A Microwave Imaging Technique Implementation for Early Detection of Breast Tumors

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Abstract—This paper presents a microwave imaging technique to detect early breast cancer. A simple breast and different sizes, positions and numbers of tumors models have been simulated under CST software. We have used a mono-static UWB antenna with a grid of 49 positions to scan the area of the breast. Finally, we have implemented an algorithm for microwave confocal imaging to locate the tumors. The dielectric properties of those tumors were used to differentiate them from the environment.

Keywords—Ultra Wide Band (UWB) Antenna, Confocal Microwave Imaging Algorithm, Breast Cancer Detection.

1 Introduction
The microwave radar imaging for the detection of breast cancer, is a nonionizing and noninvasive alternative technique for mammography using X-rays and MRI. Indeed, this interest is also justified by the existing of great contrasts, of electric properties between healthy tissue and diseased tissue [1].

The idea is to use an antenna for transmitting an electromagnetic wave and receiving the reflected waves, and due to the difference in electrical properties between healthy tissue and diseased tissue, we form an image to localize the tumors. The antenna used is miniature rectangular satisfies the UWB characteristics in terms of bandwidth and return loss S11 [2].

Under the CST MWS (Computer Simulation Technology-Microwaves Studio) software, we performed four (04) simulations, a simulation without the presence of tumors in the breast and three simulations with presence of tumors. In each of them we moved the antenna for 49 positions in a matrix of (7 x 7) for scanning the entire space above the breast. In the first simulation, without tumor, the goal was to have a signal S11 representing the environment, which we have to subtract from other simulations, in order to obtain images of tumors. In the second simulation, we have placed a tumor of 05 mm at the center of the breast. In the third, we placed three (03) tumors with different sizes (3, 4 and 5 mm radius) at different positions as shown in Fig.1. Finally, in the fourth and final simulation, we placed a 02 mm tumor of radius, as shown in Fig.2.

2 Simulation Models
In our Simulation we have two parts: the breast and the antenna.

2.1 Breast Model
In the literature, several breast models were used namely: spherical, cylindrical models, etc. In our case, we have choose a model developed by “SA Alshehri and S.
Khatun” [4], with the hemispherical shape and the most common dimensions given in Table 1. In the literature, the tumor radius size ranges from 0.2 cm to about 1.5 cm or more.

**Table 1: Dimensions of parts of the breast model**

<table>
<thead>
<tr>
<th>Model Part</th>
<th>Size (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast Diameter</td>
<td>10</td>
</tr>
<tr>
<td>Breast Height</td>
<td>6</td>
</tr>
<tr>
<td>Skin thickness</td>
<td>0.2</td>
</tr>
<tr>
<td>Chest thickness</td>
<td>2</td>
</tr>
</tbody>
</table>

The dielectric properties are given in Table 2, where $\sigma$ is the conductivity of tissue (Siemens/meter) and $\varepsilon_r$ is the relative permittivity.

**Table 2: Dielectric properties of parts of the breast model**

<table>
<thead>
<tr>
<th>Conductivity $\sigma$ (S/M)</th>
<th>Permittivity $\varepsilon_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin</td>
<td>1.49</td>
</tr>
<tr>
<td>Fat</td>
<td>0.14</td>
</tr>
<tr>
<td>Chest</td>
<td>1.85</td>
</tr>
<tr>
<td>Tumor</td>
<td>1.20</td>
</tr>
</tbody>
</table>

2.2 Antenna model

In our applications, we used a microstrip antenna [2], with a rectangular shape patch ($l = 12$ mm, $w = 10$ mm), made on a substrate type FR-4 ($\varepsilon_r = 3.34$, thickness = 0.794 mm) and size $L = 30$ mm and $W = 25$ mm, a semicircular ground plane is printed on the lower surface of the substrate, and the height $H$ is 13.2 mm, it has the same width as the substrate (Fig. 3).

![Microstrip antenna](image)

Fig. 3 The microstrip antenna [2]

The antenna has satisfied our expectations in terms of return loss $S11$ with a bandwidth ranging from 3.55 to 11.17 GHz, (Fig. 4).

