MAMMOGRAPHIC PHANTOM IMAGES USING RECEIVER OPERATING CHARACTERISTIC ANALYSIS

NOR'AIDA BINTI KHAIRUDDIN

UNIVERSITI TEKNOLOGI MALAYSIA

MAMMOGRAPHIC PHANTOM IMAGE ANALYSIS FROM RECEIVER OPERATING CHARACTERISTIC (ROC) CURVE

NOR'AIDA BINTI KHAIRUDDIN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Science (Physics)

Faculty of Science
Universiti Teknologi Malaysia

JULY 2014

To my beloved mother,

sisters and brothers

ACKNOWLEDGEMENT

My period as a graduate student at Universiti Teknologi Malaysia has provided me with great opportunities from many aspects. I wish to extend my hearty thanks to all whom I am indebted for supporting me as I complete this thesis.

An especially thanks are to *Assoc Prof Dr Wan Muhammad Saridan Bin Wan Hassan*, as my supervisor for all his support, guidance, providing the time to discuss my work and helpful discussions.

I also thanks the radiologist and radiographers at Diagnostic Imaging Department, Hospital Sultan Ismail, namely *Dr Hasnizan Bin Hassan*, *Puan Salabiah Binti Shapawi* and *Puan Tay Bee Hua* who have given me an opportunity to have the use of equipments and for all their assistance and co-operation.

In addition, I am grateful to *Puan Norriza Binti Mohd Isa* from Malaysian Nuclear Agency, Bangi for her kind assistance in experimental, constructive ideas and valuable suggestions.

I wish to thanks my beloved mother *Puan Hjh Zamnah Binti Hj Jiman* for her unconditional love, support and guidance through all my years of schooling and to my beloved siblings and friends for all their encouragement.

Finally, I would also like to express my gratitude to the Malaysian Ministry of Science, Technology and Innovation (MOSTI) for their financial funding through Science Fund grant and Universiti Teknologi Malaysia for providing the Zamalah research scholarship. I also wish to thanks to Malaysian Ministry of Education (MOE) for allowed me to undertake full time study leave.

ABSTRAK

Kanser payudara adalah sejenis kanser penyebab utama kematian wanita di seluruh dunia. Sebahagian imej mammografi digital mempunyai hingar dan kontras yang rendah. Teknik pemprosesan imej telah digunakan untuk meningkatkan kualiti imej. Tujuan penyelidikan ini adalah untuk melakukan analisis ciri operasi penerima (ROC) terhadap imej fantom mamografi yang dikenakan dua teknik peningkatan untuk menentusahkan sama ada teknik peningkatan itu meningkatkan kualiti imej. Imej mammografi digital ini ditingkatkan menggunakan teknik morfologi dan ubah bentuk gelombang kecil. Bagi teknik morfologi, imej dipertingkatkan menggunakan pembesaran untuk operasi morfologi dan penutupan morfologi. Bagi peningkatan ubah bentuk gelombang kecil, penuras *wavelet biorthogonal 2.8* dengan dua tahap penguraian (L=2) telah digunakan. Empat orang pemerhati menilai imej yang mengandungi nodul, gentian dan mikronodul. Prestasi pengesanan terhadap imej asal dan imej yang telah diproses melalui tersebut dinilai dengan lengkung ROC. Imej juga dinilai berdasarkan tahap kontras, ketajaman serta kualiti imej keseluruhan. Analisis ROC menunjukkan pengesanan terhadap mikronodul memberi luas di bawah lengkungan dan nilai sensitiviti yang lebih tinggi daripada pengesanan terhadap nodul dan gentian. Bagi penilaian keseluruhan kualiti imej menggunakan skala penilaian subjektif pemerhati pula, imej asal menunjukkan nilai min yang lebih tinggi daripada imej yang ditingkatkan.

