Faculty of Information and Communication Technology

ELLIPTICAL ULTRA-WIDEBAND ANTENNA SENSOR WITH MODIFIED TIME REVERSAL ALGORITHM FOR BREAST TUMOUR LOCALIZATION

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DECLARATION

I declare that this thesis entitled "Elliptical Ultra-Wideband Antenna Sensor with Modified Time Reversal Algorithm for Breast Tumour Localization" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : Sameer Abdulateef Hussein

Date : 25-8-2022

APPROVAL

I hereby declare that I have read this thesis and, in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

Signature : ....

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Date : 25-8-2022

DEDICATION

To my beloved parents

ABSTRACT

Breast cancer is a serious health problem and the second leading cause of death around the globe. The skin around fatty tissues like the breast are the most common and fastest growing of all cancer types. Thus, ultra-wideband (UWB) antenna sensors are considered a promising instrument in microwave imaging tomography with the least destruction in the body's tissue. Several studies have recommended UWB antennas to acquire the target's characteristics and localize them. However, they showed some limitations in terms of bandwidth and resolution to even spending larger printing areas despite showing acceptable outcomes. In addition, the imaging algorithms are usually utilized to combine and sum all the received signals, create an image of the dielectric scatter (tumour) within the human organ, and remove the clutters and artifacts. However, the problem is how to apply and utilize an algorithm for microwave imaging to reconstruct the image of the target in a cluttered environment (like skin and breast) with the most possible artifact and clutter removal (not to mask the tumour response). Therefore, this thesis proposes a UWB antenna sensor with good directional beamwidth, high fidelity, high efficiency, and low group delay at the frequency range of 0-30 GHz. A novel weighted Time Reversal algorithm is introduced to improve the image quality along with removing the clutter in the imaging environment. The proposed elliptical patch antenna sensors loaded by stubs, slots, and truncated ground show complementary results for the imaging of breast skin as they achieve broad BW (>18 GHz), simple elliptical shape of the patch, miniaturized dimensions (15 × 15 mm2), and high fidelity (> 90 % hence low distortion). Notably, there is a good agreement shown between the simulation and measurement results of the proposed antenna. The imaging results show that the proposed algorithm obtained better results in terms of accurate localization, and better removal of image artifacts and clutter. It has shown the accuracy with more than 95 % detection of tumours in breast skin and can perform a hollow with a diameter of 3 mm in any location within the trunk. Besides, no significant discrepancy exists between the images using simulated and measured scattering indicates the system's ability to the detection of tumours in the breast skin.

PENDERIA ANTENA ULTRA-JALUR LEBAR ELIPS DENGAN ALGORITMA PEMBALIKAN MASA YANG DIUBAHSUAI UNTUK PENYETEMPATAN TUMOR PAYUDARA

ABSTRAK

Kanser payu dara merupakan masalah kesihatan yang serius dan merupakan penyebab utama kedua kematian di dunia. Kulit di sekitar tisu lemak seperti payu dara merupakan jenis kanser yang paling biasa dan yang tumbuh pantas antara semua jenis kanser. Oleh itu, sensor antena ultrajalur lebar (UWB) dianggap sebagai instrumen yang menggalakkan dalam tomografi pengimejan mikrogelombang dengan kemusnahan tisu badan terendah. Beberapa kajian telah mengesyorkan antena UWB bagi mendapatkan karakteristik sasaran dan menyetempatkan mereka.Walau bagaimanapun, mereka menunjukkan beberapa limitasi dari segi lebar jalur dan resolusi hingga membataskan kawasan pencetakan yang lebih besar walaupun menunjukkan hasil yang boleh terima. Di samping itu, algoritma pengimejan biasanya digunakan untuk menggabung dan menjumlahkan semua isyarat yang diterima, mewujudkan imej serakan dieletrik (tumor) dalam organ manusia, dan menyingkirkan selerakan dan artifak. Walau bagaimanapun, masalahnya ialah cara untuk mengaplikasi dan menggunakan algoritma bagi pengimejan mikrogelombang bagi membina semula imej sasaran dalam persekitaran yang berselerak (seperti kulit dan payu dara) dengan artifak yang paling wajar dan penyingkiran serakan (bukan untuk melindungi respon tumor). Oleh sebab itu, tesis ini mengesyorkan sensor antena UWB dengan lebar alur terarah yang baik, fideliti tinggi, keberkesanan tinggi, dan kelambatan kumpulan yang rendah pada julat kekerapan 0-30 GHz. Algoritma pembalikan masa berpemberat yang novel telah diperkenalkan bagi memperbaiki kualiti imej di samping menyingkirkan serakan dalam persekitaran pengimejan. Sensor antena tampal elips yang disyorkan yang sarat dengan stub, slot, dan kawasan terpangkas menunjukkan hasil komplementari bagi pengimejan kulit payu dara akibat mereka menerima BW lebar (>18 GHz), bentuk tampal elips yang mudah, dimensi mini (15 × 15 mm2), dan fideliti tinggi (> 90 % oleh itu pengherotan rendah). Yang ketaranya, terdapat hubungan baik yang ditunjukkan antara simulasi dan dapatan pengukuran bagi antena yang disyorkan. Dapatan pengimejan menunjukkan bahawa algoritma memperoleh dapatan yang lebih baik dari segi persetempatan yang tepat, dan penyingkiran artifak imej dan serakan yang lebih baik. Ia menunjukkan ketepatan dengan lebih daripada 95 % pengesanan tumor pada kulit payu dara dan dapat melaksanakan lompang dengan diameter 3 mm pada sebarang lokasi dalam badan. Di samping itu, tidak terdapat diskrepansi signifikan yang wujud antara imej yang menggunakan penyerakan yang disimulasi dan diukur serta memperlihatkan keupayaan sistem bagi mengesan tumor pada kulit payu dara.

