

Holographic Microwave Induced Imaging System: A Numerical Study

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Abstract—This paper presents a holographic microwave induced (HMI) imaging method based on microwave imaging and ultrasound imaging techniques to detect breast lesion. A numerical system, including a breast model and an HMI measurement model, is developed to investigate the feasibility of breast tumor detection. Results show that the small breast lesion can be clearly detected in the HMI images. The proposed framework has the potential to become a useful tool for breast lesion detection.

Keywords—microwave imaging; elasticity imaging; holographic; microwave antenna; breast cancer

I. INTRODUCTION

Microwave imaging has been proposed as an alternative or additional approach to the conventional mammography for the early diagnosis of breast cancer [1]. MI-based approaches have not been extensively studied in clinical settings due to several limitations include long scanning time and limited image resolution [2]. To solve these challenges, develop a high dynamic MI technique has attracted many researchers' interests over the past two decades [3-5]. Harmonic motion imaging method has been proposed to detect breast lesion based on the elastic parameters contrast between the healthy and abnormal tissues [6]. In this method, the acoustic radiation force of focused ultrasound is applied to generate a locally oscillatory displacement inside the soft tissue. The produced pressure variation in normal tissue is different from that in abnormal tissue due to the dielectric properties contrast between the healthy and abnormal tissues. The authors recently developed a holographic microwave imaging technique for breast lesion detection [7], which has the potential to produce a high-resolution image. The image quality is improved significantly by using a spiral antenna array [8].

This paper aims to investigate the feasibility of using holographic microwave induced (HMI) imaging that combines the benefits of harmonic motion imaging and holographic microwave imaging techniques to identify breast tumors based on monitoring the electrical and mechanical properties of the breast model. A computer simulation system includes a breast model and signal processing model is developed to demonstrate the working principle of HMI. Various simulation experiments are conducted to evaluate the effectiveness and performance of the proposed HMI method.

II. THEORY

Figure 1 shows the schematic diagram of HMI. The system consists of a microwave generator, a microwave antenna array

includes a transmitter and several receivers, a focused ultrasound probe, and a breast model. The microwave antenna array is placed in far field distance to the breast model.

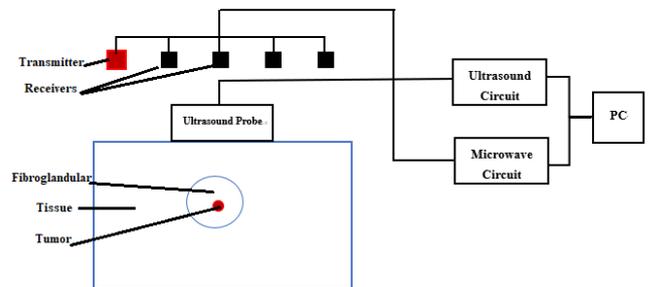


FIGURE I. ILLUSTRATION OF THE HMI SYSTEM

During data collection, the microwave generator generates microwave signals to the breast through the microwave transmitter, at the same time, the ultrasound probe induces vibration inside the tissue, and the backscattered signals from the target region are recorded by each microwave receiver. The received signals contain phase and amplitude information due to holographic technique and vibration. These signals depend on the dielectric properties, volume and maximum displacement of the vibrating region. The scattered energy is changed if the vibrating region contains a different material from the background. This response is related to both the mechanical and electrical parameters of the tissue. Thus, more useful information can be obtained than the microwave or elasticity imaging.

Define breast intensity as [7]:

$$I(\vec{s}) = \left(\frac{k_0^2}{4\pi}\right)^2 |\epsilon_r(\vec{s}) - \epsilon_0|^2 \vec{E}_T(\vec{s}) \cdot \vec{E}_T^*(\vec{s}) \quad (1)$$

Where k_0 denotes the wavenumber of free-space, $\Delta x_\mu(\vec{s}) =$, ϵ_r is the relative permittivity of object, ϵ_0 is the relative permittivity of free-space, $\vec{E}_T = \vec{E}_{inc} + \vec{E}_{scat}$, \vec{E}_T , \vec{E}_{inc} and \vec{E}_{scat} are the total electric field, incident electric field and scattered electric field, respectively.

Acoustic attenuation is mainly caused by absorption, and the applied force to the target object can be represented as [9]:

$$F = \frac{\alpha p_0^2}{\rho c^2} \cos^2(2\pi ft) \quad (2)$$

Where α denotes the absorption constant, c denotes the velocity of ultrasound in the tissue, ρ denotes the tissue density, f is the operating frequency of the ultrasound sensor, P_0 denotes the peak pressure at transducer $P_0 = \sqrt{\frac{2\rho cP}{\pi/(a^2-b^2)}}$, P is the ultrasound probe power, a and b are the board and narrow band of the ultrasound sensor, respectively.

