Experimental Study for Microwave-Induced Thermoacoustic Tomography

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***Abstract*— The advantage of Microwave-Induced Thermoacoustic Tomography (MI-TAT) hybrid modality is its ability to take advantage of the microwave absorption coefficients which provide high contrast across soft tissues and materials. This in combination with the superior spatial resolution of ultrasound waves is important in providing a low-cost alternative to MRI and early breast cancer detection methods as well as high resolution and contrast for Non-Destructive Evaluation (NDE).**

I. INTRODUCTION

Ultrasonography is widely used in medical practice as a low-cost alternative and supplement to magnetic resonance imaging (MRI). Although ultrasonography has relatively high image resolution (depending on the ultrasonic wavelength at diagnostic frequencies), it suffers from low image contrast of soft tissues having similar characteristic acoustic impedances. The properties of ultrasonography can be contrasted with those of microwave imaging, which is used extensively in Non-Destructive Evaluation (NDE) and is used in early breast cancer detection [1]. Microwave imaging has high contrast due to the varying conductivities of the materials, including soft tissues. However, it suffers from poor resolution due to the long wavelengths at microwave frequencies. Microwave-Induced Thermoacoustic Tomography (MI-TAT) is a noninvasive hybrid modality which improves contrast by using thermoelastic wave generation induced by microwave absorption and provides improved resolution with generated ultrasound signals. Samples are irradiated with sub-microsecond electromagnetic pulses. These microwave pulses cause a quick thermal expansion and contraction thereby inducing acoustic waves in the sample. The acoustic waves are then detected with an unfocused transducer. The strength of the generated acoustic wave is determined by the amount of microwave energy that is absorbed by the target and the length of the microwave pulse. Having a shorter pulse leads to quicker thermal expansion and contraction. Higher power microwave pulses allow for more energy to be deposited into the sample which causes more heating to occur.

II. DESIGN AND SETUP

Fundamental research on MI-TAT has been conducted over the past several years; most recently a finite element analysis model was developed and validated against a hybrid finite-difference-time-domain (FDTD) model [2]. This paper presents an experimental setup that combines both microwave induced ultrasonic wave generation with ultrasonography. The proposed experimental setup is shown in Figure 1. The experiment utilizes a microwave power supply with 5 kW peak power. Minimum pulse length of the power supply is 300 nanoseconds. However, through experimentation it is found that a pulse length of 500 nanoseconds provides the most power without compromising the shape of the pulse. The output frequency of the power supply is variable from 2.4 GHz to 2.5 GHz. A significant part of the design effort went into shielding the experiment so microwave leakage was kept to a minimum. The sample is placed inside an oil filled acrylic tank. This tank is then surrounded with carbon impregnated foam. This microwave absorbent foam absorbs the microwave energy to minimize the reflections of the microwaves in the system. Acoustic signals are received with an unfocused ultrasound transducer and an ultrasound Pulser/Receiver (P/R) is used to pre-processes the signal before it is recorded on an oscilloscope. The amplitude of the ultrasound signals is in the millivolt to nano-volt range. Such low voltage signal creates a very poor signal to noise ratio (SNR). Therefore, a custom designed ultrasound pre-amplifier is used to improve the SNR

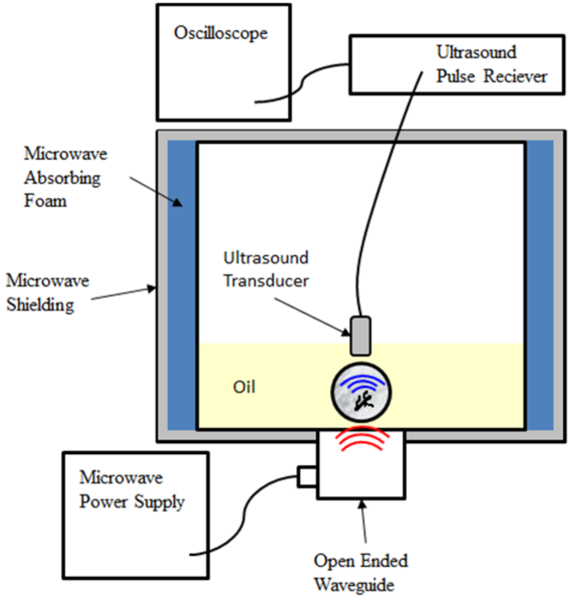

Figure 1: Block diagram of the experimental setup.

of the system. The system is synchronized so that when the microwaves are pulsed the ultrasound P/R starts to processes received signals from the transducer. This enables accurate time estimation for the MI-TAT signal. To achieve this synchronization a function generator is used with a repetition frequency of 100 Hz. This 100 Hz square wave is sent to the microwave power supply, the ultrasound P/R and it also provides the trigger line for the oscilloscope.