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LIST OF ABBREVIATIONS

APES	-	Amplitude and Phase Estimation
BSR	-	Basal Stem Rot
BW	-	Bandwidth
CT	-	Computed Tomography
CST		Computer Simulation Technology
CMI	-	Confocal Microwave Imaging
CPW	-	Co-palanar Waveguide
CR-DAS	-	Channel Ranked Delay-And-Sum
DA	-	Information-adaptive
DAS	-	Delay and Sum
DI	-	Information-Independent
DMAS	-	Delay Multiply and Sum
ECVT	-	Electrical Capacitance Volume Tomography
EBG		Electromagnetic Band Gap
FCC	-	Federal Communication Commission
FDAS	-	Filtered Delay-And-Sum
FDTD	-	Finite Difference Time- Domain
GND	-	Ground
GPR	-	Ground Penetrating Radar
HRXCT	-	High-Resolution X-Ray
ISM	-	Industrial Scientific Medical
MSA	-	Microstrip Slot Antenna
MW	-	Microwave
MWT	-	Microwave Tomography
OPT	-	Oil Palm Trunk
SCB	-	Standard Capon Beamformer
SSIM	-	Structural Similarity Index for Image
SUT	-	Sample Under Test
TL	-	Transmission
TR	-	Time Reversal
UAV	-	Unmanned Aerial Vehicles
US	-	Ultrasonic
UWB	-	Ultra-wide-band
VNA	-	Vector Network Analyser
VSWR	-	Voltage Standing Wave Ratio
WSN	-	Wireless Sensor Network

LIST OF PUBLICATIONS

1. Alani, Sameer, Zahriladha Zakaria, Tale Saeidi, Asmala Ahmad, Hussein Alsariera, Othman S. Al-Heety, and Sarmad Nozad Mahmood. 2021. 'Electronic Bandgap Miniaturized UWB Antenna for Near-Field Microwave Investigation of Skin'. *AIP Advances* 11(3).

2. Alani, Sameer, Zahriladha Zakaria, Tale Saeidi, Asmala Ahmad, Muhammad Ali Imran, and Qammer H. Abbasi. 2021. 'Microwave Imaging of Breast Skin Utilizing Elliptical Uwb Antenna and Reverse Problems Algorithm'. *Micromachines* 12(6).

3. Alani, Sameer, Zahriladha Zakaria, Tale Saiedi, Asmala Ahmad, Sarmad Nozad Mahmood, Mohammed Ayad Saad, Sami Abduljabbar Rashid, Mustafa Maad Hamdi, and Ma'ath Abdulla A. Arab. Albeyar. 2020. 'A Review on UWB Antenna Sensor for Wireless Body Area Networks'. *4th International Symposium on Multidisciplinary Studies and Innovative Technologies, ISMSIT 2020 - Proceedings*.

