Microwave Medical Imaging

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Abstract

This paper reviews microwave imaging techniques used in the screening and diagnosis of cancer cells with special reference to breast cancer cells. There are various microwave imaging techniques which can be used to diagnose cancer cells which can be categorised into three modalities. These are: hybrid microwave induced acoustic imaging techniques, ultra-wide band radar based imaging and microwave tomography. Out of these three modalities, the ultra-wide band microwave (UWB) imaging technique is a particularly polpular, emerging, new field of research. Currently, mammography is the most prevalent screening method in most medical institutions. However it has its disadvantages. It uses ionising energy, it is highly uncomfortable because it involves compression of the breast while offering low resolution images. UWB on the other hand, utilizes non-ionizing radiation and eliminates the discomfort of breast compression. However, the sensitivity and the possibility of differentiating between benign and malignant tumours is still highly debatable in this field of research. This paper reviews past, current and future potential use of microwave imaging methods, the fundamental principles in physics dominating this new field of research and the mathematical analysis that goes along with interpreting the results obtained through microwave imaging. Research in microwave medical imaging is still being carried out till this day and still debatable whether this technique will take over current imaging modalities.

Introduction

Medical imaging is the technique and process by which visual representations of the in- terior of a human body are created for clinical analysis and medical intervention. It's purpose is to render a visual rendering of the human's internal organs and tissues in order to enable better understanding of the human anatomy and physiology (Vinod and Solanke, 2016). Medical imaging is also essential in diagnostics and disease treatment and incor- porates all types of biological imaging and radiology techniques, ranging from magnetic resonance imaging to ultrasound, endoscopy, nuclear and even microwave medical imag- ing, amongst several other imaging techniques. Currently the most popular microwave imaging technique is the Ultra Wideband radar based microwave imaging technique. It utilizes a small part of the electromagnetic spectrum, within the microwave frequency range of 300 MHz to 300 GHz (Zubaida 2012). This imaging modality is currently the most researched technique within the medical physics community.

Currently used Screening Methods

The first time a patient is screened for breast cancer, mammography is used. If the patient is diagnosed with an abnormality which might suggest the presence of a tumour, ultrasound is carried out. Failure in this method in providing any definitive information on whether the patient has any tumour cells, then an MRI scan is carried out. Failure in this method in providing any definitive information on the abnormality of the observed breast leads to a medical biopsy. In this process, the beast tissue is excised and tested in the laboratory. This will enable a classification of the breast sample as healthy, benign or malignant. In this section we are going to go through the basic physics principles which govern mammography, ultrasound and magnetic resonance imaging and go through the advantages and disadvantages of each. Figure 1 shows that for every 1000 women aged between 50 to 69 who have a mammogram every two years for two decades, 334 will be diagnosed with an abnormality, amongst whom 280 will be diagnosed as false positive and 54 as positive. From the original 1000 women, 9 will have breast cancer, but the tumour will not be diagnosed from screening, i.e. 9 will have a false negative. Amongst those 54 diagnosed with cancer and those 9 diagnosed as false negative, 13 will die of cancer. From the rest of the 54 diagnosed with cancer, 7 would have been prevented from dying of breast cancer and the other 34 referred to other imaging techniques. All these observations are summarised in the block diagram (Figure 1).

