SIMULATION OF BREAST CANCER IMAGING USING MAGNETIC INDUCTION TOMOGRAPHY

by

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LIST OF ABBREVIATIONS

MIT	Magnetic Induction Tomography
LBP	Linear back projection
NOSER	Newton one-step error
TSVD	Truncated singular value decomposition
RES	resolution
MAG	magnification
PE	position error
FEA	Finite Element Analysis
2D	Two-dimensional
3D	Three-dimensional
ANN	Artificial neural network
ELM	Extreme Machine Learning
MIS	Magnetic induction spectroscopy
IV	Induced voltage
IPS	Inductive phase shift

Pengimejan Kanser Payudara dengan Menggunakan Tomografi Aruhan Magnet

ABSTRAK

Dalam usaha untuk mengurangkan trauma fizikal yang disebabkan oleh tekanan payudara, pendedahan kepada radiasi dan kos yang tinggi bagi menjalani ujian diagnostik, sistem kos baru yang berkesan, iaitu, magnet aruhan tomografi (MIT) dicadangkan untuk mengenal pasti dan mengesan kedudukan tumor dalam kalangan tisu payudara heterogen. Teknik ini beroperasi dengan cara yang tidak invasif dan tanpa bersentuhan secara langsung dengan dada. Sistem pengimejan simulasi berangka ini terdiri daripada 16 gegelung penderia dengan 1 gegelung bertindak sebagai pemancar dan yang lain sebagai penerima pada tempoh masa yang tunggal, yang membawa kepada sejumlah 240 bacaan penerima. Bacaan penerima dan 240 matriks sensitiviti yang dihasilkan kemudiannya digunakan untuk membina semula imej payudara menggunakan algoritma linear unjuran belakang (LBP) selepas perbandingan yang teliti telah dibuat ke atas algoritma tersebut dengan algoritma newton satu langkah ralat (NOSER) dan nilai tunggal dipenggal penguraian (TSVD). Imej-imej yang dibina semula telah dinilai dari segi tiga metrik ralat yang penting iaitu resolusi (RES), pembesaran (MAG), dan kesilapan kedudukan (PE). Ralat purata adalah 0.004728, 13,7793, dan 45,1929 untuk metrik RES, MAG dan PE masing-masing. Walau bagaimanapun, ralat purata nilai metrik untuk imej barah yang terletak paling dalam, di asalan (0,0), menunjukkan keputusan yang lebih baik dari segi PE, iaitu -2,5356. Korelasi yang kuat antara bacaan penderia MIT dan saiz barah payudara simulasi juga diperhatikan daripada nilai persegi R larasan iaitu 0.998, ini menunjukkan bahawa data yang diperhatikan sangat rapat dengan garisan regresi. Keputusan yang diperolehi mengesahkan bahawa reka bentuk MIT dan imej algoritma pembinaan semula yang dicadangkan menyediakan alternatif yang menjanjikan untuk pengimejan kanser payudara walaupun kajian lanjut diperlukan untuk mengesahkan data simulasi MIT.

Breast Cancer Imaging Using
Magnetic Induction Tomography

ABSTRACT

In order to reduce the physical trauma caused by breast compressions, exposure to radiations and the high price of diagnostic tests, a new cost effective magnetic induction tomography (MIT) system is proposed to identify and locate tumors among the heterogeneous breast tissues. This technique operates in a non-invasive and contactless manner with the breasts. The numerical simulation imaging system consists of 16 sensor coils with 1 coil acting as the transmitter and the rest as receivers at a single time period, leading to a total of 240 receiver readings. The receiver readings and 240 generated sensitivity matrices were then used to reconstruct the images of the breast using linear back projection (LBP) algorithm after a careful comparison has been made on the algorithm with newton one-step error reconstruction (NOSER) and truncated singular value decomposition (TSVD) algorithms. The reconstructed images were assessed in terms of three essential error metrics which are the resolution (RES), magnification (MAG), and the position error (PE). The average errors are 0.004728, 13.7793, and 45.1929 for the RES, MAG and PE metrics respectively. Nonetheless, the average error metric values for the images of tumors located deepest, at the origin (0,0), show better results in terms of PE, that is -2.5356. A strong correlation between the MIT sensor readings and the size of simulated breast tumor was also observed from the adjusted R square value which is 0.998, indicating that the data fitted are very close to the regression line. The obtained results verify that the proposed MIT design and image reconstruction algorithm provide a promising alternative for breast cancer imaging although further studies are required to validate the simulation MIT data.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The detection of early breast cancer in surrounding normal tissue can be challenging, but it is essential to determine the subsequent treatment. The physical basis of magnetic induction is being profited to propose novel diagnostic techniques for breast cancer, but with challenges that need to be overcome. Moreover, its reliability and feasibility is still in the focus of much controversy as there are only few database available and detailed research that has been conducted. Therefore, the aim of this study is to investigate the feasibility of magnetic induction as pathological phenomena biomarker in the breast cancer diagnosis, in order to establish a new approach for not only reliable, low-cost, non-invasive and real-time detection of breast cancer but also in a contactless environment with the patient.

