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Low-Cost Photoacoustic Tomography System Based on Water-Made Acoustic Delay-Line

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***Abstract*—In this study, an acoustic delay line module is proposed to improve the imaging quality and speed of low-cost photoacoustic tomography (PAT) system. In PAT system, the PA signals are generated by the instantaneous pulse laser excitation. For image reconstruction, it needs to receive PA signals simultaneously in different angles requiring multi-channel data acquisition (DAQ) device. By applying the proposed delay line module, it can merge multichannel PA signals into one output, which reduces system cost of DAQ and the time consumption for signals sampling. The acoustic delay line module aims at sharing the DAQ's limited channel by combining multiple PA signals into single series signal. In this paper, a PAT system with a four-in-one acoustic delay line module was developed to verify its feasibility. Delay line unit is based on ceramic piezoelectric plates to transmit and receive ultrasound, and water as the propagation medium. The four-in-one acoustic delay line module can compact four simultaneous PA signals into one output and distinguish with different time delays. Moreover, the merged output signal can be reconstructed into multiple signals in the digital domain by computer. With the contribution of the delayed signals, the image of target can be reconstructed by the low-cost PAT system.**

Keywords—photoacoustic tomography, delay-line, PA signal, acoustic, piezoelectric

I. INTRODUCTION

As a new biomedical imaging technique, PAT shows its unique advantages and has become an emerging technology. PAT combines both rich optical absorptions contrast and good acoustic penetration depth beyond the limitation of optical diffraction[1]. Photoacoustic effect is the fundamental physical mechanism of the PAT system[2]. More specifically, the instantaneous pulse laser illuminates the tissue of interest, with the light absorption and thermal expansion the imaging target releases the energy by ultrasonic emission[3, 4].

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In PAT system, the PA signals are generated by the instantaneous pulse laser excitation. For the image reconstruction, it needs to receive PA signals simultaneously in different angles requiring multi-channel data acquisition (DAQ). The synchronously arrived PA signals are a set of burst pulse analog signals[5]. The PAT image is reconstructed according to the signals delay time and waveforms by the beamforming delay-and-sum algorithm[6]. In this paper, the water-made acoustic multi-channel delay-line module delayed the PA signal with a stationary time duration and maintained the original waveform with little distortion. By applying the acoustic proposed delay-line module, the pulse PA signals dramatically realize a settable delay in the time domain for each channel. Moreover, the acoustic delay line is feasible because the laser repetition rate is usually less than 20 Hz in PAT system (50 ms per excitation), and the duration of PA signal is usually no more than 30 microseconds[7].

II. METHOD

In the PAT system, the PA signals are generated by the instantaneous laser pulse illumination, and the circular distributed ultrasonic transducers receive the signals synchronously[8, 9]. With the traditional sampling method, the PA signals are connected with DAQ channels point to point and all the DAQ equipment works on a low efficiency status due to low duty cycle[10]. Alternatively, step-by-step scanning method is time consuming for the PAT imaging and impossible for real-time imaging for single-channel DAQ device[11].

A. The Delay-line Module

In this paper, a water-made multi-channel delay-line module is proposed to solve the above-mentioned limitations of the PAT system. The multi-channel delay-line module is based on three delay line units that can distinguish four synchronous input signals. By applying three analog signal adders, it can merge four input signals into one output. The overall diagram of the 4-to-1 delay-line module is shown in Fig. 1.

