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A Prototype System of Microwave Induced Thermo-Acoustic Tomography for Breast Tumor

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***Abstract*—Microwave-induced thermo-acoustic tomography (MITAT) is an innovative technique for tumor's detection. Due to there has high contrast in terms with permittivity and electrical conductivity of tumor versus normal tissue, even if the tumor still in the early phase it can be imaged clearly. For the proposed MITAT system, low energy microwave pulses are used as the irradiating signals, while the received signals are ultrasound, high contrast and high resolution images can be obtained. After some theoretical research and basic fundamental experiments, the first prototype of experimental system is designed and built. It includes the microwave radiator, the arrayed sensor bowl, the circular scanning platform, the system controller and the signal processor. Based on the experimental results using this integral MITAT clinic system, the images contrast can be reached higher than 383:1; while the sub-millimeter special resolution is obtained for a 1cm3 scale tumor mimic.**

I. INTRODUCTION

The microwave-induced thermo-acoustic tomography (MITAT) is an innovative technique for tumor's detection, it employees the modulated microwave pulses to irradiate the biologic tissue, there has thermo-deposition due to the electromagnetic energy absorbed by the tissue. Because the difference of tissue heating is originated by its electric parameters, the detectable ultrasonic signals are generated by this procedure. Especially the malignant tumor with distinct permittivity and electrical conductivity versus the surrounding normal tissue, microwave-induced thermo-acoustic (MITA) signals can be obtained with very high signal-noise-ratio. For the microwave pulses used as the irradiating signals, while the received signals are ultrasound in microwave-induced thermo-acoustic tomography system, high resolution and contrast images can be obtained. It has becoming a promising technology in medical imaging field. The past research works of MITAT is usually focused on theory of the thermo-acoustic mechanism [1] and some simple experiment on acoustic signal characteristics and imaging approaches [2]. However, to design a near-clinic MITAT system has many engineering difficulties [3, 4]. The primary target of this paper is to analyze and solve those difficulties, and finally to build a prototype system that fits the need of early phase clinical experiments.

The major innovative parts of the MITAT system is listed as follows: the circular horn microwave radiator, the arrayed sensor bowl made by Polytetrafluoroethene (PTFE), the 86dB wide-band ultrasound pre-amplifier with switch, the system controller and the signal processor.

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II. THE DESIGN OF MITAT SYSTEM AND MODULES

A. Overview

The experimental system of MITAT is a combination of mechanics, microwave engineering, acoustic engineering and digital signal processing. The purpose of the system is to build a platform that can let the patient prone on it and make tomography of her breast one by one, with the method of MITAT. Fig.1 shows the system sketch of the whole system.

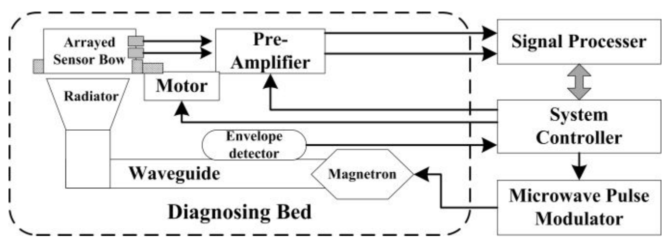


Figure 1. Block sketch of the MITAT system

The signal processor is an industrial computer which is in charge of the scanning process and imaging approaches. The system controller is in charge of the basic timing control and power source distributions of the whole system. The microwave pulse modulator is designed to drive and modulate a regular continues wave 2.45GHz magnetron to produce a 500ns rectangular pulse, as described in [3]. The output of the envelop detector is conditioned to trig the sample sequences of acoustic signals. The radiator is a rectangular-to-circular horn antenna with the center frequency at 2.45GHz. The design of the other modules is illustrated in the following sections.

B. The Design of ultrasonic Sensor Array Bowl

In the MITAT application scenery, where the patient prone on the bed, the microwave energy is transmitted upwards onto the front of the breast, and the acoustic sensors needs to be aligned on the side of the breast to get the tomography, while for the best angle resolution they has to be aligned horizontally as a circular array with $\lambda/2$ spacing. For the frequency range of MITA signal in the breast tissue, the array spacing needs to be less than 2.5mm. But the MITA signal is so weak that the sensor needs to have fairly large aperture to get enough signal-to-noise ratio (SNR), for example, the sensor in the proposed system is V314-SU made by Olympus [4], with a 19mm diameter aperture. In order to build the required sensor array, a synthetic aperture arrayed sensor bowl is developed. The cylinder expansion view of the bowl is shown in Fig.2.