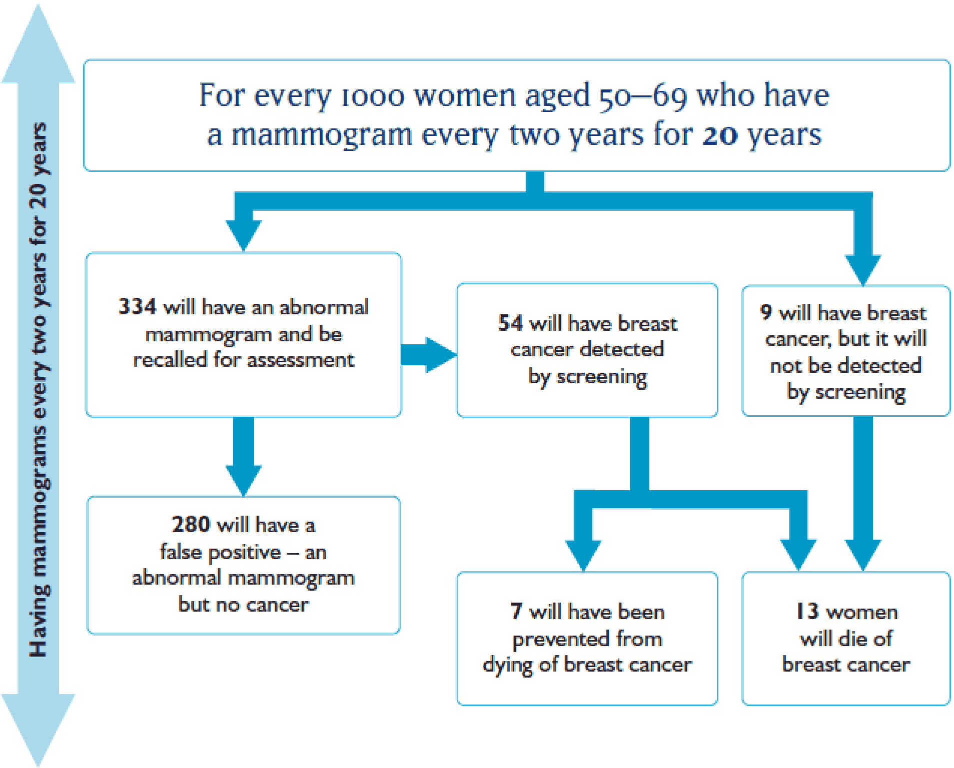

Figure 1: These numbers have been estimated by applying the results of overseas studies to New Zealand.(Health, 2007)

Mammography

Mammography works on the physics principle of applying concentrations of X-rays over the breast in order to obtain an image which maps the geometrical and density distri- butions of the breast. For this technique, the breast is placed between two compressive plates and squashed from different angles during the screening process. When applying concentrations of X-rays over the breast, a gray-scale image is produced where white regions correspond to fibro-glandular tissues and black region correspond to breast tis- sues. The maximum part of most fatty breasts consist of fibro-glandular regions. Hence any discovered tumour using X-ray illumination gives off white regions. Although this technique gives high resolution images, one of its drawbacks is that it does not render much contrast between breast tumours and fatty breast tissues (Raghavan and Ramaraj, 2012). The reason for this stems from the fact that mammograms create images of the breast based on density differences within the breast and in reality, there is only a slight difference in density between normal tissue and tumour cells. Hence this issue becomes problematic when imaging women with dense breasts (Fear, 2008). This results in a low positive predictive rate and many unnecessary biopsies. Other concerns include patient discomfort and pain when compressing the breast and various other health risks associated with exposing the patient to low levels of ionizing radiation (L. Lianlin et al., 2010). These low levels of radiation each time increase the probability of the patient inducing a breast tumour due to the screening method itself (Fear, 2008).

Ultrasound

Ultrasonic Imaging is another diagnostic imaging technique which this time maps the interior of the patient through the exposure of the test area with non-harmful radiation low frequency radiation of sound waves ranging from 1MHz to 15MHz. Ultrasound only determines whether the 'area under consideration consists of a cancerous tissue or not. For a solid tissue found in the testing, it will require a biopsy to be conducted to verify if it is cancerous in nature' (Zubaida, 2012). Ultrasound has many benifits. One of them is that it induces no discomfort to the patient since the transducers/receivers of ultrasound can be positioned at any angle or orientation to the breast. Since ultrasound is non-ionizing, it can also be used extensively used to examine women with dense fibro-glandular tissue or implants while offering high image contrast and resolution. One of its drawbacks is that it cannot detect deep lying lesions (Zubaida, 2012) and does not provide definitive information on whether a solid tumour is malignant or benign (Fear, 2008). Unfortunately it also has a high system performance dependence, meaning that it highly dependent on the human workforce and experience (Zubaida, 2012).

Magnetic Resonance Imaging

Magnetic Resonance Imaging (MRI) is another diagnostic imaging technique which pro- vides a good map of tissue distributions in the breast from different orientations. It is 'a non-invasive technique'. MRI utilized a combination of strong magnets an RF coil and three gradient coils in order to provide images of high density contrasts and resolu- tion (Zubaida, 2012). It has the capability of detecting small tumours, multi-functional cancers, breast implants and ruptures as well. In order to avoid 'interference of the en- vironmental clutter, the system is placed in a protected and shielded room' (Zubaida, 2012). MRI is an excellent imaging tool, however it has its drawbacks. One of them is that it is patient invasive, meaning that most of the time, the patient needs to be injected with a contrast agent, in order for MRI to perform an effective diagnosis of the patient. Most of the time this contrast agent is needed in order to pinpoint minor calcifications or small emerging lymph nodes (Fear, 2008) and (Zubaida, 2012). Moreover, eventhough a contrast agent might sometimes be used, an MRI scan might still not provide a definitive diagnosis of malign cancer. Moreover, although the uptake and washout of the contrast agent in the vicinity of the suspicious lesion is monitored, it may be difficult to provide a definitive diagnosis of malign cancer cells. This stems up from the fact that malign cancer cells do not have behave in a consistent and distinctive manner like their benign coun- terparts (Fear, 2008). Another reason why MRI screening is also not an ideal screening method is because it requires a large area for optimal operation. This forces the machine to be kept at a fixed location and makes it hard to be transferred to another location. As a result, MRI is not ideal for large-scale screening programs. Moreover, patients have to lie down on a table as they are slowly moved into a large cylindrical structure. This has been observed to induce a ‘claustrophobic effect’ on the patient. The situation is not helped by the fact that one screening process is quite lengthy and very time consuming. This results in a small amount of patient scans that one can perform in a day (Zubaida, 2012). This screening method is also quite costly.