The displacement of the local tissue can be written as [10]:

$$X(t) = X_0 \cos(2\pi ft + \phi) \quad (3)$$

Where X_0 denotes the maximum displacement, which depends on the mechanical properties of the local tissue and the intensity of the applied ultrasound force. ϕ denotes the phase change, which depends on the total path length.

If the target breast lesion is relatively small, then the polarization density inside the lesion can be obtained [11]:

$$\vec{P} = \frac{3\varepsilon_b(\varepsilon_r - \varepsilon_b)}{\varepsilon_r + 2\varepsilon_b} \varepsilon_0 \vec{E}_{inc} \quad (4)$$

Where ε_b denotes the relative permittivity of the surrounding medium. \vec{E}_{inc} is the incident field on the breast lesion.

The microwave transmitter transmits microwave signals to the breast model:

$$\vec{E}_{inc} = \left(-\frac{jk_0}{2\pi^2}\right) \vec{E}_0 \left(\frac{e^{-jk_0 \vec{R}_{Txm}}}{\vec{R}_{Txm}}\right) A_N B_B h(\theta, \phi) \vec{P}\vec{O}(\theta, \phi) \quad (5)$$

Where \vec{R}_{Tx} denotes the distance vector from the breast to the transmitter located at \vec{T}_x , \vec{E}_0 is the wave amplitude of TE10 mode, A_N and B_B are the narrow and broad aperture dimensions of antenna aperture, respectively. $h(\theta, \phi)$ is radiation pattern, and $\vec{P}\vec{O}(\theta, \phi)$ is the polarization vector, k_0 denotes the wavenumber of free-space. $k_0 = 2\pi f_1 t/c_1$, f_1 denotes the operating frequency of microwave antenna, c_1 denotes the speed of light.

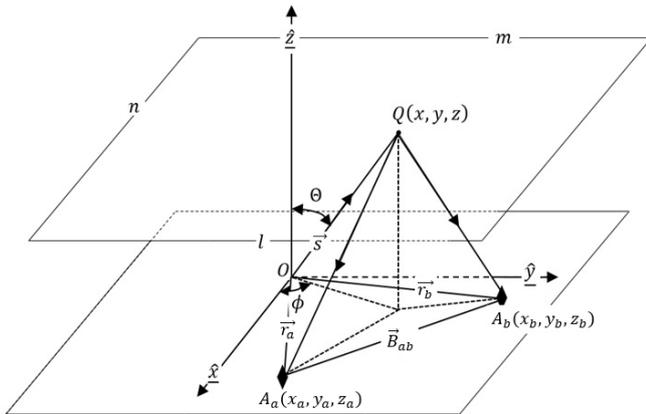


FIGURE II. MICROWAVE ANTENNA PAIR

Referring to Figure 2, the scattered signals measured by the microwave receiver located at \vec{r}_i can be represented as:

$$\vec{E}_{scat}(\vec{r}_m) = \left(\frac{k_0^2}{4\pi}\right) \int_V |\varepsilon_r(\vec{s}) - \varepsilon_0| \{a\vec{E}_T(\vec{s}) + (b\vec{E}_T(\vec{s}) \cdot \vec{R}_n)\vec{R}_n\} G(\vec{r}_m, \vec{s}) dV \quad (6)$$

Where G denotes the green function.

The total scattered signals from any two receivers located at \vec{r}_i and \vec{r}_j can be presented as [8]:

$$\Delta \vec{E}_{scat}(\vec{r}_i, \vec{r}_j) = \langle \vec{E}_{scat}(\vec{r}_i) \cdot \vec{E}_{scat}^*(\vec{r}_j) \rangle \quad (7)$$

Where \vec{E}_{scat} and \vec{E}_{scat}^* are the scattered field and the conjugate complex of the scattered field, respectively. The scattered field contains phase and amplitude information.

Referring to Figure 2, the breast image can be obtained by:

$$\vec{I} = \iint \Delta \vec{E}_{scat}(u_{ij}, v_{ij}) e^{-j2\pi(u_{ij}l + v_{ij}m)} dudv \quad (8)$$

Where $l = \sin\theta \cos\phi$, $m = \sin\theta \sin\phi$, $u_{ij} = (\vec{x}_j - \vec{x}_i)/\lambda_b$, and $v_{ij} = (\vec{y}_j - \vec{y}_i)/\lambda_b$. θ and ϕ are the receiver angle to the z direction and the angle to the x-y direction, respectively. λ_b denotes the wavelength of microwave signal.