ABSTRACT

Breast cancer is a form of cancer which is a leading cause of death among women worldwide. Some digital mammographic images are noisy and have low contrast. Image processing techniques have been used to improve the quality of images. The aim of this study is to perform receiver operating characteristic (ROC) analysis on mammographic phantom images subjected to two enhancement techniques in order to verify whether the enhancements improve the quality of the images. The digital mammographic images were enhanced using the morphological and wavelet transform techniques. For the morphological techniques, the images were enhanced using dilation for morphological operation and morphological closing. For wavelet transform enhancement, biorthogonal 2.8 wavelet filter with two levels of decomposition (L=2) was used. Four observers evaluated the images that contain fibres, nodules and micronodules. The detection performances of the original and enhanced images were evaluated using ROC curves. The images were also rated based on contrast visibility, sharpness and overall image quality. The ROC analysis showed that detection of micronodules gave higher area index of curves and sensitivity than the detection of nodules and fibrils in all image datasets. For evaluation of overall image quality using observers' subjective rating scale, original images have higher mean values than the enhanced images.

TABLES OF CONTENTS

LISTS OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A	-	Atomic mass
A_z	-	Area index of curve
b	-	Structuring elements
C_{rad}	-	Resultant radiation contrast
D_b	-	The domain of b
f	-	Gray scale dilation
kV	-	Kilovoltage
N_A	-	Avogadro's number
N	-	Number of atoms per unit volume
n_A	-	The mean number of X-rays transmitted
n_0	-	The mean number of X-rays incident
σ	-	Standard deviation
σ_t	-	Total cross section
ρ	-	Weight density of the material
μ	-	X-ray attenuation coefficient of the tissue
μ'	-	X-ray linear attenuation coefficient
μ_m	-	Mass attenuation coefficient
μ_t	-	Total linear attenuation coefficient
Ψ^D	-	Diagonal wavelets
Ψ^H	-	Horizontal wavelets
Ψ^V	-	Vertical wavelets
$\tilde{\Psi}(\omega)$	-	Fourier Transforms of synthesis wavelet
$\tilde{\varphi}(\omega)$	-	Scaling function
z	-	Breast thickness

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

Breast cancer is the most common form of cancer in the female population and continues to be leading cause of death among woman around the world. Early detection and treatment of breast cancer are the most effective methods to reduce mortality. Breast cancer mortality has declined among woman of all ages over the past decade although breast cancer incidence has increased (Fieg *et al.*, 1998). Mammography screening had reduced the mortality and improved the treatment of breast cancer (Buseman *et al*., 2003). Mammography has proven to be the most effective tool for detecting breast cancer in early stage.

Digital mammography has provided useful radiographic information and advantages including digital image management, digital data transfer and new medical applications. Digital detectors of digital mammography have improved the efficiency of absorption of incident X-ray photons. A photoconductor such as amorphous selenium (a-Se) captures the X-rays photons and converts absorbed X-rays directly to a digital signal. Digital detectors have a wide range of X-ray intensities and low noise system. Digital mammography improved the lesion visibility with wide dynamic range (1000:1) compared to screen film mammography, dynamic image manipulation and ability to postprocess (Mahesh, 2004).

Digital mammography also could overcome the limitation of screen film mammography and improved detection and diagnosis of breast cancer (Yaffe, 2001). Digital mammography does not only provide outstanding technology for X-

ray detection but also a powerful instrument system for image acquisition, image review and image storage. The design of digital mammography allows the new medical applications such as Computer Aided Detection (CAD), tomosyntesis, telemammography and quantitative image analysis.

Hiroshi *et al*. (2006), Yip *et al.* (2001), Williams *et al.* (2008) and Young *et al.* (2010) found that digital mammography has improved contrast sensitivity and specificity compared to screen film mammography. Image processing technique could enhance visibility of digital mammography. Wavelet transformations, image filtering and grey-level enhancements were the examples of image processing technique which had been studied by Diekmann *et al*. (2001). Different types of enhancement including different set of algorithms and parameters are applied depending on different types of mammographic lesions.

Quantitative imaging has an important role in developing image analysis methods to extract quantitative data more accurately in detection and diagnosis (Giger, 2008). Receiver Operating Characteristic (ROC) analysis is one of the imaging analysis methods to compare the accuracy of two or more imaging modalities. The ROC curve represents sensitivity (True Positive Fraction) and specificity (True Negative Fraction). ROC analysis evaluates the plots by calculating the area under the curves. The mammographic images are scored based on subjective interpretation by observers. Many researchers had proved that quantitative diagnostic assessments from ROC curves could provide valuable feedback to improve diagnostic performance.