In this study, the aforementioned magnetic induction based technology will be developed in a simulation platform for identifying malignancies transcutaneously through a systematic study, ranging from the analysis phase to the verification and validation phase. This includes the generation of 2D and 3D models of the breast with various coil configurations for single transceiver pair (spectroscopy) as well as multi transceiver pairs

(tomography) of the magnetic induction system, reconstruction of images obtained from the simulation results using suitable image reconstruction algorithms and verification of the simulation system by using suitable classification techniques, statistical analysis and image quality assessments.

This pioneering work will provide proof-of-concept for cancer diagnosis based on the electrical signatures that differentiate malignancies from normal tissue, utilizing the magnetic induction technique. Furthermore, this work will also contribute to the understanding of correlations between electrical properties and biological functions, which will help to explore magnetic induction techniques for wider medical and bioscience applications. Moreover, this research will also be conducive to investigations of novel devices for cancer diagnosis in clinical practices. If its clinical applicability is demonstrated, magnetic induction based breast cancer detection could be the next giant leap in cancer diagnosis as it changes the assessment mode of breast cancer and opens the door for the development of a more efficient way of treating such patients.

1.2 Problem Statement

Detection of breast cancer surrounding normal tissue is a challenging task and the detection is very essential to determine the subsequent treatment. The traditional imaging modalities which include ultrasound, mammography as well as Magnetic Resonance Imaging (MRI),each have their limitations that urge the need for a new pre-diagnosis method that is economical, safe, non-invasive and causes lesser or almost no physical and mental trauma to users. However, the new pre-diagnosis method must be able to detect

tumor size as small as 0.01 m radius or lesser, in conjunction to the the actual stage 1 breast tumor sizes (Stevens, 2016). Among the promising alternatives that fit the aforementioned criteria of a good pre-diagnosis method is the magnetic induction method.

1.3 Hypothesis

A transmitter coil introduces primary magnetic field into the breast tissue and electrical current will be induced in the receiver coil as a function of magnetic induction. A perturbation of the primary magnetic field, the secondary field, will be generated upon transmission through the electrically conductive medium of breast and tumor volumes. Therefore, a voltage difference that is derived from both the aforementioned magnetic signals collected from the receiver coil estimates the ultimate inductive phase shift which denotes the malignancy status of the breast.

1.4 Significance of the Study

- The understanding of the distibution of electrical conductivity, induced current density, magnetic vector potential, current density and inductive phase shift differences between normal breast tissues and malignant tumors.
- The understanding of the technical challenges of magnetic induction mechanism based breast cancer detection system.
- The knowledge of the optimal frequency range for magnetic induction based breast cancer detection system.

- The understanding of correlation of the inductive phase shift measurements with different inductor-sensor coil configurations, tumor locations and sizes.

1.5 Research Objectives

The use of magnetic induction technique for malignancy identification is considered novel with existing challenges that need to be overcome thereby enhancing its applicability that is still in the focus of much controversy. Therefore the objectives of the research are to

i. Investigate the inductive phase shift utility as a cancerous breast tissue biomarker using Finite Element Analysis (FEA) on:

a. Normal breast model

b. Breast with malignant tumor model

ii. Study suitable image reconstruction algorithms to reconstruct images from 2D MIT simulation results.

iii. Test and validate the MIT system using suitable classification algorithms and image quality assessments.