Advantages of Microwave Imaging Techniques

Hence MRI and ultrasound are modularities that are not sensitive/specific enough, too op- erator dependent and costly. Combined with the tremendous toll that breast cancer takes on its patients, and persisting concerns with regards to X-ray mammography, scientists continue to drive the search for alternative breast-screening tools that image other phys- ical properties or metabolic changes. Microwave breast imaging is one of the promising alternatives under investigation (Lianlin et al., 2010).

One of the reasons why microwave medical imaging techniques are favoured over the previously outlined methods is because it is non-invasive. No surgery is required and it does not induce any breast compression. Aside from this, this technique gives immediate results and is highly sensitive in detecting cancerous tumours in the breast (Wang, 2014). Moreover, it is non-ionizing, making it significantly safer than X-rays. It also utilizes low illumination power levels, making it ideal for regular screening. Microwaves are hence resulting to be better and safer diagnostic techniques while offering more distinct elec- trical contrast between cancerous tumours and healthy breast tissue, lower power radio frequency signals and low health risks and more comfort to the patient (De Zaeytijd et al., 2007).

Microwave imaging techniques are also low cost. The expense for building a mi- crowave imaging system could potentially be far less than that for CT and MRI. With the widespread use of microwaves in everyday life especially in telecomunications, the man- ufacturing costs of essential components has decreased dramatically. This has enabled components to become smaller, cheaper and more powerful in the construction of new microwave imaging systems. (Fang, 2004) Recent studies have shown that Microwave imaging can also be developed as a detector for ‘perfusion related changes in the brain’ and used for 'imaging modality for stroke management' (Wang and Simpkin, 2013). Recently, ultra-wideband (UWB) microwave imaging has also been widely researched for early breast cancer detection. This method is favoured for its safety, low cost, and simplicity in the assembly (Wang, 2014).

Although, microwave medical imaging seems to be a very promising field in diagnostic medicine, it must be noted though that X-ray mammographies still offer high-resolution images (De Zaeytijd et al., 2007). Thus microwave imaging will probably be used as a clinical complement to x-ray mammography in the near future in order to obtain a balance between image resolution and contrast (Irishina et al., 2006). There are presently three types of microwave imaging techniques used in medical imaging. These are the passive, hybrid and active approaches (Zubaida, 2012). Several approaches to active microwave breast imaging include tomography and radar-based methods. 'Tomography reconstructs a map of the electrical properties in the breast using measurements of energy transmitted through the breast. While Radar-based approaches detect strongly scattering objects (tumours) using measurements of energy reflected from the breast' (Fear, 2008).

Overview of Microwave Imaging Techniques

Passive Microwave Imaging

Passive microwave imaging basically involves the measurements of temperature contrast between cancerous tissues and normal ones. Evidence shows that the cancerous tissues are more chemically active than healthy cells and hence emit more energy as heat. Moreover cancer cells do not have the 'thermoregulatory capacity' i.e. the 'ability to keep temper- ature within certain boundaries' like normal tissues (Zubaida, 2012). Hence by thermally exciting cancer cells one can more easily locate regions exhibiting higher energy contrasts and deduce the exact location of tumour cells. Passive microwave imaging works on this principle. Microwave energy is first targeted towards the breast and by using an array of radiometers any change in temperature at the surface of the breast is detected (Figure 2) (Zubaida, 2012).