III. NUMERICAL EXPERIMENTS

A numerical system was developed using MATLAB to validate the proposed HMI method for breast tumor detection. The system made of a microwave sensor array, a focused ultrasound transducer, and a breast model. The model ($100 \times 100 \times 50 \text{mm}^3$) was made of skin (2mm), fat, gland, and two spherical-shaped tumors (4mm in diameter), and it contained $256 \times 256 \times 55$ elements (Figure 3). The antenna array made of one transmitter and 15 receivers and a small open-ended waveguide antenna was simulated as both transmitter and receiver. The ultrasound probe and transmitter were placed next to the breast model, while receivers were randomly located in a 2D array plane ($300 \times 300 \text{mm}^2$) and they were in far-field distance from the breast model.

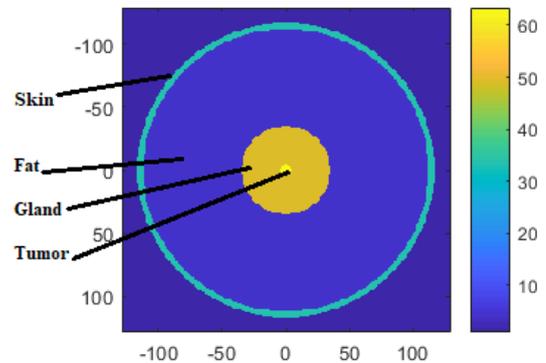


FIGURE III. BREAST MODEL

Table 1 shows the operating frequency and setup parameters for the simulation system [12]. Table 2 shows the attenuation and the velocity of the ultrasound [6].

TABLE I. SIMULATION PARAMETERS [12]

The frequency of microwave (GHz)	5, 6
The frequency of ultrasound (MHz)	3
Microwave antenna width	7.5mm
Microwave antenna length	15mm
The relative permittivity of the gland	60.537-0.93424j
The relative permittivity of fat	5.475-0.75j
The relative permittivity of skin	43.635-0.76519j
The relative permittivity of free-space	1
The relative permittivity of tumor	62.603-0.61063j

TABLE II. ULTRASOUND PARAMETERS [6]

	Attenuation (dB/cm/MHz)	Velocity (m/s)
Fat	0.34	1479
Tumor	0.79	1550
Gland	1.5	1553

IV. SIMULATION RESULTS

Figure 4 shows the reconstructed images of the breast model when the microwave frequency is 5GHz. It can be seen that the target small breast lesion only can be found in the real part of the reconstructed image.

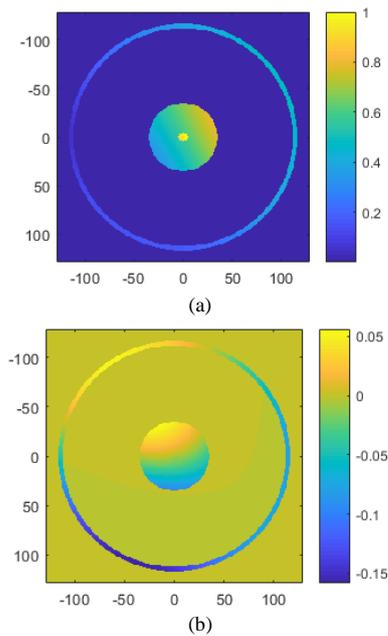


FIGURE IV. RECONSTRUCTED IMAGE OF BREAST (A) REAL-PART; (B) IMAGINARY-PART

Figure 5 shows the reconstructed images of the breast model when the microwave frequency is 6GHz. It can be seen that the target small breast lesion can be found in both real-part and imaginary-part of the reconstructed images.

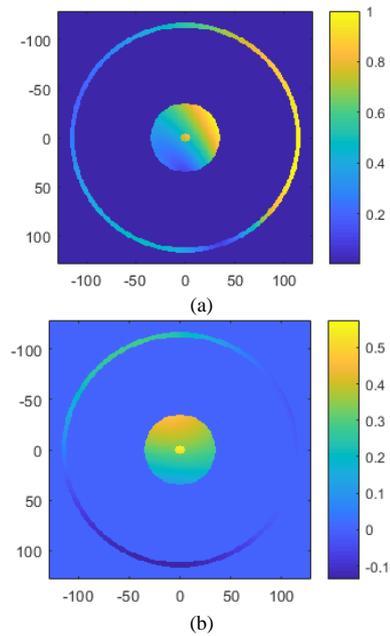


FIGURE V. RECONSTRUCTED IMAGE OF BREAST (A) REAL-PART; (B) IMAGINARY-PART

It can be seen that small breast lesion can be clearly detected when then the microwave frequency is 6GHz. However, only the real part of the reconstructed image can identify the breast lesion when the microwave frequency is 5GHz. Therefore, 6GHz can be selected as microwave operation frequency for the measurement system.

V. CONCLUSIONS

This paper demonstrated an imaging method namely HMI for small breast lesion detection. A numerical computer system consists of a simplified breast model, and the measurement model was developed to validate the proposed method. Several numerical experiments were conducted to confirm that the proposed method has the potential for breast lesion detection in the future.

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