UWB Waveguide Breast Tumor Detection System Based on Delay and Sum Reconstruction Algorithm

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Abstract— The purpose of this contribution is breast malignant tumor detection through the confocal delay and sum reconstruction algorithm. The tumor signal is extracted from background and used for reconstruction. For higher accuracy the scattered signal from all four UWB waveguide antennas, which are located around the breast, were used.

1. INTRODUCTION

Breast cancer is one of the major diseases among women. Unfortunately, over 2000 of affected women die from breast cancer in the Czech Republic. The chances of survival for the patient are dependent on disease stage when cancer is captured. Therefore, it is necessary to diagnose this disease as soon as possible. Currently for breast cancer detection mammography is utilized. For this examination ionizing X-Rays are used. X-Rays increases likelihood of the built up of cancer which is a risk for healthy patients. It is therefore necessary to develop new methods for tumor detection. To the most promising method developing in laboratories we can count microwave tomography and confocal microwave imaging.

2. ANTENNA SYSTEM CONFIGURATION

For imaging purposes the UWB double-ridged horn antenna intended for medical imaging was adopted from [1]. Total four antennas are placed equidistantly around a breast model (see Figure 1). The whole antenna system is immersed in canola oil.

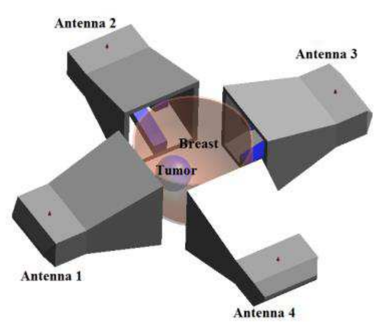


Figure 1: Used numerical model with breast with tumor and four UWB antennas.

3. NUMERICAL BREAST PHANTOM

A simple circular homogeneous breast phantom (100 mm in diameter) with a thin skin layer (2 mm thick) was used. This used breast phantom is based on a phantom published in [2]. In this phantom a spherical tumor of diameter 20 mm at various positions was inserted. The values of relative permittivity and conductivity of fat, skin and malignant tumor tissue are listed in Table 1.

Table 1: Dielectric properties of tissues in numerical phantom (adopted from [3]).

Material	Relative permittivity ε [-]	Conductivity σ [S/m]
Fat	9	0.4
Skin	35.7	3.17
Tumor	50	4
Canola Oil	3	0.04

4. IMAGE RECONSTRUCTION ALGORITHM

Time signals needed for reconstruction were obtained from numerical simulations in FDTD electromagnetic field simulator SEMCAD X Aletsch 14.8 [4]. The reconstruction algorithm for delay and sum was implemented. The transmitting antenna sends a RF pulse through the breast model. Transmitted signal is a Gaussian pulse of central frequency 4.5 GHz and bandwidth 8 GHz (see Figure 2).

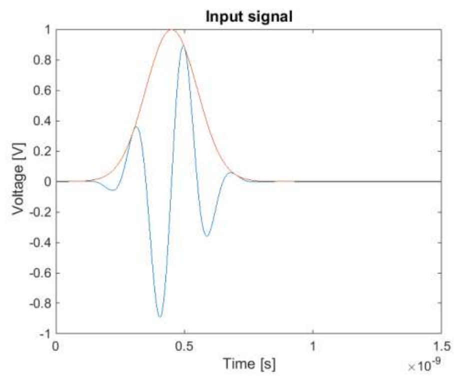


Figure 2: Transmitted Gaussian pulse with bandwidth 8 GHz.