1.6 Scope

In this work, only 2D model simulation data is utilized as a proof of concept for breast cancer imaging using MIT. Following the data collection, data verification using classifications and image quality assessments, also, predictive validation using parametric statistical analysis are done.

1.7 Thesis Organization

This thesis elaborates and justifies the principle of magnetic induction tomography, also its applicability in detecting and positioning malignant breast lesions respectively. The whole process of the research project carried out is presented in seven unique chapters.

Chapter 1 (current chapter) basically serves as a prologue to introduce the research project and the organization of the overall dissertation.

Chapter 2 gives a retrospective idea on the techniques used in the diagnosis of breast cancer. It begins with an overview of breast cancer, followed by a brief description on earlier research works done related to electrical bio-impedance, microwave, photoacoustic and other hybrid techniques in diagnosing breast cancer; a brief introduction on the magnetic induction technique and its potential in detecting breast tumor; image reconstruction algorithms are also discussed.

Chapter 3, which is divided into two parts namely, magnetic induction spectroscopy and magnetic induction tomography. This chapter describes the feasibility of the magnetic induction concept to detect the cancer of the breast, the forward problem of the 2D and 3D FEA model of the breast with the respective breast cancer detection or imaging systems, the parameters involved in the simulation setup as well as the simulation criteria.

Chapter 4 begins with the introduction to sensitivity matrix as it is the key step for every inverse problem. The inverse problem is the electrical conductivity image reconstruction of the simulation data collected. It is done using LBP, NOSER and TSVD is later elaborated in this chapter. Verification works using artificial intelligence and image quality assessments are also discussed in depth followed by statistical tools used to validate the simulation data.

Chapter 5 and Chapter 6 present and discuss the results obtained throughout the research. Chapter 5 shows and discusses the simulation results of the MIS while Chapter 6 explains both the eight and 16 channel MIT results. The latter include the reconstructed images using algorithms outlined in Chapter 4, the classification results using ANN and ELM, the results of image error metrics and statistical analysis.

Chapter 7 summarizes the findings of the research project with respect to three ultimate goals of the project as per stated in Chapter 1. The contributions of the current work as well

as suggestions on future improvements for commercialization of the invention are also briefly described.

1.8 Research Contribution

The main contribution of this work is the breast cancer imaging using 16 channel MIT. Also a new coil configuration is proposed for the MIS.

CHAPTER 2

COMPARISONS BETWEEN NEW BREAST CANCER DETECTION TECHNIQUES

2.1 Introduction

Breast cancer is an abnormality that is due to the rapid and progressive division of a certain cluster of cells that originates from the breast region of the human anatomy. It is a disease that is frightened by most women as the likelihood of them getting it is higher than men. This is mainly because women generally have denser breast cells and connective tissue (Stevens, 2016). The traditional imaging modalities include ultrasound, mammography as well as magnetic resonance imaging (MRI). Each of them have limitations that urge the need for a new pre-diagnosis method that is economical, safe, non-invasive and causes lesser or almost no physical and mental trauma to users. Many alternative techniques have been actively explored to date in the search for an ultimate solution, to the defects of the conventional imaging modalities in order to detect breast lesions in the least severe stage possible. In the present section, we will be discussing the insights of some of the previously mentioned alternative techniques which are the electrical bio-impedance, microwave, photoacoustic and other hybrid techniques. A potential magnetic induction based alternative to detect breast cancer, and image reconstruction algorithms are also discussed.

2.2 An Overview of Breast Cancer

The statistics shown in one of the articles provided by the National Cancer Registry 2003 states that one out of every nineteen Malaysian woman is bound to develop with this killer disease and this figure is nearly one in eighth for the Europe and United States citizens. In most cases, the patients meet the doctor when a lesion has grown to a very large size and do not come for follow up sessions even if it is discovered in the early stage. This is because the lesion that is cancerous is expected to double in size in a period of three months. Further treatment is only done once the doubling effect and other cancerous features like spiculations are confirmed (Dite et al., 2003). Therefore, it is necessary to detect the cancer at the preliminary stage.