1.1 Research Background

A digital mammogram is considered as high quality when the diagnostic sensitivity and specificity are high. Oliver *et al.* (2010) confirmed that most radiologist and physicians had missed the presence of different types of breast lesions. A small number of radiologists available and large amount of mammographic images to be analysed make such readings labour intensive and often inaccurate.

The contrast, resolution and noise properties of the image describe the technical image quality. Mammographic images usually are noisy and have low contrast regions. Image processing techniques are the other alternative to improve the quality of image which should be independent of image acquisition and display. Parameter settings affect the display devices by mapping pixel values to luminance. Digital detectors affect image resolution, gain, modulation transfer function and noise characteristics. Digital Imaging and Communications in Medicine (DICOM) header provides acquisition parameters such as anode material, filtration and kVp. Mahesh (2004) found that radiation dose decreased for thicker breast with digital mammography.

A recent study by Pisano *et al.* (2004) shows that image processing has improved visualization and more accurate detection of abnormalities from mammographic images. Masses or calcifications could be detected from the evaluation of eight different image processing algorithms. The image processing techniques were performed using histogram and mixture model based intensity windowings, peripheral equalization, multiscale image contrast applifications, Contrast Limited Adaptive Histogram Equalization (CLAHE) and unsharp masking.

The performance using different processing techniques for screen-film mammographic images and digital mammographic images are still being studied. Default techniques, multiscale image contrast amplification and CLAHE combination were applied in both digital mammographic images and screen film images. Cole *et al.* (2005) found that the detection of masses were better for screen film images compared to digital images. The specific image processing algorithms need to be improved based on machine and breast lesion type.

The effect of wavelet processing on a mixture of mammographic findings was investigated by Kallergi *et al*. (2004). The study was evaluated using Localization Response Operating Characteristic (LROC) with 500 negative, benign, masses and calcification clusters. They found that wavelet enhancement improved all case combinations. The mammographic images require more advanced processing technique than standard grayscale adjustments.

Dominquez *et al.* (2008) and Guillaume *et al.* (2007) found that the positive effect of performance still have room for improvement. More research is needed to utilize more accurate enhancement and optimize image processing techniques for future improvement of the breast lesion detection.

1.2 Problem Statement

Mammography images are difficult to interpret by the radiologists because the features are typically very small, poor contrast and have a wide range of anatomical patterns. For radiologists, reading mammography images is a very demanding job make the detection and diagnose difficult. The radiologists' judgement depends on their training, experience and subjective criteria.

Radiologists have to view many of digital mammographic images and are required to complete the task. This could result in clinical dissatisfaction. The electronic reading rooms may leads to greater fatigue among radiologists, which could affect the diagnostic performance.

Some mammographic images are affected by noise and generate false positive results. Large amount of mammographic images have been missed or misinterpreted by the radiologists leading to greater number of false positive cases. Image analysis is very subjective and qualitative. Human observations always cause some errors.

Masses and microcalcifications are identified as the breast abnormalities which are indicators to the breast cancer. Microcalcifications have high attenuation properties, small size and low contrast. Microcalcifications sometimes can be misinterpreted as noise in the inhomogeneous background. According to Bozek *et al*. (2009), when radiologists overlook some microcalcification with higher accuracy software of detection too much, this could produce more false positive results.

Indra *et al.* (2011) and Dominquez *et al.* (2008) proved that large number of regions must be processed, which cost more in computing times and resources in

order to produce high sensitivity and less false positive.

Laszlo *et al.* (2010) found that many researchers faced difficulty to conduct with sufficient statistics and objectivity. There had been an improvement in the detection algorithms but their performance still not perfect. There were still many false positive outputs because the areas under the ROC curves were normally below 90%. Image enhancement must be developed to reduce computing times and resources. The algorithms for image enhancement must be simple and the implementation does not required complex computations while reducing the false positive results.