CHAPTER 1

INTRODUCTION

1.1 Introduction

With nearly 3.5 million new cases and billions of dollars in care costs worldwide, skin cancer is the most prevalent and fastest growing of all cancer forms. Skin around fatty tissues like the breast are the most common and fastest growing of all cancer types. A dermatologist's visual examination is commonly used to diagnose it, but visual inspection is subjective and subject to error. Skin with insufficient melanin is vulnerable to sunburns as well as the sun's harmful ultra-violet rays. Besides, the skin on the breast was also interested to be examined, especially for women since they are also at risk of breast cancer. According to the researchers, the disorder needs early detection to detect specific signs that physicians and dermatologists may use to prevent it. It has been established that this condition is unpredictable (Abuzaghleh et al., 2015).

For skin lesions and tumour margin measurement, a variety of imaging techniques are being tested as diagnostic methods. With axial and lateral resolutions of 80 mm and 200 mm, respectively, and a penetration depth of 7 mm, high-frequency ultrasound (Jovanovic et al., 2012) can visualise tumour dimensions in vivo (Petrovský et al., 2000; Astner et al., 2008). However, since the technique lacks chemical precision and cannot distinguish between benign and malignant skin lesions, its utility may be limited (Fornage, 1995). When a tumour reaches more than 15 mm below the surface, magnetic resonance imaging may provide valuable information. Magnetic resonance microscopy measurements on human skin with axial and lateral resolutions of 19 µm and 78 µm, respectively. There has been a confirmed penetration depth of 800 mm. However, the use of a whole-body imaging computer, high costs, device complexity, acquisition time, and patient claustrophobia make this procedure unsuitable for imaging skin cancer at the moment (Bushberget al., 1994).

Optical coherence tomography (OCT) and confocal microscopy are two near-infrared (NIR) imaging techniques (wavelength range 0.7-2 m). Both provide information on the structure of the tissue at a deeper level. With a penetration depth of less than 1 mm, OCT can visualise architectural improvements in tissue at spatial resolutions of 10 m. It's difficult to tell the difference between inflammatory and non-inflammatory. Confocal microscopy is a high-resolution, real-time imaging technique that can see cellular and nuclear detail in vivo with lateral and axial resolutions of 1-2 and 3-5 m, respectively, and a penetration depth of 250-300 m (Yu et al., 2002). The current narrow field of view (250250 m) prohibits macroscopic representation of tumour margins, but a larger field of view can be achieved by tiling individual frames into a mosaic (Apostolović-Stojanović et al., 2013). Backscattered photons are used in NIR techniques to create images. As a result, low penetration due to signal loss after a few hundred microns is a major limitation of these techniques. At longer wavelengths, light scattering by tissue is less of a problem.

As a result, UWB antenna sensors can be considered a promising Microwave Imaging tool. To achieve a good detection of the tumourous parts of the skin, especially on the breast with a high resolution and high speed in the analysis, a microwave system is helpful (Lassau et al., 1997; Lieber et al., 2008). Therefore, a new UWB antenna sensor with high performances such as wide BW, high gain, and fidelity is designed.

1.2 Problem statement

Breast tumour is a disease that is unpredictable and can be characterized in each step of the disease development of lesion, Among all different disease identification techniques for tumours in the human body. Besides, it affects the tomography (tomography as a general statement that can be consisted of microwave and radar imaging) outcomes of another cancerous part of the body like breast cancer. Several techniques were applied to reconstruct an image of the tumorous cells. They utilized methods like High-frequency ultrasound, Magnetic resonance imaging, and Near-infrared (NIR) like OCT and CM. Each of them showed some drawbacks that made the researchers seek an alternative. For example, the ultrasound strategies don't have chemical specificity and are not able to distinguish between kind and harmful skin injuries (Fornage, 1995; Petrovský et al., 2000); bulky, complex, more time handling (Bushberget al., 1994) and not pertinent to imaging (Kuranov et al., 2002). Other techniques were carried out to detect the tumours such as MRI, HFUS, TPI, and any others. However, these methods could not completely be trusted since they showed limitations like low resolution and penetration, more expensive, low sensitivity, and slow acquisition (Garbe and Eigentler, 2007; Moulin-Romsee et al., 2008; Xing et al., 2011; Knieling et al., 2018). Therefore, Microwave imaging has been proposed as a possible solution, especially for imaging cancerous cells in the human body. MI technique has been chosen due to its advantages such as being non-invasive, more accurate, giving full information of the material under test, etc (Tale et al, 2019).