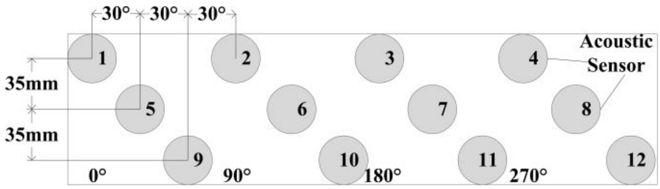


Figure 2. Cylinder expansion view of arrayed sensor bowl

Because the shape of ultrasonic sensor is cylindrical, and the axial direction of the sensor is along with the radial direction of the bowl, the method of fixing the sensor on the bowl must be carefully designed to maintain a perfect physical match and seal of coupling oil. Fig.3 shows the sketch of the design of the adapter set of sensor.

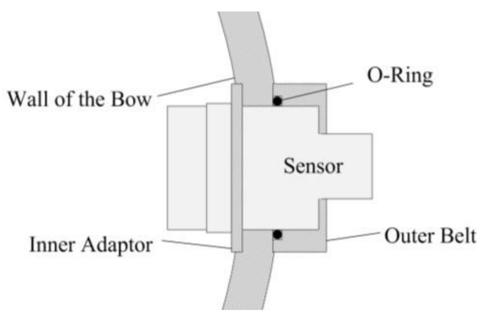


Figure 3. Fixing Method of the Sensor with the Bowl

For the consideration of transparency of microwave energy, the PTFE with relative permittivity of 2.2 is chosen as the material of the bowl. Now the microwave transparent PTFE bowl with ultrasonic sensor array attached is finished, and shown in Fig. 4.

(a) *(b)*

Figure 4. The finishing view of the scanning bowl: *(a)bird view; (b)side view*

C. *The design of Circular Scan Platform*

The bowl is driven by the scanning motor to rotate with small steps and sample the signal at each position. After rotated 90°, the sampled data of all sensors can be synthesized into a circular aperture with small arc spacing. For example, set the step as 3.6°, after 25 steps, the four sensors on one height can be synthesized into an 100 element circular array with 9mm arc spacing. For the most application purpose, the arc spacing should be less than $\lambda/2$ of the MITA signal, which is less than 3mm. With these requirements, the accuracy and precision of the circular scanning platform should be better than 1mm or less. This is quite a challenge with torque and precision.

The circular scanning platform with worm-drive transmission is developed to solve the problem. As shown in Fig.5, this structure provides a 288:1 transmission ratio. When the worm-shaft is driven by a step motor with 1.8° per-step, the worm-wheel will have 0.006° step accuracy which means 0.015mm arc spacing accuracy on the scanning bowl. This characterize satisfied the requirement of the sensor array.

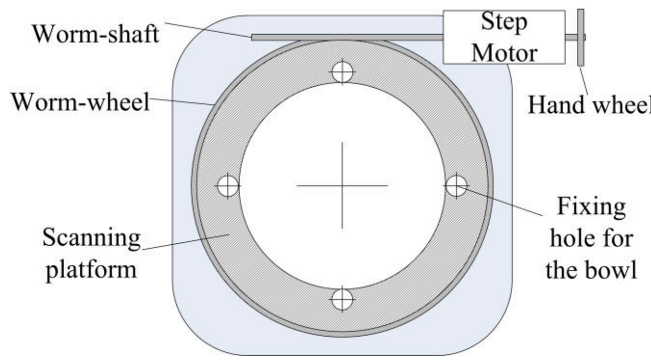


Figure 5. Sketch of the worm-drive circular scanning platform

C. *The design of the acoustic pre-amplifier*

The measured MITA signal from the sensor is at uV level. It needs to be amplified before sampling [5, 6]. The formal system mentioned in [3] used the Olympus Panametrics-NDT as the pre-amp, which gives only 54dB voltage gain. It requires the microwave peak power to be larger than 30KW to induce an enough large acoustic signal detect-able with more than 100 average times. In the proposed system, the pre-amp is specially designed to have 86dB voltage gain. This pre-amp improves the SNR of the system significantly, so the microwave peak power can be less than 10KW with average time less than 16. The average SAR is lower than calling with a GSM mobile phone.