3 Return Loss Simulation

Furthermore, we compared the $S11$ simulations with and without tumors, at some antenna positions. We have found that for the positions where the antenna is placed away from the axis of the tumor, the $S11$ in the two simulations were similar at the subband 6 to 8 GHz, (Fig. 5). However, the positions where the antenna is on the axis of a tumor, $S11$ of the two simulations with and without were differentiated, in the same sub-band of 6 to 8 GHz, (Fig. 6). This difference is used to reconstruct the image of the tumor from the recovered data with and without tumor, by implementing a confocal microwave imaging technique introduced by Li and Hagness in [5].

![S11 comparison](image)

Fig. 5 Comparison of two $S11$ (with and without tumors) - the antenna is placed away from the axis of the tumor.

![S11 comparison](image)

Fig. 6 Comparison of two $S11$ (with and without tumors) - the antenna is on the axis of the tumor.

4 The confocal microwave imaging algorithm

In this section, we present our implementation of the confocal microwave imaging technique introduced in [5]. We recall that imaging technique uses a system of monostatic radar which consists of an antenna placed at different XY positions and transmits microwaves over a wide band of frequencies.
Two sets of signals S11 at each XY position of the antenna are stored into two files. In our simulations, X and Y cover a grid of 49 positions. E_{XY}(f) represents all frequencies and signals recovered from the environment without tumor, EC_{XY}(f) representing all frequencies and signals recovered from the environment with tumors. To transform these backscattered signals, in a two-dimensional image to locate the tumor, we went through the steps reported in diagram of Fig. 7.

We have implemented this algorithm with Matlab, which we detail the steps as follows:

1) **Hamming Window**: We applied to both signals a Hamming window to reduce the level of side lobes.

\[ E_{XY}(f)_H = E_{XY}(f) \ast H \quad \text{and} \quad EC_{XY}(f)_H = EC_{XY}(f) \ast H \]  

2) **Transformation**: the resulting signals were transformed into the time domain by taking the Inverse Fast Fourier Transform (IFFT) of the signals for further processing.

\[ E_{XY}(t) = \text{ifft}(E_{XY}(f)_H) \quad \text{and} \quad EC_{XY}(t) = \text{ifft}(EC_{XY}(f)_H) \]  

3) **Calibration**: To remove the Environment signals and keep only the signature of tumors C_{XY}(t), we subtract the signals E_{XY}(t) (environment without tumors) from the signals EC_{XY}(t) (environment with tumors). This subtraction generates a higher peak at the location of the tumor by reducing the environment response.

\[ C_{XY}(t) = EC_{XY}(t) - E_{XY}(t). \]  

4) **Clutter Removal**: The signals C_{XY}(t) always contains reflections of waves due to the antenna itself and the environment. To eliminate this noise, we calculate the mean A_X(t) of each line C_{XY}(t), then the averaged signals A_X(t) are subtracted to each signals C_{XY}(t).

\[ A_X(t) = \frac{1}{N} \sum C_{XY}(t) \quad \text{and} \quad P_{XY}(t) = C_{XY}(t) - A_X(t). \]  

N represents the number of rows and columns of the grid of 49 positions of the antenna.

5) **Generating the pixels and their intensities**

In this step, we generate pixels on a surface of (10 x 10 cm), then we evaluate the distance of each antenna position to each pixel and we calculate the time it takes for the signal to travel the distance. This travel time depends to the average permittivity of the environment. This average is trivially estimated.

Finally, the Intensity values are generated for each pixel points by evaluating the signal value of the processed signal P_{XY}(t), where t is the travel time already calculated.

## 5 Results and Discussion

In this section, we show the results of the three simulations, obtained with different positions, size and number of tumors. Those results corresponding to the following figures 8, 9 and 10 are obtained through the processing algorithm described in section III.

From the results, it is evident that our imaging system is capable of detecting from 4 mm to 10 mm tumor located in different positions, however, with the presence of clutter which we’re studying to remove in post-processing of images.

It is noteworthy that the frequency band (between 6 GHz and 8 GHz) which allows us to obtain results is a compromise between high and low frequencies [4].
6 Conclusion and future works.

A confocal microwave imaging technique was implemented to identify the existence and location of tumors in a breast model. This work was successfully done for multiple tumors in a breast and also for a small tumor (radius = 2 mm). Those results are very encouraging and demonstrate the validity of our confocal imaging algorithm. Our future works consist to implement other techniques and compare them.

REFERENCES


