Frontier approach research on the detection of early breast tumor

Yang Gao, Xin Bi, Jinsong Du, Rui Su & Wei Wang
Shenyang Institute of Automation, Chinese Academy of Science,
Key Laboratory on Radar System Research and Application Technology of Liaoning Province,
Liaoning Province, Shenyang City, China

ABSTRACT: The accident and mortality ratio of various cancers are increasing continually reported by a lot of medical literatures in every year, and that more early diagnose more surviving is also the truth in the breast cancer detection and therapy field. Developing a detection instrument about the early breast cancer is the aim of this paper. The microwave-induced thermoacoustic tomography (MITAT) is an innovative technology for tumor detection. Under the microwave irradiation condition, the rapid increase in temperature causes the instantaneous pressure, resulting in the ultrasonic signal, therefore the method has both advantages of high-contrast in microwave image and high-resolution in ultrasonic image. In this paper, with the circular scanning probe method, the system achieves the thermoacoustic images of the different size tumor phantom and the complex tumor phantom of different conductivity, and the experimental results show that the system can carry out the above test samples with high contrast and high resolution imaging.

Keywords: early detection of tumor; Microwave induced thermoacoustic; image reconstruction

1 INTRODUCTION

Breast cancer is a common malignancy tumor which endangers women’s life and health [1]. With the global industrial development and the living environment deterioration, the global incidence of breast cancer is increasing year by year [2]. The previous medical study shows that the patient’s long-term survival rate drops to 95% in the case of that breast cancer can be detected and treated [1, 2]. Therefore, early detection of breast cancer is an important way to reduce mortality ratio.

X-ray, CT, ultrasound imaging and MRI are the traditional detection approaches for breast cancer [3]. However, because of the low contrast and the ionizing radiation, the above detection method cannot be an effective method for routine detection [2]. In recent years, there have been other detection methods, e.g. photo acoustic imaging technology [4], which don’t become the safe use of conventional detection methods for the detection range and cost factor. Based on the limitations of the above methods, more and more people begin to focus on microwave-induced thermoacoustic tomography technology for the detection of the early breast cancer [4, 5]. The technology makes use of the difference in electrical characteristics between normal breast and malignant tissue in microwave frequency. The biological tissue can release the ultrasonic signal, because its absorbing microwave energy causes thermal expansion. Our system can obtain microwave energy distribution image which reflects characteristics of biological tissue with the ultrasonic signal. Compared with the conventional method of breast tumor detection, the technology has several advantages as follows: non-ionizing radiation, free extrusion, non-invasive, high contrast and etc.

There are two main microwave imaging methods currently: the tomography and confocal imaging ways [4, 5, 6]. The former one, as an electromagnetic inverse scattering method, which reconstructs electromagnetic distributed parameter properties of the imaging field by scatter electromagnetic fields, can determine the target position, shape and size information, however its ill-condition and nonlinear are not resolved [5]. The latter method can obtain reconstructed image which distinguishes between the poor and strong scattering region, based on electromagnetic parameter differences [6]. The current microwave confocal imaging algorithm includes delay-and-sum (DAS), space-time beam forming and Capon beam forming method. This paper uses DAS with the stability.

The previous study has found the microwave absorbing contrast between normal and malignant tissues is 1:6, in addition, the penetration depth for the muscle is 1.2 cm in 3 GHz microwave, and it is 9 cm for adipose tissue. Combined with the characteristics of early detection of breast cancer, the system uses S-band frequency microwave as the source which irradiates tumor phantoms. The experiment results show the excellent imaging performance of the system, furthermore the image contrast and resolution can meet the requirement of early detection
for breast cancer, which have advanced domestic and international.

2 THEORETICAL BASIS AND ALGORITHMS

In the case of thermal confinement, the acoustic wave at point \( r \) and time \( t \), \( p(r, t) \), is related to the microwave absorption \( H(r, t) \) by the following wave equation:

\[
\left( \frac{1}{c_s^2} \frac{\partial^2}{\partial t^2} - \frac{1}{c_p} \frac{\partial}{\partial t} \right) p(r, t) = \frac{\beta}{c_p} \frac{\partial}{\partial t} H(r, t)
\]

where \( c_s \) is the acoustic speed, \( c_p \) is the specific heat, and \( \beta \) is the coefficient of the volume thermal expansion. \( H(r, t) \) can be written as a product form of space absorption function and an instant pulse function:

\[
H(r, t) = A(r) I(t)
\]

where \( I(t) \) is the instant pulse function, \( A(r) \) is the space absorption function.