Microwave imaging comprises antenna sensors to send and receive signals and then it can differentiate the dielectric alterations and the delays to localize the targets. The most promising sensor utilized for these purposes is (UWB) antennas which help to localize the target by applying their broad bandwidth. Moreover, it should be tried to design a UWB antenna offering high performance in terms of bandwidth, radiation efficiency, fidelity factor, and miniaturized profile.

The main challenge in applying UWB antenna sensors for imaging purposes is how to send and receive the backscattered signal with a minimum level of distortion and noise in signals. High-level distortion and high group delay are serious problems in microwave imaging (Meaney et al., 2012; Zeng et al., 2013; Ahadi et al., 2021). Thus, signal fidelity should be calculated when signal distortion is a critical problem. Fidelity is considered as the magnitude of cross-correlation when it reaches its maximum between the transmitted and received pulses. The received signal plays an important rule in the variations of delay in signal and its amplitude caused by the dispersed signal by the tumour is used in microwave imaging to detect a tumour in the breast. It is very important when the antenna sensor sends and accepts the pulse and does not alter the form of the pulse when it transmits or receives signals.

In addition to that, achieving broad working bandwidth while keeping the dimensions of the antenna sensor small is another serious challenge; for instance, recent designs of UWB antenna sensors for imaging purposes offered a larger size, narrow bandwidth, and low performances (Kaur, 2016; Sarjoghian et al., 2020).

The imaging algorithms are usually utilized to mix and construct the sample under test such as human organs and remove the clutters and artifacts. The problem is how to apply and utilize an algorithm for microwave imaging to reconstruct the image of the target in a cluttered environment (like skin and breast) with the most possible artifact and clutter removal (not to mask the tumour response). It is usually done by calculating the delay of the received signals when they are received by adjacent arrays of the transmitter. Several algorithms have been applied for microwave imaging showing some drawbacks and benefits. For instance, the delay and sum algorithm and its derivatives like improved delay and sum (Byrne et al., 2010; Elahi, 2018), Conventional Time Reversal algorithms (Fink, 1992; Kosmas and Rappaport, 2005; Lerosey et al., 2005; Kosmas and Rappaport, 2006; Chen et al., 2007; Sajjadieh and Asif, 2011; Mukherjee et al., 2018) detected the target with limitations in resolution and accuracy in localization of the target. Therefore, in this study, we will investigate a new antenna sensor to offer broader bandwidth, high radiation efficiency, directive gain, high fidelity factor, and miniaturized profile. Since the previous works had large sizes, it is tried to design an antenna that takes a small printing area; more antennas can be thus integrated and used for imaging purposes so as more scattering and accuracy (when the antenna is small more arrays can be used to more scattering and more accuracy in detection of the tumour). For instance, Islam, M.T., et al 2019, designed an antenna with a bigger size and narrower bandwidth. Furthermore, it is integrated with a robust and improved algorithm to exhibit better resolution and accuracy of the image/ tumour tissue/ object.

1.3 Research objectives

This thesis aims to develop a microwave device for the detection of cancerous cells in the model (phantom) of human skin. To achieve this, the objectives of this thesis include:

1. To design and optimize a UWB antenna sensor with good directional beam width, high fidelity, high efficiency, and low group delay at the frequency range of 0-30 GHz.
2. To develop and improve an algorithm of time reversal to construct the image of the skin and tumours with high resolution.
3. To evaluate the antenna sensor through measurement in the laboratory to verify and localize the tumour cells in the skin.

1.4 Scope of research

Figure 1.1 shows the scope of the study as solid lines are the parts that are included in our research and those with dashed lines are not. A new UWB antenna is designed for an imaging application. This thesis starts with Microwave imaging, in microwave imaging, a UWB is required. During the antenna design, A technique is required to improve the antenna performance like getting wider bandwidth. Thus, a circular ring electronic bandgap (EBG) structure has been used in the antenna design. This EBG structure is utilized to prevent some undesired operating modes

After choosing the antenna sensor shape and type it's designed and fabricated, an antenna using the concept and specifications of a stack patch antenna, wide slot, and monopole antenna with some loadings are utilized for the proposed antenna. Meanwhile, the skin and breast material are fabricated and then dielectric characteristics of the material under test are performed using the open-ended sensor contacted to a coaxial cable. In this research, only the semi-spherical arrangement of the antenna is considered. However, the planar arrangement is used just to show is the antenna works or not. After meeting the UWB antenna sensor requirements in terms of S-parameters, and radiation characteristics, the time domain considerations are performed. The time-domain characterization is to get the received signals in time so they can be used later. Afterward, signal processing and image reconstruction are performed. The passive algorithm like TR is used not the active ones like MIST. It should be mentioned that the tests and results have not been tested on any human sample, it is for future works and the next level of study.