The place of the change in dielectric parameters of material (canola oil X skin X fat X tumor) scatters the incident wave. The scattered wave can be received in all antennas which are placed around the breast. The method consists of two phases. In the first phase a scan of scattered field of breast without the tumor is performed. In the second phase (e.g., after 1 year in next medical examination) second scan will be made. For all signals Hilbert transformation is applied and prepared signals with/without tumor are subtracted from each other. Obtained differential signals are reflections from changes, which occurred (e.g., from tumor). From the knowledge of the average velocity wave propagation in the breast and from measured time difference between peak of the transmitted signal (from transmitting antenna) and received signal peak. Then the distance of the reflections from each antenna is found (assumed tumor position). The velocity of propagating wave (v) is calculated according to the Equation (1).

$$v = \frac{\sqrt{2}}{\sqrt{\varepsilon \cdot \mu}} \cdot \frac{1}{\left(\sqrt{1 + \left(\frac{\sigma}{\varpi \cdot \varepsilon}\right)^2}\right) + 1} \tag{1}$$

where c is speed of light [m·s^{-1}], ε is permittivity [F·m^{-1}], μ is permeability [H·m^{-1}], σ is conductivity [S·m^{-1}] and ω is angular velocity [rad·s^{-1}].

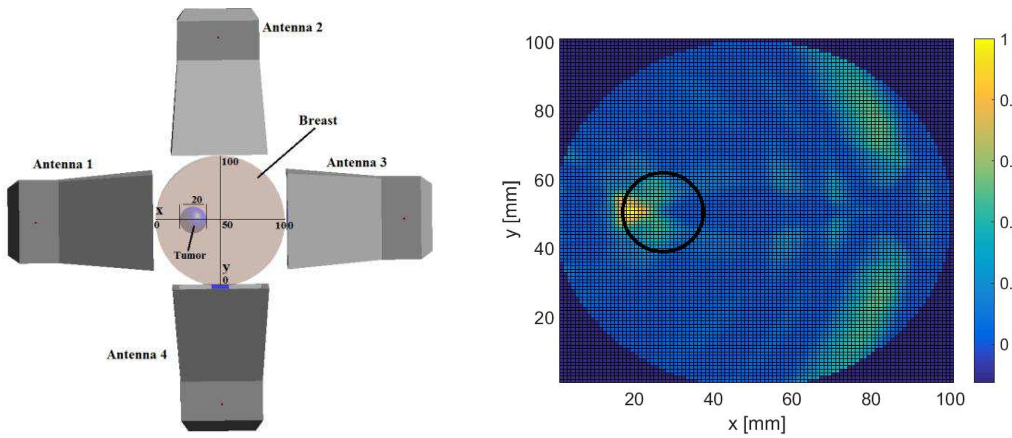
Position of the wave diffuser is on the circle with the center in the antenna power probe. The power intensity for each position in the breast is the sum of power intensity from each receiving antenna. For tumor localization the distance must be measured even from other antennas. Then it is possible to calculate intersections of the circles defining the distance of the tumor from each antenna. For high accuracy it is good to use all antennas as transmitters sequentially. In the case of uncertain tumor position (in case that peak appears more than once in signal) we can rotate the whole antenna system by 45 degrees and thus increases the localization accuracy. Used method seems to be very promising for breast tumor detection. Its disadvantage is the need to dispose signals from the breast at a time when the tumor did not occur.

5. RECONSTRUCTION RESULTS

We tested the algorithm for 20 mm diameter tumor that was inserted in the numerical breast phantom. For better algorithm evaluation we investigate two different tumor positions. The first tumor position is on the main axes in front of the antenna 1. For the second tumor position we rotate the whole breast by 45 degrees. Thus we deflect tumor which now does not lie on one of main axes passing center of antennas.

5.1. First Position

In the Figure 3(a) is the tumor position in the breast (tumor center $x = 30$, $y = 50$) and Figure 3(b) shows the reconstruction results. The black circle indicates the real tumor position in our numerical model which is shown in the Figure 3(a). The highest signal intensity indicates the predicted tumor position. The biggest intensity of received signal (reflection) is on the left side of the tumor. This is caused because antenna 1 is nearest to the tumor and therefore has the strongest signal. Used hemispherical numerical model has larger diameter, so we get small response from more distant antennas (e.g., antenna 3). According to the reconstruction results it is possible to estimate the position of the tumor relatively accurate. It is worse with the size and shape determination.