In the microwave pulse irradiation period, the tissue inhomogeneity leads to pressure wave unevenly distributed. Every non-zero sound pressure can be regarded as a heat source which propagates sound waves outwards. The initial sound pressure depends on the electromagnetic parameters of biological tissue, the source frequency and amplitude of the field intensity.

3 EXPERIMENTAL INTRODUCTION

The experimental platform uses an array consisted of four ultrasonic sensors to acquire 180-positions sample signal whose interval is 2 degree in a circular scan, and reconstructs the electrical field image which reflects the tissue character. The principle pattern is shown in Figure 1, S-band power microwave is radiated to sample via the circuit and the horn antenna (The peak power is 60 kW, the carrier frequency is 3 GHz, the pulse width is 400 ns. The average amount of electromagnetic radiation is 0.097 mW/cm², and the value is less than 20 mW/cm² which is body electromagnetic radiation safety standard in 2005 IEEE). The sample is immersed into transformer oil to prevent the microwave signal attenuation and the air absorption for ultrasonic signal. With the absorption of microwave pulse energy causing the instantaneous expansion, the sample generates ultrasonic pressure wave which carries the physical information of the sample. The signal is received by ultrasonic sensors, and processed to obtain the image reflecting the electromagnetic characteristics.

4 RESULTS AND DISCUSSION

4.1 Samples of different sizes

The system uses different size tumor phantoms which are formed from the colloid hybrid heating solidified with water and agar by a certain percentage to validate the detection ability. Figure 2 shows the different size square colloids (2 × 5 mm, 2 × 10 mm and 1 × 15 mm), which contains ink to be distinguish clearly and does not affect the physical properties. Figure 3(a) shows the imaging results of five different size tumor phantoms, and it can be distinguished from the background, which proved the high-contrast performance of the imaging system. The energy amplitude of the 5 samples of the same physical characteristics exist difference, because of the larger size sample absorbs the more energy. From the result, the system can detect the 5mm square phantom clearly, and it is enough for the early detection of breast cancer.

4.2 Samples of different conductivity

In practice, the growth of the tumor is a gradual process. Even for the same tumor, the different locations will exhibit different physical characteristics, and which provides a reference for the grasp of tumor growth phase and the judgment of the development state. In this paper, we use the complex tumor phantom composed from the sample superimposed by the three different conductivity phantoms, to verify the ability to distinguish between complex objects. Figure 4(a)
shows the photo of the experiment sample, where the green one’s conductivity is the lowest, and the black is the lowest. Figure 4(b) shows the imaging result, which clearly distinguish differences in the physical characteristics of the sample at different locations, and the location of a large electrical conductivity, energy amplitude is large. The energy magnitude difference accords with the actual conductivity difference, so that the system can distinguish the physical characteristic difference at the different locations of the same tumor.

5 CONCLUSION

Based on the theory and thermoacoustic imaging system, this article assesses the multifaceted performance of the 3 GHz microwave thermal acoustic imaging system, and uses different sizes and conductivity to achieve microwave-induced thermoacoustic tomography image. From the experimental results, the image reconstruction errors are control less than 5%, and the resolution is enough for early detection of the early breast tumor. This paper use the complex tumor phantom composed from the sample superimposed by the three different conductivity phantoms, to verify the ability to distinguish between complex objects, which clearly distinguish differences in the physical characteristics of the sample at different locations. It helps for the grasp of tumor growth phase and the judgment of the development state.

In summary, the system for early detection of breast cancer has the potential advance of high contrast ratio, non-invasive, and etc. The experiment results can provide a reliable safeguard for the next vivo animal and clinical studies, as well as the next phase of quantitative microwave thermoacoustic tomography reconstruction of the conductivity distribution to form a solid foundation.

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REFERENCES