The pre-amplifier is designed with all operational amplifiers for the purpose of the best repeatability and re-productivity. AD797 with the best noise performance is used as the first stage with gain of 10. OPA847 with the best gain and bandwidth product is used at the second stage with gain of 151 followed by the OPA846 as output stage. Fig.6 shows the block sketch of a single channel of the amplifier. The electric parameters of the amplifier are listed in Table 1.

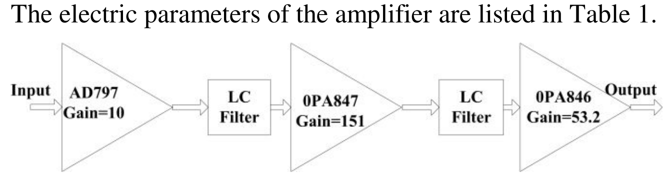


Figure 6. The block sketch of the pre-amplifier

TABLE I. Parameters of Pre-Amplifier

Gain:	86dB (20000)
High-pass Frequency:	30±0.5KHz
Low-pass Frequency:	5.7±0.2MHz
Input Impedance:	100KΩ
Output Impedance:	50Ω
Noise Floor RMS:	70mV
Output Vpp	7.32V
Gain Miss Match between Channels:	<1dB
Pass Band Ripple:	<1dB
Stop Band Attenuation:	>40dB/0ct

C. The design of the system controller

The system controller connects and controls all the other modules in the system. It is the bridge between the signal processer and the microwave ultrasonic sub-system. The main function of the system controller is described as:

- Supply power for each modules;
- Generate the drive pulse for the step motor;
- Generate the trigger pulse for the microwave pulse modulator;
- Conditioning the signal from the envelop detector and generate the TTL trigger pulse for the digitizer in the signal processer.

Fig.7 shows the block sketch of system controller. The 24V/3A DC Power is a switching AC-DC power module that provides power to the step motor. The Low Ripple DC Power is a linear adjustable power module that provides ±6V clear power rail for the acoustic pre-amplifiers. The EM trigger generator is a TTL buffer with 100mA output capability to drive the EM pulse modulator. The digitizer trigger generator is a high speed voltage comparator followed by a mono-stable circuit to trigger the digitizer to sample the acoustic array signal, 12channels simultaneously.

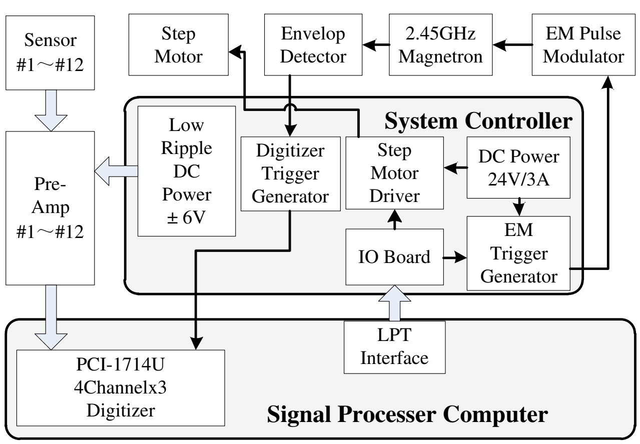
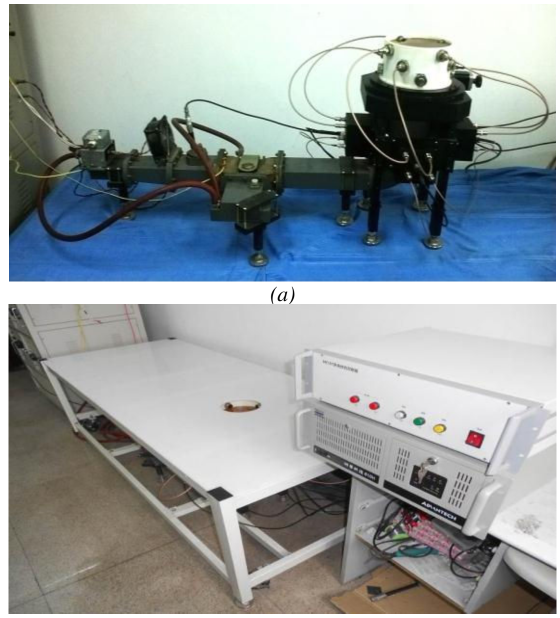


Figure 7. The block sketch of system controller

The microwave module and the acoustic module are integrated as the core part of the system shown as Fig.8-(a). And the finishing view of the whole system is shown as Fig.8-(b).