For accuracy and repeatability the experimental setup includes a custom designed 2D scanner. This scanner utilizes stepper motors to move the transducer to any location inside the tank, enabling raster scanning of any target and accurate experimental repeatability.

III. EXPERIMENT RESULTS

The experimental setup is used on samples ranging from tissue phantoms to concrete samples (homogenous and non-homogenous). The concrete samples are used to assess MI-TAT capabilities for nondestructive testing on structures and/or material characterization. While the biological phantoms assess MI-TAT for medical applications including early breast cancer detection. Averaging 1024 1-D waveforms for a given position, improves the SNR of the MI-TAT signal allowing for the relatively low 5 kW peak power microwave pulse compared to other published works. Averaging combined with a low noise preamp improves the SNR to provide a measureable MI-TAT signal. Figure 2 shows a pulse/echo acoustic signal. This purely acoustic signal is taken to predict the time location for the MI-TAT signal. In this case the P/E mode signal is at 18 µs.

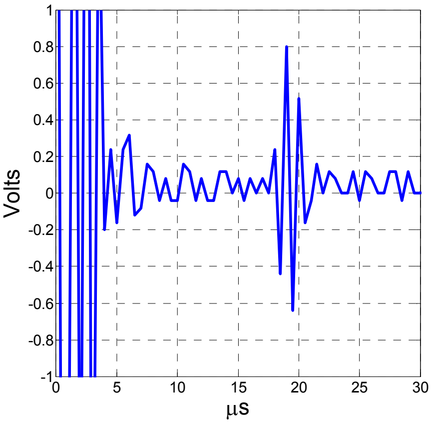

Figure 2: Acoustic signal from tissue a sample to estimate the location of MI-TAT signals.

Therefore, the predicted MI-TAT signal should be at about 9 µs. Figure 3 (a) shows a MI-TAT signal at 10 µs. This signal was averaged a total of 1024 time using an oscilloscope. Figure 3 (b) is the same experiment run without a tissue sample in the tank. It can be seen from Figure 3 that the experimental setup is successful in generating a MI-TAT signal. The results show promise for a low cost, non-ionizing imaging system, cheaper and faster than MRI. With superior special resolution and dielectric contrast compared to pure ultrasound or microwave approaches.

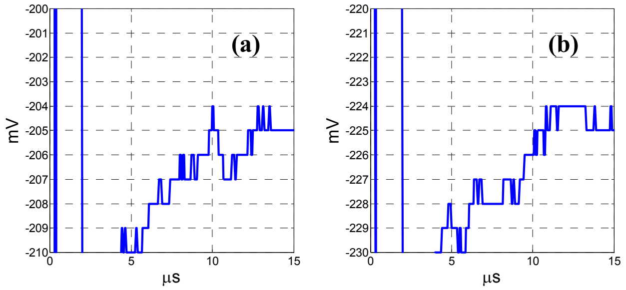

Figure 3: Recorded MI-TAT signal from a tissue sample. Figure 3 (a) shows the recorded data with the sample and Figure 3 (b) shows the recorded data when no sample is present.

IV. FUTURE WORK AND CONCLUSIONS

Validation of the experimental setup was done using a FDTD simulation. Construction of an experimental setup has been completed and tested with successful generation of MI-TAT signals. With the successful recording of 1D MI-TAT signal the next step is to reconstruct a 2D image of the target samples. Future work on the setup will include automating data collection process. For example, data from the oscilloscope will automatically be pulled in real time so that the processing of the data will be easier and more efficient. Also the placement and movement of the ultrasound transducer will be computer controlled so ensure accurate and repeatable measurements across several days and not just for a single experimental run. The preliminary MI-TAT signals that where recorded did not use the preamp and relied only on averaging of 500 – 1000 waveforms. Future experimental runs will evaluate the effectiveness of a preamplifier for improving the SNR of the system. This will reduce the required number of averages for recording a MI-TAT signal as well as the required microwave power needed to generate such a signal.

REFERENCES

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