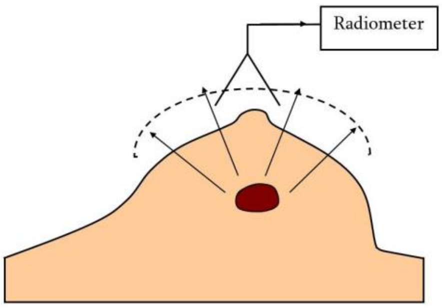

Figure 2: Passive Microwave Imaging

Hybrid Microwave Induced Acoustic Imaging

During the eighties hybrid microwave induced acoustic imaging techniques were introduced. These methods work on a similar principle as that of passive microwave imaging. This time, microwaves are used to selectively heat the tumour cells. Once the tumour cells absorb this heat they expand and any generated acoustic waves are detected with the aid of an array of ultrasound transducers as shown in Figure 3. Hybrid microwave imaging works on the property that malignant tissues have higher conductivity properties than healthy cells and hence absorb more microwave energy. This results in the generation of stronger acoustic/pressure waves. These induced acoustic signals are then sensed by ultra-sensors (Raghavan and Ramaraj, 2012). This approach is highly sensitive to tumours and provides high resolution images (Zubaida, 2012).

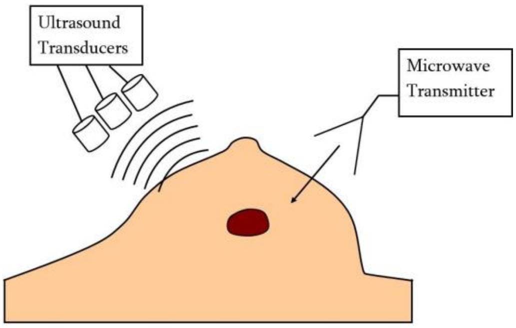

Figure 3: Hybrid Microwave Imaging

Thermo-Acoustic Imaging Techniques

Invited during the early 1980's thermos-acoustic imaging is based on the idea hybrid mi- crowave imaging techniques. Figure 4 shows the first 3D thermoacoustic image of breast cancer while Figure 5 shows the world's first 3D thermoacoustic breast scanner. These thermoacoustic images (Figure 5) consist of the axial, coronal and sagital views of the cancer cells. Thermo-Acoustic imaging techniques fall under hybrid imaging techniques whereby, exposing biological tissues to microwave pulses results in the generation of acous- tic waves. Using an array of transducers, this acoustic wave is then detected and used to generate a tomogram of the targeted tissue. Research has shown that thermo-acoustic techniques can be enhanced with the use of nanosecond microwave pulses. Theory also suggests that the shorter the wavelength of the pulses the higher is the resolution of the generated images. These pulses are also advantageous as they reduce the amount of healthy tissue exposure to microwave energy (Lewin, 2014).

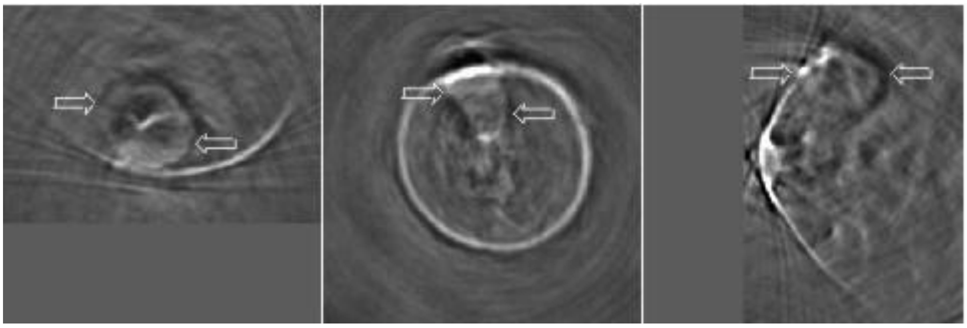

Figure 4: From left to right: images depict axial, coronal and saggital views of the cancer (arrows).[13]

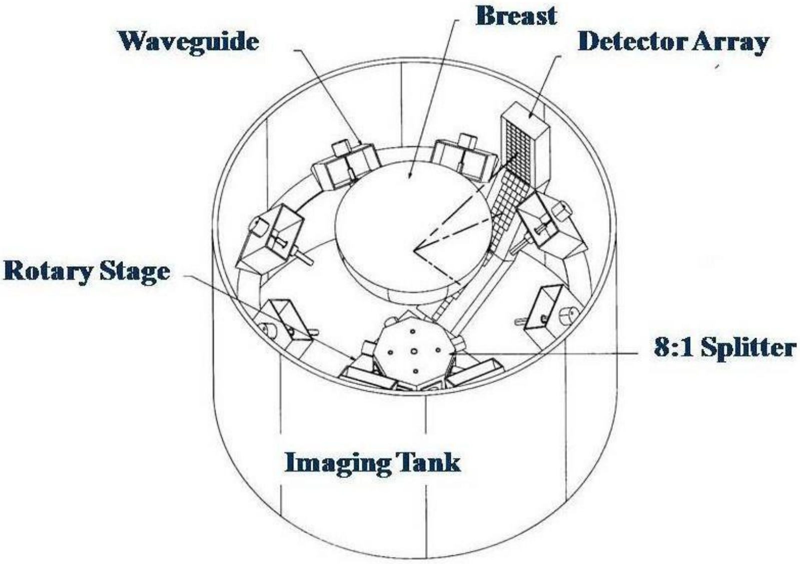

Figure 5: World's first 3D thermoacoustic breast scanner.