1.3 Research Objectives

The aim of the research is to perform the quantitative mammographic phantom image analysis using Receiver Operating Characteristic (ROC) technique. The objectives are:

- To develop image enhancement techniques and determine whether the techniques improve the image quality.

- To determine the peak signal to noise ratio (PSNR) and mean squared error (MSE) values for original and enhanced images.

- To compare the quality of images with and without enhancement techniques by using ROC analysis.

- To evaluate mammographic phantom images using subjective evaluation rating scale.

1.4 Scope of Study

This study was intended to determine the quantitative mammographic phantom image quality using Receiver Operating Characteristic (ROC) analysis. Each mammographic phantom was divided into eleven partitions which contain micronodules, nodules and fibrils were arranged randomly. Twenty mammographic phantom images were analysed to investigate the characteristic and accuracy of detection of nodules, fibrils and micronodules.

The mammographic phantom images were obtained using Digital Mammography System at Sultan Ismail Hospital with kilovoltage range between 28 kV to 30 kV and multiple types of filter. Different values of kVp, mAs and type of filters were used to test the effect on image quality.

For the preprocessing techniques, low pass Gaussian filter were used to denoise the image. The structures of the image were enhanced using morphological techniques and 2D wavelet transform. Morphological operation using dilation and morphological closing were used in morphological techniques. In 2D wavelet transform application, Biorthogonal 2.8 wavelet filter was applied with two levels of decomposition (L = 2). The performances of the selected methods were compared.

After enhancement, each observer interpreted the embedded structures in each mammographic phantom image subjectively. The images before enhancement also have been scored based on the selected scale. The performance of the enhancement methods were evaluated using ROC analysis and rated based on contrast visibility of mammary gland and adipose tissues with its granularity and sharpness.

1.5 Organization of Thesis

The thesis is organised as follow, Chapter 1 describes the usage of digital mammography among radiologists, image enhancement development, research objectives and scopes of this study. In Chapter 2, literature review regarding previous studies in wavelet applications and morphological techniques will be discussed. Theory about principle of digital mammography, basic principles of image acquisition and enhancement methods will be elaborated in this chapter. The development of breast phantom, the working flow of image acquisition, image enhancement techniques, image scoring and ROC analysis method will be elaborated in Chapter 3. Chapter 4 will be discussed the comparison of ROC area under the curves between observers. The relationship between the curves from the ROC analysis and subjective evaluation rating scales will be explained in this chapter. Finally in Chapter 5, the conclusion of this study and future work will be discussed.

REFERENCES

Adel, M., Zuwala, D., Rasigni, M. and Bourennane. S. (2008). Filtering Noise on Mammographic Phantom Images using Local Contrast Modification Functions. *Image and Vision Computing*. 26: 1219 - 1229.

Ahmed, S.N. (2007). *Physics and Engineering of Radiation Detection*. London: Elsevier. 97 – 101.

Alfonso, R.D. and Asoke, K.N. (2008). Detection of Masses in Mammograms via Statistically based Enhancement, Multilevel-Thresholding Segmentation and Region Selection. *Computerized Medical Imaging and Graphics*. 32: 304 - 315.

Alvarez, M., Velo, A.F., Miranda, R.A., Pina.D.R. and Duarte,S.B. (2011). Automatic Detection of Masses and Nylon Fibers in Mammographic Phantom Images. *Proceedings of the International Conferences on Mathematics and Computational Methods Applied to Nuclear Science and Engineering*. Rio de Janeiro, Brazil.

Alvarez, M., Pina, D.R., Duarte, S.B., Souza, R.T.F., Velo, A.F., Trindade, A.P. and Miranda, J.R.A. (2013). Wavelets in the Computed Evaluation of Mammographic Accreditation Phantom Images. *IFMBE Proceedings*. 39: 811 - 814.

Amutha, S., Ramesh Babu, D.R., Ravi Shankar, M. and Harish Kumar, N. (2011). Mammographic Image Enhancement using Modified Mathematical Morphology and Bi-Orthogonal Wavelet. *IEEE Transaction On Medical Imaging*: 548 - 552.

