

A Feasibility Study of Microjets Applied to Breast Cancer Detection

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Abstract – The feasibility of detecting small tumors of diameter 0.5mm inside a human breast is demonstrated using microjets. Microjets are photonic nanojets scaled to microwave frequencies wherein a plane-wave-illuminated dielectric sphere produces a high-intensity, narrow beam of light extending from the shadow-side surface. Contrasting electromagnetic properties (permittivity and conductivity) of normal and malignant breast tissue are the basis for the detection via a simple image processing approach to extract the backscattering from the tumor. Simple proof-of-concept simulation results are presented to illustrate the effectiveness of the new approach.

1 INTRODUCTION

Although X-ray mammography is the most common technique for breast cancer detection, it has high false negative and false positive rates, especially in pre-menopausal women where increased breast density can obscure nonpalpable lesions [1]. On the other hand, measurements at microwave frequencies indicate a significant contrast in electromagnetic properties between healthy and malignant glandular tissues [1], [2]. Thus, the detection of early-stage tumors within the breast by microwave propagation has been proposed using this contrast.

A photonic nanojet is defined as a narrow, high-intensity beam of light that emerges from the shadow side of a plane-wave-illuminated dielectric sphere or cylinder of diameter larger than the wavelength. Photonic nanojets have previously been shown to provide sufficiently one-dimensional (1-D) illumination of three-dimensional (3-D) targets [3], yielding the ability to detect at distances of multiple wavelengths in the backscatter direction ultra-subwavelength inhomogeneities embedded within the dielectric targets [4]-[8].

In this work, we propose the application of photonic nanojets scaled to microwave frequencies for breast cancer detection. The use of photonic nanojets within this frequency range will thus be referred to as microjets. To test the application of microjets to breast cancer detection, we perform finite-difference time-domain (FDTD) [9] simulations of a microjet interacting with a simplified breast model.

2 Breast Model and Microjet

The breast is assumed to consist of two regions: skin and underlying tissue. In order to account for the frequency dependence of the tissues, the relative permittivity, ϵ_r and conductivity, σ (S/m), are calculated at the center frequency of operation $f = 20GHz$ using first-order (Debye) dispersion:

$$\epsilon_r - j\frac{\sigma}{\omega\epsilon_0} = \epsilon_\infty + \frac{\epsilon_s - \epsilon_\infty}{1 + j\omega\tau} - j\frac{\sigma_s}{\omega\epsilon_0} \quad (1)$$

These calculations result in the parameters listed in Table 1. Then to simulate a more realistic breast model, the normal breast tissue is modeled as having random variations of up to 10% around the calculated values of Table 1 ($\epsilon_r = 8.7$, $\sigma = 1.8$ (s/m)).

Parameter	ϵ_∞	ϵ_s	σ_s	$\tau(ps)$	ϵ_r	σ
<i>Skin</i>	4	37	1.1	7.23	22.1	19.4
<i>Tumor</i>	3.9	54	0.7	7	32.2	28.3
<i>Tissue</i>	7	10	0.15	7	8.7	1.8

Table 1: Electromagnetic parameters of different regions in a malignant breast at 20 GHz

The geometry of the problem is shown in Figure 1. The microjet is a sphere of radius 6 cm which is about three times larger than wavelength at the designed center frequency. Also, the breast is modeled by a sphere of radius 8 cm filled with the tissue and containing tumor inside it. The tumor is a sphere of diameter 5 mm located 2.5 cm from the skin. The FDTD grid cell resolution is 0.75 mm ($\lambda/20$).

We illuminate the microjet-generating sphere with a Gaussian pulse modulated at $\lambda = 1.5$ cm (20 GHz) and choose an observation point 2 cells from the sphere on the illuminating side as illustrated in Figure 1. The backscattered waveform recorded at the observation point is caused by skin, normal tissue and tumor respectively. Reflection from the skin and

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normal tissue obscures the desired reflections of the tumor. Since we are interested in tumor detection, the recorded signal is calibrated by subtracting the backscattered waveform produced at the same observation point for the case wherein the tumor is and is not present.