Active Microwave Imaging

Active techniques involve methods that rely on the significant electrical properties and contrast between malignant and normal breast tissues at microwave frequencies' (Zubaida, 2012). There are basically two imaging techniques. These are microwave tomography and radar-based microwave imaging techniques. Both utilize low-power microwave signals which are used to illuminate the breast and the backscattered signals studied in order to interpret the dielectric properties of the breast (Zubaida, 2012).

Tomographic Imaging Techniques

Microwave Tomography work on the principle of collecting multiple signals from sensors or antennas at different positions but equal distances from the surface of the breast (Figure 6). Through signal processing the measured data is then used to create a map of the relative permittivity geometric distributions of the breast. Tumours usually reduce the strength of the scattered signal, hence any observed areas of higher relative permittivity and conductivity values corresponds to the presence of tumour cells. Using several inverse scattering problems the dielectric profile of the tissue under test is then deduced (Zubaida, 2012).

During this screening process patients usually lie ‘with the breast pendant through a hole in the examination table and immersed in a tank filled with glycerin water.’ This glycerine water acts as a ‘coupling liquid’ and reduces ‘environment clutter’ (Zubaida, 2012). The ratio of glycerin to water is varied in order obtain a fluid whereby its dielectric properties match with those of the breast under test. By rotating the sensors several times, measurements are recorded at several positions of the breast. At each position one antenna acts as a transmitter while the rest act as receivers. At the end of the process, all measurements are used to render the dielectric profile of the breast (Zubaida, 2012). Figure 7 shows a constructed tomography setup consisting of a ‘24 double- layer vivaldi antennas (DLVAs), supported inside a Plexiglas imaging chamber. The antennas have an operating bandwidth from 3 to 10 GHz’.

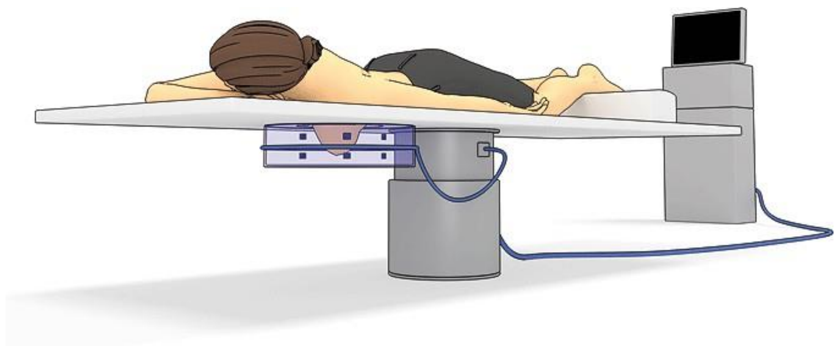

Figure 6: Microwave tomography screening method. (Microwave tomography for breast cancer detection, 2014)

When Larsen and Jacobi first imaged canine kidneys back in the 1970’s, they were the first, successful in producing two-dimensional (2D) images with clearly discernible images of cancer tissues using microwaves. By measuring the transmitted signal between two antennas opposite each other along a boresight, the imaged organ was scanned in a plane perpendicular to the line connecting the two antennas. This resulted in a recorded signal being a function of two position coordinates, relative to a reference point on the imaged organ (Amineh et al., 2012). This was the first radar-based diagnostic technique.

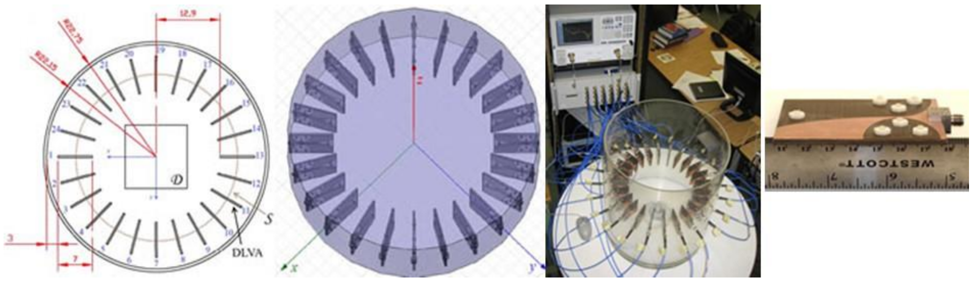

Figure 7: The tomography imaging chamber constructed by researchers at the Manitoba University Electromagnetic Imaging Group, (University of Manitoba Online Repository, e.d.)