Aneja, R.D., Gupta, S. and Batra, V. (2011). An Enhanced Bi-Orthogonal Wavelet filter for Image Compression. *International Journal of Computer Sciences and Communications.* 2: 351-354.

Bikesh, K.S. (2011). Mammographic Image Enhancement, Classification and Retrieval using Color, Statistical and Spectral Analysis. *International Journal of Computer Applications.* 27: 18 – 23.

Bozek J., Mustra, M., Delac, K. and Grgic, M. (2009). A Survey of Image Procesing Algorithms in Digital Mammography in Grgic, M., Delac, K. and Ghanbari, M., (Eds), *Recent Advances in Multimedia Signal Processing and Communication*, Berlin Heidelberg, Springer, 631- 657.

Buseman, S., Mouchawar, J., Calonge, N. and Byers, T. (2003). Mammography Screening Matters for Young Woman with Breast Carcinoma. *American Cancer Society.* 352-358.

Caldwell, C.B. and Yaffe, M.J. (1990). Development of an Anthropomorphic Breast Phantom. *Medical Physics*. 17: 273 – 280.

Cheng, H.D. and Hu, H. (1998). A Novel Fuzzy Logic Approach to Microcalcification Detection using Fuzzy Logic Techniques. *IEEE Transaction On Medical Imaging*. 17: 442 – 450.

Cole, E.B., Pisano, E.D., Zeng, D., Muller, K., Aylward, S.R. (2005). The Effects of Gray Scale Image Processing on Digital Mammography Interpretation Performance. *Academic Radiology*. Elsevier.

Diekmann, F., Heinlein, P., Drexl, J., Grebe, S., Gossler, A., Schneider, W. And Hamm, B. (2001). Visualization of Microcalcifications by Full-Field Digital Mammography using a Wavelet Algorithm. *International Congress Series*. 1230: 526 – 530.

Dominquez, A.R. and Nandi, A.K. (2008). Detection of Masses in Mammograms via Statistically based Enhancement, Multi-Level Thresholding Segmentation and Region Selection. *Computerized Medical Imaging and Graphics*. 32: 304 – 315.

Dougherty, G. (1998). Computerized Evaluation of Mammographic Image Quality using Phantom Images. *Computerized Medical Imaging and Graphics*. 22: 365– 373.

Eigen, Z. (2007). Morphological Enhancement of Medical Images in a Logarithmic Image Environmnet. *IEEE Transaction on Digital Signal Processing*. 171-174.

Eckert, M.P. and Chakraborty, D.P. (1994). Quantitative Analysis of Phantom Images in Mammography. *SPIE Image Processing*. 2167: 887 -899.

Fan, J., Upadhye, S. and Worster, A. (2006). Understanding Receiver Operating Characteristic (ROC) Curves. *Can J Emerg Med*. 8(1): 19 – 20.

Fawcett, T. (2006). An Introduction to ROC Analysis. *Pattern Recognition Letters*. 27: 861 – 874.

Feig, S.A., D'Orsi, C.J., Hendrick, R.E., Jackson, V.P., Kopans, D.B., Monsees, B., Sickles, E.A., Stelling, C.B., Zinninger, M. and Buchalla, P.W. (1998). American College of Radiology Guidelines for Breast Cancer Screening. *American Journal of Radiology*. 171: 29-33.

Ferreira, C.C., Ximenes, R.E., Garcia, C.A.B., Vieira, J.W. and Maia, A.F. (2010). Total Mass Attenuation Coefficient Evaluation of Ten Materials commonly used to simulate Human Tissue. *Journal of Physics: Conference Series* 249: 1– 5.

Giger, M.L., Chan, H.P. and Boone, J. (2008). History and Status of CAD and Quantitative Image Analysis: The Role of Medical Physics and AAPM. *Medical Physics:* 35.

Gonzalez, R.C., Woods, R.E. and Eddins, S.L. (2004). *Digital Image Processing*. Prentice Hall. New Jersey. 366 – 374.