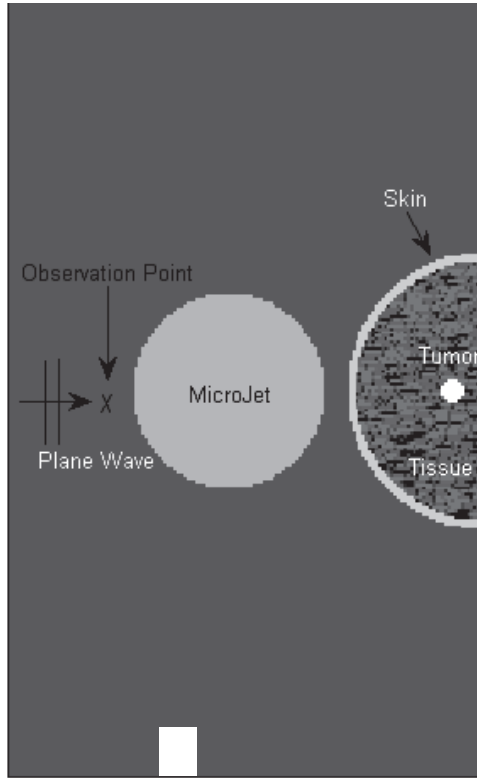


Figure 1 2-D slice of the geometry of a 3-D dielectric microsphere exciting the breast containing a tumor

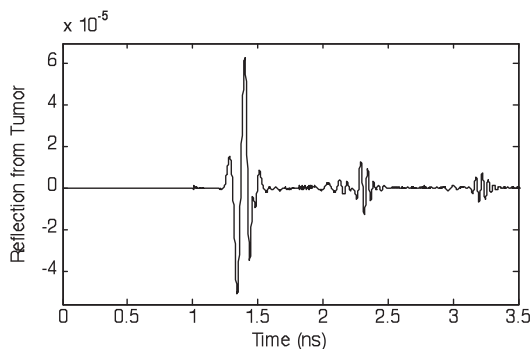


Figure 2 Recorded backscattered time waveform a breast containing tumor illuminated by the micro jet

Considering the backscattered time waveform of Figure 2 (already subtracted result for the cases having a tumor and without), there is a main echo positioned at 1.372 ns. A hand calculation of the round-trip time for backscatter from the tumor located in the normal tissue with specification in table 1, is 1.38 ns. This agrees with our simulation

results. The other pulses around 2.4 and 3.3 ns are due to reverberations of the electromagnetic pulse.

In a second experiment, the microjet sphere travels along a two dimensional plane of the three-dimensional grid at a fixed normal distance from the tumor (fixed z). The observation point also remains fixed relative to the microjet sphere. At every FDTD cell in the two-dimensional plane, we record and calibrate the backscattered electric field as done for the result in Figure 2. The presence of the tumor causes a peak backscattered energy perturbation relative to the backscattered energy of the isolated breast. We know that the calibrated backscattered electric field waveform is a function of time and position of the microjet sphere on the surveying surface, $E^{i,j,n} = E(i\Delta x, j\Delta y, k_0, n\Delta t)$

The energy at each time step is calculated as [10]:

$$Energy(i, j, k_0) = \sum_{n=1}^{n_{max}} |E_{norm}^n|^2 \quad (2)$$

The result of energy received at observation point is shown in Figure 3 and Figure 4.

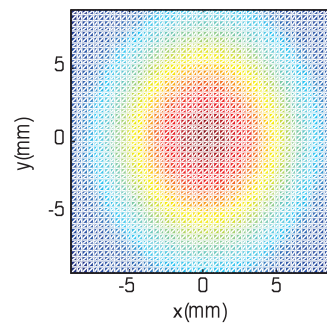


Figure 3 Color image of the backscattered energy for breast of Figure 1 containing a 5-mm-diameter tumor located at a depth of 2.5 cm below the skin surface

According to Figure 3 and Figure 4, since the microjet can provide us with 1-D wave propagation, there is a correlation between the diameter (and shape) of the tumor and half-power beamwidth of the energy signal which can be used to determine the size of tumor.

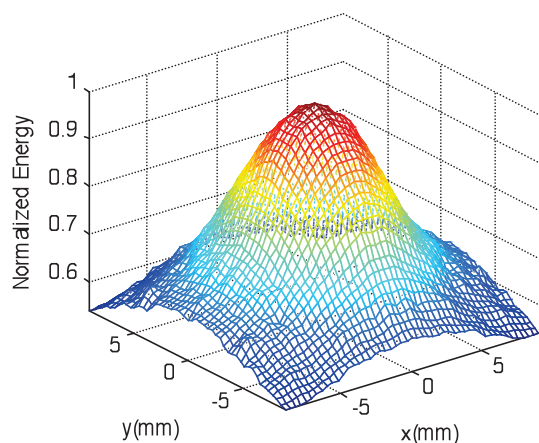


Figure 4 Energy diagrams measured from the breast of Figure 1 containing a 5-mm-diameter tumor located at a depth of 2.5 cm below the skin surface

3 Conclusion

The results presented in this paper suggest that microjets are a feasible tool for detecting and localized breast tumors in three dimensions. Microjets may provide unique advantages over more traditional antennas due to the one-dimensional propagation and interaction capabilities.

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