Radar Based Imaging Methods

Radar-based imaging methods are also known as confocal microwave imaging (CMI) tech- niques. Reflections are observed at a number of antennas located on the breast, and images are created by summing the reflections or synthetically focusing these reflections (Figure 8). Synthetic focusing involves calculating the time-delay from each antenna to a focal point, and time-shifting and summing the recorded signals. If a tumour is located at the focal point, then reflections from the tumour add together, resulting in a large contribution to the image at that focal point location. With the focal point in normal tissues, reflec- tions tend to add incoherently, resulting in a small contribution to the image (Fear, 2008).

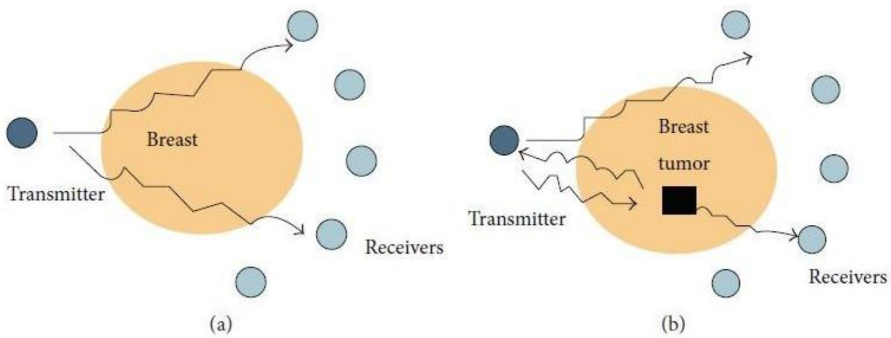

Figure 8: Signal transmission of breast cancer detection.

In one aspect, detecting the presence or absence of a tumour within a breast including skin and an interior volume, comprise the steps of:

- illuminating the breast with microwaves from a plurality of locations and recording the reflections received at each location as a signal;

- identifying a first skin reflection and a second skin reflection separated by a period of time and time-gating the signal by setting all data arriving before the first skin reflection and after the second skin reflection to zero;
- creating a first estimate of reflections from the skin and subtracting said first skin reflections from each signal;
- creating a second estimate of reflections from the skin for a single location from the signals received in at least two adjacent locations and subtracting the second skin reflections from each signal; and
- constructing a three-dimensional image of the interior volume from the signals show- ing the presence or absence of microwave reflecting tissues (Fear, 2008).

UWB Radar Based Microwave Imaging technique falls under such radar-based imaging. It is considered as a cost effective solution to early breast tumour detection and basically consists of illuminating the material under test with a microwave signal which might either be absorbed or back scattered from the targeted cells. The observed backscatter is used to allocate the position of strong reflections and hence verify the presence of any tumour cells (Figure 9). It must be noted that UWB only detects the presence of any existing cancer cells and does not provide any information of the dielectric distributions within the breast. This principle is very comparable to that of ultrasound (Zubaida, 2012).

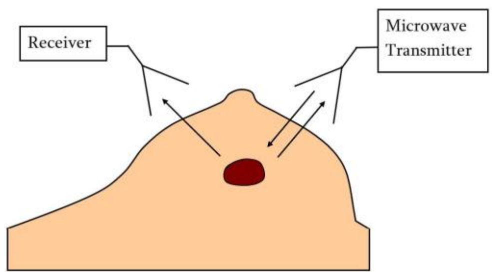

Figure 9: Active Microwave Imaging

The Microwave Stethoscope

The most hands-off, accurate microwave diagnostic technique in measuring lung water is the microwave stethoscope. Having the size of an average coin (Figure 10), this sensor can be placed on a patient's chest. It emits frequencies within 300 MHz and 30 GHz and detects the corresponding reflection coefficient. The ability of measuring and detecting fluid in a patient's lungs can be used as an indicator of the patient's 'reaction to medication, the effectiveness of treatment for critically burned patients [and] the extent of heart failure.' A compact microwave transmitter such as a waveguide is used to obtain a clear signal and tightly focus beams of energy. The microwave stethoscope constitutes of a microwave transmitter, a focusing antenna and a receiver. It works on the principle of radar based technology (Lewin, 2014).