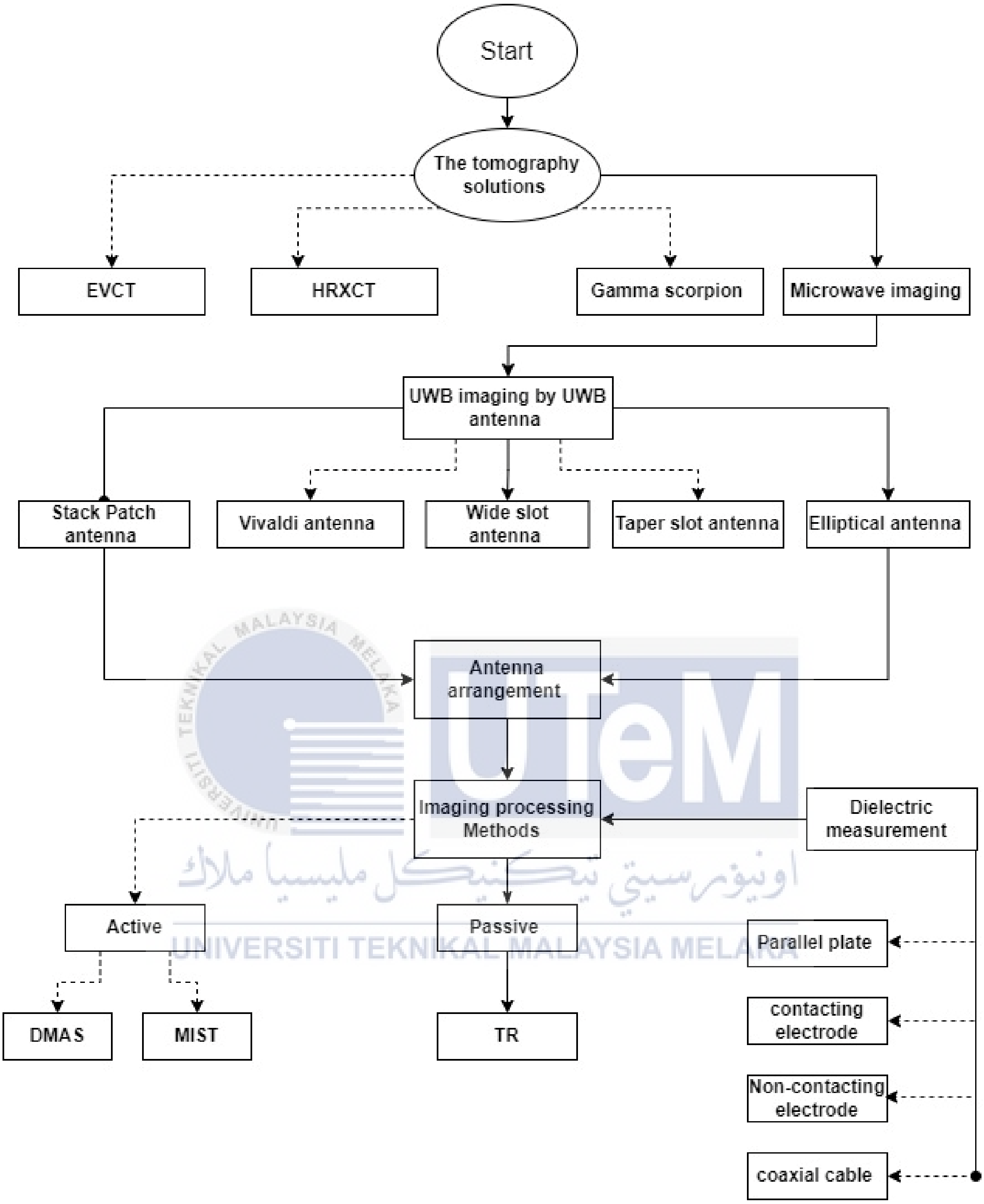

Figure 1.1: Research scopes (solid lines are in scope and dashed lines are out of scope)