Guillaume, K., Tiedeu, A. And Martin, K. (2007). Automated Detection of Masses in Mammograms by Local Adaptive. *Computers in Biology and Medicine*. 37: 37 – 48.

Gunturu, V.K. and Sharma, A. (2010). Contrast Enhancement of Mammographic Images Using Wavelet Transform. *IEEE Transaction of Medical Imaging*.

Hajar, M., Setayeshi, S., Karimian, A.R., Sirous, M., Akbari, M.E. (2012). Comparing the Performance of Image Enhancement Methods to Detect Microcalcification Clusters in Digital Mammography. *Iranian Journal of Cancer Prevention*. 5: 61 – 68.

Haralick, R.M., Sternberg, S.R. and Zhuang, X. (1987). Image Analysis using Mathematical Morphology, *IEEE Transactions on Pattern Analysis and Machine Intelligence*. 9: 532 – 550.

Harish, K.N., Amutha, S. and Ramesh, B.D.R. (2012). Enhancement of Mammographic Images using Morphology and Wavelet Transform. *International Journal of Computer Technology & Applications*. 3: 192 – 198.

Heinlein,P., Drexl, J. and Schneider, W. (2003). Intergrated Wavelets for Enhancement of Microcalcifications in Digital Mammography. *IEEE Transaction in Medical Images.* 22: 402-413.

Heric, D. and Potocnik, B. (2006). Image Enhancment by Using Directional Wavelet Transform. *Journal of Computing and Information Technology – CIT 14*, 4: 299 – 305.

Hiroshi, K., Tokiko, E., Mitsuru, I., Mikinao, O. and Ishigaki, T. (2006). Evaluation of New Image Processing Conditions for Digital Mammograms from Fuji Computed Radiography. *Nagoya Journal Medical Science*. 68: 131 – 138.

Indra, K.M., Sanjay, N. And Bandyopadhyay, S.K. (2011). Identification of Abnormal Masses in Digital Mammography Images. *International Journal of Computer Graphics*. 2: 17 – 30.

Juarez, C.L., Ponomargov, V and Sanchez, J.R. (2006). Detection of Meicrocalcifications in Digital Mammographic Images Using Wavelet Transform. *Proceedings of the Electronics, Robotics and Automative Mechanics Conference*. Mexico.

Kallergi, M. (2004). Computer- Aided Diagnosis Of Mammographic Microcalcification Clusters. *Medical Physics*. 31: 314 – 326.

Kimori, Y. (2011). Mathematical Morphology-based Approach to the Enhancement of Morphological Features in Medical Images. *Journal of Clinical Bioinformatics*. 1: 1 – 10.

Krupinski, E.A. and Jiang, Y. (2008). Anniversary Paper: Evaluation of Medical Imaging Systems. *Medical Physics*. 35: 645 – 659.

Kumar, R. And Indrayan, A. (2011). Receiver Operating Characteristic (ROC) Curve for Medical Researchers. *Indian Pediatrics*. 48: 277 – 287.

Laszlo, K.T., Nino, A.S., Schreiber, E., Ellis, R., Goralnik, C., Scislaw, S., Cheruvu, R., Masrani, D., Zhang, D., Muller., S. and Heffernan, P. (2010). Three Digital Mammography Display Configurations: Observer Performance in a Pilot ROC Study. *IWDM 2010*. Berlin Heidelberg, Springer,. 280 – 287.

Lee, Y., Tsai, D.Y. and Shinohara, N. (2010). Computerized Quantitative Evaluation of Mammographic Accredition Phantom Images. *Medical Physics*. 37: 6323 – 6330.

Mark, B.W.,Anthony, J.S., Joseph, Y.L. and Yaffe, M.J.(2008). Optimization of Exposure Parameters in Full Field Digital Mammography. *Medical Physics*. 35: 2414-2423.

Mahesh, M. (2004). Digital Mammography: An Overview. *RadioGraphics*. 24: 1747-1760.