Currently, early detection of breast cancer is done by X-ray Mammography, which is also presently referred to as the gold standard modality by many healthcare institutes. Nevertheless, it is not very accurate and safe as it is unable to distinguish benign and malignant lesions due to their morphological similarities, its reduced sensitivity with age, its radiation hazards plus, its reduced efficiency in diagnosing cancer in patients with denser breast tissues (Jalalian et al., 2013). On top of that, almost 80% of the positive breast cancer cases diagnosed by this modality are negative when malignancy of the tumors is further investigated during biopsy. However, a better pre-biopsy technique should be introduced as biopsy procedures can be both physically and mentally painful. On the other hand, ultrasound is currently used to differentiate cystic and non-cystic growths as it is known for a number of advantages over other imaging modalities that is, it is safe and

thereby is suitable for repetitive scanning, painless, and aids in needle biopsy. Despite its noble features, ultrasound still lacks in the sense that it is not efficient in imaging microcalcifications that are the prognostic indicators of breast cancer. Breast MRI though it has high sensitivity, it is expensive and can be used only under certain clinical circumstances which are mainly for patients with implants or suspected multifocal carcinoma. The potential of Nuclear medicine, Microwave imaging (E. C. Fear, Hagness, Meaney, Okoniewski, & Stuchly, 2002), MRI based Elastography (Van Houten, E. E. W., Doyley, M. M., Kennedy, F. E., Weaver & B., and Paulsen, 2003), Thermography (Ng, E. Y.K. and Fok, 2003), Photoacoustic Imaging (Mallidi, Luke, & Emelianov, 2011), Electrical Impedance Scanning (Malich et al., 2003) and Optical Mammography (Grosenick et al., 2003) in this area have also been discovered but with limited success (Ng, Sree, Ng, & Kaw, 2008). Meanwhile, mastectomy, which is the surgical removal of partial/entire breasts, ligature, which is commonly known as sutures and cautery are other techniques used which causes pain that is rather excruciating. Cautery is an agent to burn, sear or destroy abnormal tissues by means of injection of electric current or burning or laser. Hence, X-ray Mammography still remains as the primary method of diagnosis (Israyelyan, 2003).

Moving on to the anatomy of the breasts, the breasts are visualized as a structure that has many sections called lobes and inside them are smaller subsections called lobules, which connect with the aforementioned lobes via thin tubes formally known as ducts. The above visualization later facilitated in the classification of cancer, namely, cancer cells that arise from lobes, which is called lobular cancer, a cancer that arises from ducts which is called ductal cancer, cancer that has not spread elsewhere, which is the non-invasive (in-

situ) cancer type, and cancer that has spread to other body parts via metastasis which is invasive (infiltrating) cancer type. Many other less common cancer types include inflammatory cancers, medullary carcinoma, mucous carcinoma and tubular carcinoma. In (Wu SC, Hotes J, Fulton JP, Chen VW, Howe HL, Correa C, 2002) ,(Edwards BK, Howe HL, Ries LA, Thun MJ, Rosenberg HM, Yancik R & Jemal A, 2002) it has been reported that the risk factors of breast cancer can vary from early puberty, age, late menopause, high radiation exposure, obesity, race or ethnicity where non-Hispamic white, Hawaian and black women stand higher chance, no child or late first pregnancy, sedentary lifestyle , hereditary (Dite et al., 2003), and miscarriage. Other speculated factors include no breast feeding, abortions, usage of contraceptive pills, dietary practices that consist of high fats, less fruits consumption, alcohol and smoking habits, less intake of phytoestrogens or isoflavenes from plants or soy products (Stephens, 1997). In the same note, the stages of breast cancer in accordance to the Union Internationale Centre Cancer (UICC) can be illustrated based on the size of tumor (T), presence of sentinel axillary lymph nodes and local invasion and evidence of distant metastasis (M).

The following section elaborates on the various researches performed on the four main techniques of the breast cancer diagnosis. The elaboration includes the methods used, databases, analyses softwares used, results and the advantages and disadvantages of their research for future references.