(b)

Figure 8. The finishing view of the MITAT system: *(a) core part; (b) entire system*

III. THE EXPERIMENT RESULTS

Based on the experimental system of MITAT, some imaging experiments have been processed. The purpose of the early phase experiments is to verify the system and evaluate the image contrast and resolution. With this consideration, the mimic of tumor, which is made by agar, is used as the target. Its electrical parameters are easy to be set closely with tumor tissues and its shape is easy to control. The mimic is lifted by thin wires at the desired position in the bowl. During the mimic experiments, the bowl is full filled with transformer oil, which has considerable small electrical conductivity. For the future experiments on human tissues, safer coupling liquid like castor oil will replace the cheaper transformer oil.

The imaging approach is the PSTD-TRM method proposed in [3]. Fig.9 shows the single 1cm^3 cubic mimic imaging results. The cubic mimic is hanging in the middle of the bowl. The scanning step of sensor is 1.8 degree, providing 200 uniformly distributed sensor position on one circle. This result is also used to calculate the resolution as 0.83mm and the 10dB image contrast as 383:1.

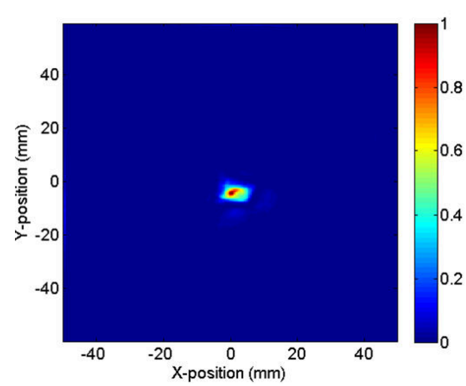
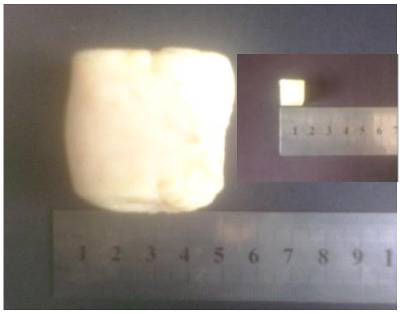
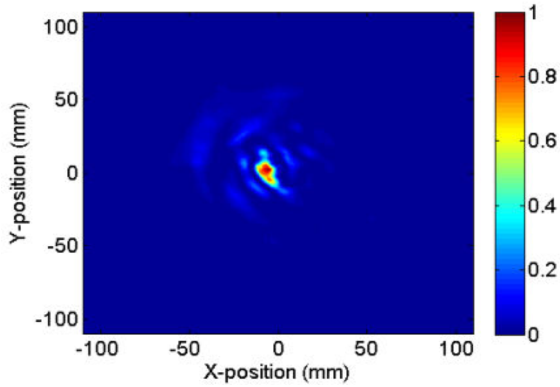


Figure 9. Imaging result of single 1cm3 mimic

Fig.10 shows the image results of one 1.2cm^3 mimic buried in the 5cm^3 pure fat (from pig). It proves the high contrast between tumor mimic and normal fat and also proves the potential of the MITAT system for the detection of breast tumors.



(a)



(b)

Figure 10. Imaging result of single 1.2cm^3 mimic buried in 5cm^3 pure fat *(a)target measuring ; (b) imaging result*

Due to the page limitations, more results may not be figured out in this paper. A full article about the system and more convincing results will also be included.

IV. Conclusion

The proposed prototype system of MITAT is designed for early phase detection of breast tumor. The PTFE bowl integrated with synthetic aperture arrayed sensor is designed to get high SNR on acoustic signal while fitting the spacing requirements of the circular array. The wide-band pre-amp provides 86dB voltage gain and significantly reduced the microwave SAR lower than calling with a GSM mobile phone. The system controller and the signal processer organize the system and perform the imaging approaches. Single cubic imaging result is given and analyzed, which verifies the system has high imaging contrast and sub-millimeter spatial resolution. More results will be include in the next paper and future work include clinical experiments are still in progress.

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