detection through CAD system (Dolejši, 2007). Observation of pulmonary nodules' abnormalities in CAD system by using lung low contrast CT images is often unfathomable and it will also affect all further processing and analysis. Thus, a contrast enhancement technique is indispensible preprocessing technique to tackle with the lack of contrast in lung CT images.

Extensive similarity between pulmonary vessels, bronchus and arteries in lung region is another factor, which affects pulmonary nodule extraction in CAD system. In spite of the nominated factors, location diversity of lung pulmonary nodules also makes their investigation a difficult task. Therefore, precise image segmentation could be exploited as another preprocessing technique to cope with difficulties involved in pulmonary nodule detection. Although, Image segmentation technique could simply help to extract pulmonary nodule candidates, yet it is a challenging task (Hui Cui, et al., 2013).

Many researchers merely attempted to develop manifold image contrast enhancement and segmentation techniques for general kind of images. Even though these techniques yield adequate results on general images, their performance on lung CT images yields insufficient results. Unexpected results obtained by advanced techniques are due to lung CT images specific characteristics. Thus, in order to cope with lung CT image characteristics a particular image preprocessing is required to tackle with CT images characteristic as well as facilitating and boosting the accuracy of pulmonary nodule extraction.

At last, it is noticeable that the implementation of image processing techniques on lung CT images produces many tumor-like candidates, which could be enumerated as a tumor. So a specific rule is required to identify the type of tumor. In this case, the morphological characteristics of the tumor should be investigated. The features and the traits of the candidates should be analyzed in order to remove the isolate pixels (noise) and eliminate the small candidates that are not identified as a malignant tumor. Therefore, nodules' discrimination and malignant tumor identification is highly challenging.

Ultimately, all aforementioned obstacles that pulmonary nodule detection encounters throughout its performance could simply be summarized as below:

- Dynamic range of gray level, the distribution of gray pixels and their frequency of occurrence throughout the Lung CT images that yield insufficient contrast in CT image (Agarwal, T.K. et al., 2014) and cause

to provide paucity of information that makes the nodule examination and their interpretation difficult.

- Location diversity of lung pulmonary nodules.
- Extensive similarity between pulmonary nodules, vessels, bronchus and arteries in lung region (Hui Cui, et al., 2013).
- Deficiency and unavailability of particular image preprocessing techniques for lung CT images.

1.3 Objectives of Research

As discussed earlier, exactitude and high precision of pulmonary nodule extraction is dependent on several factors. This research is conducted to overcome with these factors by obtaining specific aims as follow:

- To enhance the contrast of lung CT image by proposing a particular image contrast enhancement technique.
- To propose a precise image segmentation (Thresholding) technique to facilitate the pulmonary nodules' candidates extraction.
- To improve the detection of pulmonary nodules without being affected by their location diversity
- To discriminate the extracted candidates as malignant or benign based on their size and eccentricity

1.4 Research Questions

Having an organized mind has always been useful to construct the research substratum comprehensibly that leads the research into a well-projected path. Thus, in order to conduct the research in a well resasoned and coherent way several questions have been designed based on the aformentioned research problems and objectives. The questions are as below:

- Which image processing techniques can be utilized to optimize the lung CT image contrast?
- Which image thresholding technique could be exploited to enhance the precision of lung CT image segmentation?
- How could juxtapleural nodules be extracted as well as parenchymal nodules?
- What type of morphological analysis could sufficiently discriminate the benign and malignant nodules?

1.5 Scope of Research

The scope of this study is to extract and discriminate lung pulmonary nodules solely by image processing technique. The cardinal image processing techniques used in this research are simply divided into image preprocessing such as contrast enhancement and image segmentation and the post processing techniques to extract the nodule candidate and isolate them based on their size and eccentricity as malignant or benign nodules. The instrument used in this research is the original lung Computed-Tomography (CT) image known as lung DICOM files.

The results obtained in image contrast enhancement is compare with six advanced technique such as HE, CLAHE, DSIHE, BBHE, LHE and RMSHE. The performance of image segmentation (Thresholding) technique also has been compared with OTSU and PSO, which are the well-known image segmentation techniques. Furthermore, the performance of pulmonary nodule classification is evaluated by specific criteria to measure it sensitivity and accuracy.

1.6 Contribution of Research

The accuracy of lung nodule extraction and their classification is extremely dependent on the quality of CT images. As stated previously, the quality of lung CT is inappropriate for further analysis. Thus a meticulous image preprocessing is required to simplify the nodule extraction task and enhance it exactitude. Therefore, the major contributions of this research is to propose a method to enhance the contrast of CT images as well as propounding precise image segmentation and nodule extraction.

In this research a Regional Contrast Enhancement (RCE) technique is proposed to boost up the quality and contrast of lung CT images and refine their pixels' intensity value for further analysis. The RCE technique also redistributes the gray pixels and equalized the gray-level's interval to regenerate image histogram. The RCE algorithm is mainly work based on pixels' regional variation throughout the image.

Another contribution of this research is the proposed Four-Directional Thresholding (FDT) techniques in which the neighbor pixels play significant role in determination of every individual pixel's intensity value. Ultimately, nodules will be extract after implementation of those two proposed techniques by performing various morphological techniques. Then extracted nodule will be investigated and discriminated into benign and malignant nodules.

1.7 Thesis Organization

This chapter provides the introduction to the research discussed in this study. The current chapter basically explicates preliminary information about lung nodule extraction. It also provides related problem that had been the main focus of this study that encouraged researching the solitary pulmonary nodule extraction and their classification. This chapter also clarifies research objectives, questions, contribution and the scopes.

Chapter 2 profoundly expounds rudimentary knowledge about lung structure and lung cancer. The chapter also describes nodules and their characteristics. The features of benign and malignant nodule are also elucidated in Chapter 2 as well as their similarities and differences. Computed tomography and DICOM images are also presented.

Following the rudimental information of lung structure and nodules characteristics the prior studies and their achievements are looked over in Chapter 2. These studies are fundamentally construed into two distinct sections as preprocessing and post processing. In which each section thoroughly reviewed pertinent literatures.

Chapter 3 utterly explicates the methodology utilized to conduct this study. It clearly expounds the process followed in this research as well as exploited methodology. The research design, data collection, sampling and instrumentation are simply described. And the designed framework and performance measurements approaches are thoroughly presented.

The proposed approaches to conduct this research are profoundly delineated in Chapter 4. The proposed algorithms for image preprocessing and post processing are discussed in detail and their info-graphic are provided.

Chapter 5 discusses the experimental results of every single proposed algorithm respectively. It clearly elucidated the performance of proposed techniques and evaluates their result based on specific evaluation metrics given in Chapter 4 and the discussed the achievements.

Ultimately the study is concluded in Chapter 6 and the future work is conferred. It clearly draws conclusion of research and describes the possible future works that could be accomplish to enhance this study.

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