Figure 10: The Micorwave Stethoscope (Sarah Lewin, 2014)

Physical Principles governing Microwave Imaging

As mentioned before, microwave images for medical applications are maps of the electri- cal property distributions in the body by means of electromagnetic fields at microwave frequencies of 300 MHz to 30 GHz. When we consider microwave tomography, we are interested in the amount of scattered energy. Malignant tumours have high-water con- tent as compared to low-water content in normal fatty breast tissues. This results in a significant amount of observed scattering. On the other hand, low-water content in fatty breast-tissue means that the absorption coefficient is low. Hence by observing the amount of back scattered signals from normal and malignant breast tissue one would be obtaining a good physical interpretation of the dielectric properties of biological matter (Wang et al., 2014).

It is found that the dielectric properties of normal breast tissues are similar to fat, while the properties of malignant breast tumours resemble those of muscle (Wang et al., 2014). Biological matter with high water content, have different dielectric properties then normal biological tissue (Lianlin et al., 2010) and (Wang et al., 2014). According to data measured by many sources, the dielectric properties of normal breast tissues vary in an approximate 10% range around $\varepsilon_r = 9$ and $\sigma = 0.4 S/m$, whereas for malignant tumours, $\varepsilon_r = 50$ and σ

= 4*S/m* (Wang et al., 2014). The lowest dielectric values are found in bone, fatty tissue and lung while the highest permittivity values are observed in blood and muscle due to the 'abundance of water and free ions' (Fang, 2004). It is this contrast in the dielectric properties of biological matter which enables the detection of cancer cells through microwave imaging (Lianlin et al., 2010) and (Wang et al., 2014).

As microwaves undergo a change in material dielectric property as they propagate through biological matter, scattering of the incident wave alters the energy detected at the receivers and the transmitter. The presence of any homogeneities in the dielectric properties of the medium alters the propagation pattern of the signal, the amplitude, phase and polarization of the signal and results in distortions of the electromagnetic field. These distortions encode the spatial distribution of the dielectric properties of the medium and reflect the macroscopic electrical property characteristics of the tissue (Fang, 2004). This implies that there are several bulk representations of numerous microscopic physical or bio-chemical processes in the tissue concerned. 'In general, the value of the permittivity is related to the molecule dipole moment per volume, while the conductivity is related to the free path length and speed of the electrons inside the material. Therefore the value of the dielectric properties can be used as indicators for the microscopic environment of the cellular or molecules processes.' When the biological tissues undergo physiological changes, as when victim to diseases, external stimulations, or even variations in environmental temperature, the microscopic processes can deviate from their normal state and impact the overall dielectric properties of the tissues. 'By monitoring the variations of the dielectric properties with respect to those for the healthy tissues, one may be able to diagnose abnormalities or use the information for treatment of the disease' (Fang, 2004). Images are then formed from the information of detected signals. Amongst the de- tected signals are also reflections which might have occurred within the biological medium but still detected by the transmitter (Jiatong, 2014). These detected signals encode the phase and spatial information of the reflection coefficient. The measured reflection coeffi- cient is then used to calculate the complex visibility data and object scattering intensity distribution by applying the Inverse Fourier transform (Wang and Simpkin, 2013). 'The major challenges in microwave tissue imaging include difficulties in coupling the microwave power into the tissue, significant tissue loss, relatively coarse resolution, significant tissue heterogeneity, and relatively low contrast between malignant and healthy tissues' (Amineh et al., 2012).

Microwave Tomography

Breast Phantom Models

Breast tissue phantoms (artificial breasts) are often used to illustrate the typical electrical parameters of breast tissues in the frequency range of 3–10.6 GHz (Raghavan and Ramaraj, 2012). Studies by Wang, (2014) have shown that a simple breast model can be constructed in CST microwave studio as presented in Figure 11. The model consists of a hemispherical model of the breast having a radius of 50 mm made up of just breast tissue, without any skin layer. As illustrated in the studies of Wang (Figure 11), four horn antennas encircling the breast at equal heights can be used to transmit and receive the microwave signals.

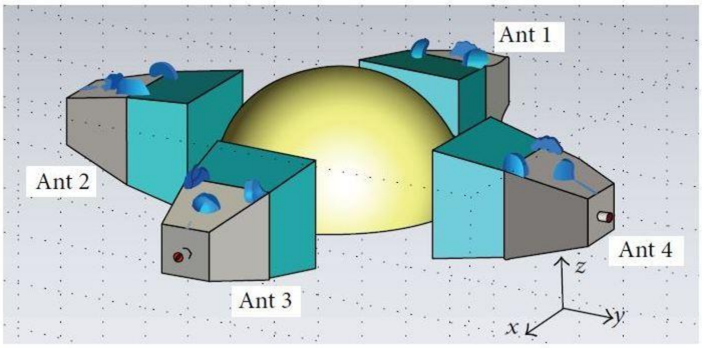

Figure 11: Simulated breast model constructed in simulation tool. (Wang et al., 2014)