Marques. (2011). *Practical Image and Video Processing using MATLAB*. Hoboken, New Jersey: John Wiley & Sons. 299-334

Mayo, P., Rodenas, F., Verdu, G. (2004). Comparing Methods to Denoise Mammographic Images. *Proceedings of the 26th Annual International Conference of the IEEE EMBS.*

Mehroob, A., Badawy, W., Dimitrov, V. and Jullien, G. (2005). An Efficient Architecture for a Lifted 2D Biorthogonal DWT. *Journal of VLSI Signal Processing*. 40: 335 – 342.

Mencattini, A., Salmeri, M., Lojacono, R., Frigerio, M. and Caselli, F. (2008). Mammographic Image Enhancement and Denoising for Breast Camver Detection Using Dyadic Wavelet Processing. *IEEE Transaction on Instrumentation and Measurement*. 57: 1422 -1430.

Metz, C.E. (1978). Basic Principles of ROC Analysis. Seminars in Nuclear Medicine. 8: 283 – 298.

Mohideen, K. Perumal, A., Krishnan and Sathik, M. (2011). Image Denoising and Enhancement using Multiwavelet with Hard Threshold in Digital Mammographic Images. *International Arab Journal of e-Technology*.2: 49 – 55.

Mostafa, L., Rozi, M., Abd Rahman, R., Suhaimi, N., Beikzadeh, M.R. and Wan Eny Zarina, W.A.R (2011). Effects of Image Processing Techniques on Mammographic Phantom Images: A Pilot Study. *Pertanika Journal Science & Technology*. 19: 67 – 76.

Muller, S. (1997). Full-field Digital Mammography Designed as a Complete System. *European Journal of Radiology*. 31: 25 34.

Naseem (2007). Assessment of Radiation Protection Awaremess Levels in Medical Radiation Science Technologies. *Journal of Postgraduate Medical Institute*. 21: 169-172.

Nien Yu, S., Yuei Li, K. And Kun Huang, Y. (2006). Detection of Microcalcifications in Digital Mammograms using Wavelet Filter and Markov Random Field Model. *Computerized Medical Imaging and Graphics*. 30: 163 – 173.

Norhene, G.B.A., Alima, D.M. and Dorra, S.M. (2012). Robust Contrast Enhancement for Digital Mammography. *International Journal of Computer Applications.* 56: 15 -19.

Obuchowski, N.A. (2003). Receiver Operating Characteristics Curves and Their Use in Radiology. *Radiology*. 229: 3 – 8.

Oliver, A., Freixenet, J., Marti, J., Perez, E., Pont, J., Denton, E.R.E. and Zwiggelaar, R. (2010). A Review of Automatic Mass Detection and Segmentation in Mammographic Images. *Medical Image Analysis*. 14: 87 – 110.

Panda, R.N., Panigrahi, B.K. and Patro, M.R. (2009). Feature Extraction for Classification of Microcalcifications and Mass Lesions in Mammograms,*IJCSMS International Journal of Computer Science and Network Security*. 9: 255-265.

Papadopoulos, A., Fotiadis, D.I. and Costaridou, L. (2008). Improvement of Microcalcifications Cluster Detection in Mammography Utilizing Image Enhancement Techniques. *Computers in Biology and Medicine*. 38: 1045 – 1055.

Park, S.H., Goo, J.M. and Hee Jo, C. (2004). Receiver Operating Characteristics (ROC) Curve: Practical Review for Radiologists. *Korean Journal of Radiology*. 5: 11 – 18.

Pickard, J.M. (2004). *Using Receiver Operating Characteristics (ROC) Curves to Evaluate Digital Mammography*. University of Texas Health Science Center, San Antonio, Texas, USA.

Pisano, E.D., Yaffe, M.J. and Kuzmiac, C.M. (2004). *Digital Mammography*. Philedelphia, Lippincolt: Williams & Wilkins. 1 – 11.

Ponraj, D.N., Jenifer, M.E., Poongodi, P. and Manoharan, J.S. (2012). Morphological Operations for the Mammogram Image to Increase the Contrast for the Efficient Detection of Breast Cancer. *European Journal of Scientific Research*. 68: 494 – 505.

