A Novel Microwave Power Deposition Monitoring Method by Thermoacoustic Imaging

(*invited paper*)

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***Abstract*—This paper presents a novel technique for monitoring microwave power deposition based on thermoacoustic imaging. It can be applied in breast cancer hyperthermia using a microwave antenna array to focus microwave energy at breast tumor. Compressive thermoacoustic imaging technique is applied to expedite the imaging and monitoring process. Simulation results using a realistic breast phantom are provided.**

Keywords—breast cancer; compressive sensing; hyperthermia; power deposition monitoring; thermoacoustic imaging

I. Introduction

Breast cancer is a great threat to women due to its high morbidity and mortality [1]. Several techniques are currently adopted for clinical treatment of breast cancer, including radiation treatment, chemo treatment and breast biopsy. However, each of these techniques suffers from some deficiencies such as low efficiency, severe side effect to human body, invasive and high cost. Hyperthermia is an emerging alternative mechanism for treating breast cancer noninvasively by heating up breast tumors to above 42 °C [2]. Focused microwave hyperthermia, i.e. applying microwave as the source of heat and focusing microwave beam only at the tumor, can greatly improve the efficiency of hyperthermia and has attracted lots of attention [3,4].

Successful implementation of focused microwave hyperthermia requires real-time monitoring of the microwave power deposition in the breast to judge if the microwave beam achieves the desired focusing status or not. The already available methods for this task are ultrasound imaging [5] and MRI [6]. But the former has low sensitivity and the latter is bulky and not cost-effective.

We propose employing microwave-induced thermoacoustic imaging (TAI) to provide reliable monitoring of the focusing status [7-9]. TAI integrates the high contrast of microwave imaging and excellent resolution of ultrasound imaging [10-15]. In a TAI modality system, a pulsed microwave signal is pumped into an object to launch ultrasound waves via thermoacoustic effect. The ultrasound waves are then captured by detectors and processed to reconstruct an image of the object. This image represents a spatial distribution of the microwave power deposition in the object. For the focused microwave hyperthermia, the tumor has larger conductivity and receives much higher microwave radiation due to microwave focusing than the surrounding tissues. Thus, the tumor generates stronger acoustic waves than the surrounding tissues and appears to be an obvious hot spot in the image. Therefore, applying TAI to monitor the microwave power deposition for breast hyperthermia is very straightforward.

Conventional TAI setup based on back-projection imaging algorithm records the acoustic signals at over 1000 locations by scanning an ultrasound sensor array, which takes a long time to finish the entire imaging process and is not suitable for real-time monitoring. Applying compressive TAI [16-19] can greatly reduce the needed time to do the measurement and is therefore promising for real-time monitoring of the microwave power deposition in hyperthermia.

In section II, the basic modality of the proposed setup is introduced and some numerical study results are shown to demonstrate the validity of the method.

II. Numerical Study

The setup of the proposed monitoring scheme based on compressive TAI mainly contains two parts. The first part is a microwave antenna array that radiates microwave energy into the breast and the phase and amplitude of each array element can be adjusted to realize the desired focusing condition, i.e. focusing the microwave energy only at the breast tumor. The second part is an ultrasound detector array that measures the outcoming acoustic signals. All the antenna elements and detector elements are largely evenly distributed on a big bowl-shaped surface around the breast. Electric field distribution in the breast phantom is simulated first by a commercial software package solving the Maxwell's equations. Resulting microwave power deposition profile is then used to simulate the acoustic pressures at the deployed ultrasound detectors by a homemade program. Details of the modeling technique of TAI can be found in [10,20,21].

A realistic human breast phantom is used to perform the microwave and acoustic simulations [22]. A spherical tumor is inserted in the phantom as shown in Fig. 1. In total 30 rectangular patch antennas and 20 circular ultrasound detectors are located around the breast phantom with a distance to the skin layer of the phantom of about 3 cm. Simulated microwave power deposition profiles and compressive thermoacoustic imaging results are shown in Fig. 2 and 3, respectively. A good agreement between the power deposition profile and the corresponding image is obtained, which demonstrates the validity of the proposed method in monitoring the microwave power deposition via compressive thermoacoustic imaging. The result shown in Figs. 2 and 3 is not the optimal focusing result since the highest microwave power does not occur at the tumor. Actually, the excitation phases of the 30 antenna elements in the antenna array can be optimized to achieve a desirable focusing of the microwave fields at the breast tumor. Therefore, in the ideal case, only the tumor shows a hot spot in the microwave power deposition profile, which also appears as a hot spot in the compressive thermoacoustic image.

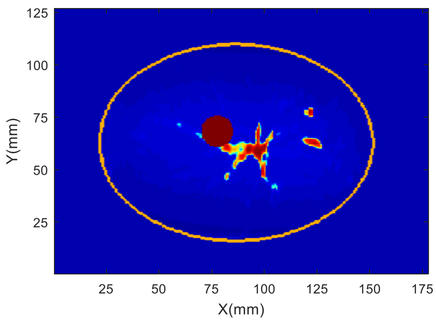

Fig. 1. Profile of the dielectric constant of the breast phantom with a tumor in a principle plane.

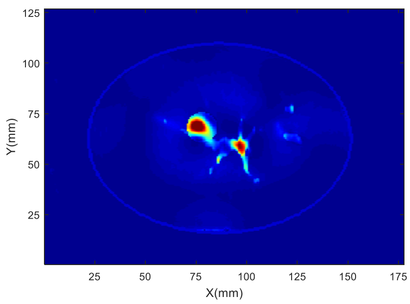

Fig. 2. Profile of the simulated microwave power deposition in a principle plane.

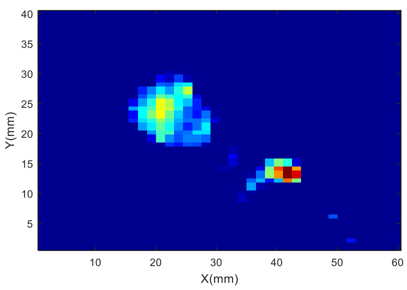

Fig. 3. Profile of the obtained image in a principle plane.

III. Conclusions

A novel technique for monitoring the microwave power deposition in breast cancer hyperthermia using compressive thermoacoustic imaging. Simulation results are shown to demonstrate the validity of the method. Currently, we are working on building the experimental system for this technique. The proposed mechanism can also find potential applications in microwave hyperthermia of other types of cancers.

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