The background material should be set as a coupling medium to ensure electrical matching between the antenna and breast. The time-delay for the propagation of the microwave signal in a given pair of transmitting/receiving antenna is calculated based on the antenna's position, position of the focal point, and an estimate of average wave propagation speed. During focusing, the focal point is moved from one position to another within the breast to create spatial beam-forming. All time-shifted responses are coherently summed and integrated at each focal point. Integration is performed on the windowed signal, and the length of the integration window is chosen according to the system bandwidth. The main advantage of the delay-and-sum algorithm is its simplicity, robustness, and short computation time. It has been found by Wang that fundamentally, the energy at the focal point in the breast can be calculated by,

$$E(x,y,z) = \int_0^T \left(\sum_1^M y(t - T(x,y,z)) \right)^2 dt \qquad (1)$$

where M is the total amount of received signal energy, y is simulated received energy signal, T is the time-delay of each focal point, and τ is the integration range. Supposing that the focal point is at (x,y,z) with a distance to antenna, the time-delay can be expressed as,

$$d_i = \frac{\sqrt{(x-x_i)^2 + (y-y_i)^2 + (z-z_i)^2}}{v} \tag{2}$$

and where v is the spread velocity in the breast-tissue which can be also calculated as;

$$v = \frac{\mu\varepsilon}{2}\left[\sqrt{1+(\frac{\sigma}{\omega\varepsilon})^2+1}\right]^{-0.5} \tag{3}$$

$$= \frac{9}{2}\left[\sqrt{1+(\frac{0.4}{9\times 10^7\pi})^2+1}\right]^{-0.5} = 0.99\times 10^8 m/s \tag{4}$$

where σ is the conductivity of the medium, ω the angular frequency, ϵ the permittivity of the medium and μ the permeability of the medium. There is a finite distance from the port location to the centre of the antenna aperture surface position; hence a time-delay factor *dt*, to take care of a phenomenon known as retardation should be included in the equation above. (Wang et al., 2014).

Mathematical Interpretation

Microwave imaging techniques can be classified as either quantitative or qualitative (Lian- lin et al., 2010). Quantitative imaging techniques, also known as inverse scattering meth- ods give the electrical and geometrical parameters of the imaged object by solving nonlin- ear inverse problems. These non-linear problems are first converted into a linear inverse problem by using Born or distorted Born approximations (Gel'fand and Levitan, 1955). Direct inversion methods can be also be used to solve this invesion problem. However, this method is not ideal when we consider higher dimensional and dense matrices. To overcome this problem, iterative solvers are used. These iterative solvers fall under the category of forward iterative methods and are usually very time consuming (De Zaeytijd et al., 2007). There are also, qualitative microwave imaging methods. These are used to generate a qualitative profile and a geometric representation of hidden objects. Approx- imations are used to simplify the imaging problem and then back-propagation is used to reconstruct the unknown image profile (Gel'fand and Levitan, 1955).

Inverse Scattering

Inverse scattering is the process by which measurements are converted into qualitative diagnostic information about biological tissues. In mathematics, inverse scattering is used to solve non-linear partial differential equations. Inverse Scattering is a non-linear analogue, and in some sense generalization, of the Fourier transform, which in turn is used to solve many linear partial differential equations (pde's). The inverse scattering transform can be applied to many of the so-called exactly solvable models. A characteristic of solutions obtained from the inverse scattering method is the existence of solitons which are basically solutions analogues to particles and waves but not to linear partial differential equations (Gel'fand and Levitan, 1955).

Conclusion

In conclusion, microwave imaging seems to be a promising area is cancer diagnostics. The main reason why it is such a promising area is due to its non-ionizing property enabling frequent diagnostic examinations and more patient services. Microwave electronics and test instrumentation is mature, compact, and relatively cheap compared to X-ray or MRI equipment and importantly, breast cancer continues to be an important and unsolved health and societal problem. The number of women victim to breast-cancer is drastically increasing. For mass screening purposes the existing breast imaging methods such as X- ray mammography and MRI are not suitable and microwave Imaging for Breast Cancer detection by far seems the best approach (Wang et al. 2014) and (Raghavan and Ramaraj, 2012). Progress in the design and development of UWB breast imaging systems will definitely help to promote other systems and applications based on the radar imaging methods. Challenges ahead in microwave imaging modalities lie in designing ultra-wide band antennas and image reconstruction algorithms, (Raghavan and Ramaraj 2012) but this seems to be highly achievable in the upcoming years.

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