Ramezanpour, H., Barati, N., Darmani, G. (2010). Application of Adaptive Filters in Noise Reduction in Mammography Images. *Proceedings of 2010 International Conference on Systems in Medicine and Biology.*, Kharagpur, India.

Salvado, J. and Roque, B. (2005). Detection of Calcifications in Digital Mammograms using Wavelet Analysis and Contrast Enhancement. *IEEE Transaction of Medical Imaging*. 200 – 205.

Singh, T., Nagraja, M., Swarnalata, R., Bhattacharya, M. And Bommanalli, S. (2011). Enhancing Image Contrast of Mammogram & Equalization of Histograms. *International Journal of Engineering Science and Technology*. 3: 563 – 572.

Sivaramakrisha, R., Obuchowski, N., Chilcote, W.A., Cardenosa, G.and Powell, K.A. (2000). Comparing the Performance of Mammographic Enhancement Algorithms: A Preference Study. *American Journal of Radiology*. 175: 45 – 51.

Song, L. Wang, Q. and Gao, J. (2006). Microcalcifications Detection using Combination of Wavelet Transform and Morphology. *IEEE Transaction on Signal Processing:* 4

Stemberg, D.R.M., Schiabel, H. and Guimaraes, L.T.G. (2009). Development of a Breast Statistical Phantom Prototype for Mammographic Image Qualification. *International Federation for Medical and Biomedical Engineering Proceedings*. 25: 106 – 109.

Strickland, R.N. and Hahn, H.I. (1996). Wavelet Transform for Detecting Microcalcifications in Mammograms. *IEEE Transaction On Medical Imaging*. 15: 218 – 229.

Tomislav, S. and Reljin, B. (2010). Enhancement of Microcalcifications in Digitized Mammograms: Multifractal and Mathematical Morphology Approach. *Faculty of Mechanical Engineering Transactions*. 38: 1- 9.

Turner, J.E. (2007). *Atoms, Radiation and Radiation Protection*. Weinheim: Wiley-Vch. 189 – 190.

Vijaykumar, V.R., Vanathi, P.T. and Kanagasabapothy, P. (2010). Fast and Efficient Algorithm to Remove Gaussian Noise in Digital Images. *IAENG International Journal and Computer Science*. 37: 1-7.

Virmani, J. and Kumar, V. (2012). Morphological Enhancement of Microcalcifications in Digital Mammograms. *Journal of the Institution of Engineers (India): Series B.* 93: 163-172.

Williams, M.B., Raghunathan, P., Mitali, J., Seibert, J.A., Kwan, A., Lo, J.Y., Samei, E., Ranger, N.T., Fajardo, L.L., McGruder, A., McGruder, S.M., Maidment, A.D.A., Yaffe, M.J., Bloomquist, A. and Mawdsely, G.E. (2008). Optimization of Exposure Parameters in Full Field Digital Mammography.
Medical Physics. 35: 2414 – 2423.

Yaffe, M.J. (2001). Digital Mammography – Detector Considerations and New Applications. *Nuclear Instruments and Methods in Physics Research* . 471: 6 – 11.

Yin, F.F., Giger, M.L., Doi, K., Vyborny, C.J. and Schmidt, R.A. (1994). Computerized Detection of Masses in Digital Mammograms: Automated Alignment of Breast Images and its Effect on Bilateral-Subtraction Techniques. *Medical Physics*. 21: 445-452.

Yip, W.M., Pang, S.Y., Yim, W.S. and Kwok, C.S. (2001). ROC Curve Analysisof Lesion Detectability on Phantoms: Comparison of Digital Spot Mammography with Conventional Spot Mammography. *The British Journal of Radiology*. 74: 621 – 628.

Yoon, J.H. and Yong, M. (2002). Enhancement of the Contrast in Mammographic Images using The Homomorphic Filter Method. *IEICE Transactions on Informations and Systems.* 85: 298-303.

Young, K.C., Engen, R.V., Bosmans, H., Jacobs, J., Zanca, F. (2010). Quality Control in Digital Mammography. *Digital Mammography (Eds) U. Bick and F. Dlekmann*. Springer. 220.