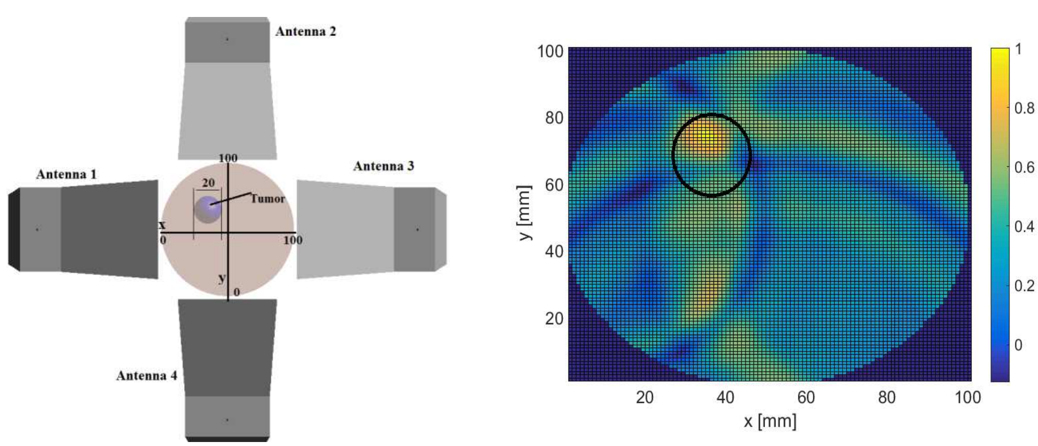


(a) (b)

Figure 3: (a) Numerical model with tumor and (b) reconstructed 2D cross section.

5.2. Second Position

In the Figure 4(a) the second tumor position is shown. The breast was turned by 45 degrees against the position 1. The position of the tumor is $x = 35$ mm and $y = 70$ mm. Therefore the tumor is not on any of major axis that passes through the center of waveguide antenna. Used waveguide antennas have the highest intensity of electric field in the center of aperture. That's why the reflected signal has lower intensity and therefore is in the Figure 4(b) lower contrast. Even though the tumor imposition outside the main axis can be also detect with relative high accuracy. According to the Figure 4(b) it is clear that the tumor image is less contrast than in the position 1.



(a) (b)

Figure 4: (a) Numerical model with tumor and (b) reconstructed 2D cross section.

6. CONCLUSION

In this contribution the delay and sum algorithm was implemented for tumor detection in simple heterogeneous numerical breast phantom. The reconstructed tumor position was reconstructed from the acquired time signals. For successful detection of tumor position it was necessary to obtain time signals when the tumor was not present. In the case used for reconstruction only signals obtained from transmitting antennas (which were also receivers) the reconstruction with multiple tumor positions was obtained. Major improvements of reconstruction images brought signals obtained from side antennas from transmitting antenna point of view. These signal intensities are normally by about one order lower in magnitude. So it was necessary to normalize these signals and properly sum them with other signals. In this contribution the tumor detection is discussed. We examine the reconstruction algorithm by 2 tumor positions. The obtained results seem to be very promising. Another important step for future work is finding the right way how to normalize the acquired signal and how to compensate the attenuated signal.

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REFERENCES

1. Latif, S., S. Pistorius, and L. Shafai, "A double-ridged horn antenna design in canola oil for medical imaging," *2013 International Conference on Advances in Electrical Engineering (ICAEE)*, 421–424, 2013.
2. Davis, S., H. Tandradinata, S. Hagness, and B. Van Veen, "Ultrawideband microwave breast cancer detection: A detection-theoretic approach using the generalized likelihood ratio test," *IEEE Transactions on Biomedical Engineering*, Vol. 52, No. 7, 1237–1250, 2005.
3. Li, X. and S. Hagness, "A confocal microwave imaging algorithm for breast cancer detection," *IEEE Microwave and Wireless Components*, 130–132, 2001.
4. SPEAG AG, SEMCAD X Reference Guide, Online Available: http://download.speag.com/releases/semcad/1485/documentation/SEMCAD-X-Manual.pdf.