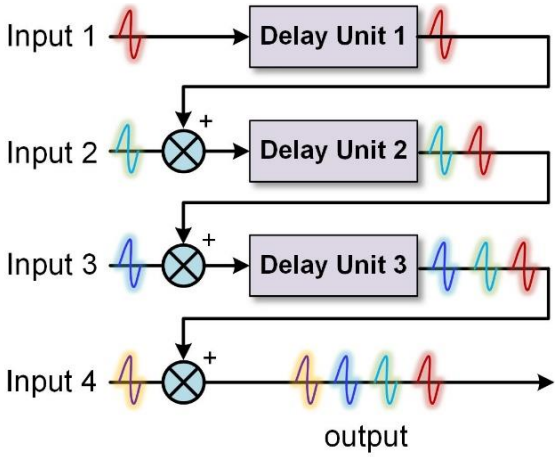

Fig. 1. The overall diagram of the 4-to-1 delay-line module

The ultrasonic transducer converts the PA wave into an electrical signal and amplified by a preamplifier. Comparing with the electric signal, the acoustic wave is easier to realize dozens even hundreds of microseconds' time delay[12]. In the PAT system, with the laser illumination region and energy limitation, the PA signal time duration is usually less than 30 microseconds, which is feasible for the acoustic delay-line module[5, 13]. Consequently, the simultaneous inputs PA signals can be easily distinguished with each other by the acoustic delay-line with different time delays.

The piezoelectric ceramic plate is an economical material to translate the signal mode between electrical and acoustic signals[14]. The photograph of the piezoelectric ceramic plate is shown in Fig .2. In this paper, the water made delay line module based on the piezoelectric ceramic plates is demonstrated to evaluate its feasibility. The piezoelectric ceramic plate's central is 2.5 MHz. Water is an optimum transmission media, which propagates the ultrasound with a constant speed at 1480 m/s, and is easy to couple ultrasound with less attenuation[11].

One delay line unit consists of two piezoelectric ceramic plates and a constant length acoustic transmission line. The water made acoustic delay-line module is shown in Fig .3. For each delay line unit, the two piezoelectric ceramics are aimed to translate the signal between electrical and acoustic wave. The acoustic transmission media between two piezoelectric ceramics is water made agar gel sealed in an acrylic tube.

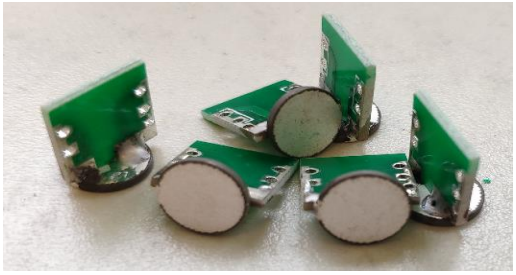

Fig. 2. The photograph of piezoelectric ceramic plate

Fig. 3. The water made acoustic delay-line module

The delay-line unit transfer characterization as shown in Fig. 4, where Fig. 4(a) is the input PA signal waveform, and Fig. 4(b) is the amplified delayed signal. The result shows that the output signal follows the input with a constant time delay.

B. Delayed Signal Reconstruction

As shown in Fig .1, the three delay units are connected by three analog adders. The output delayed 4-to-1 combined signal will be sampled by a DAQ channel. However, for PAT imaging, the combined signal should be reconstructed into four independent signals in the digital domain. The delayed signal and reconstructed signals' waveforms are shown in Fig. 5. Fig. 5(a) is the delayed signal waveform, and Fig. 5(b)-(e) are the waveforms of the reconstructed signals.

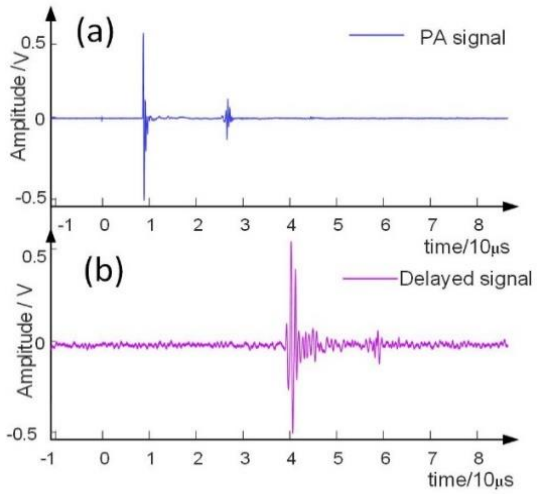

Fig. 4. The delay-line unit transfer characterization, (a) the input PA signal waveform, (b) the amplified of piezoelectric captured delayed signal

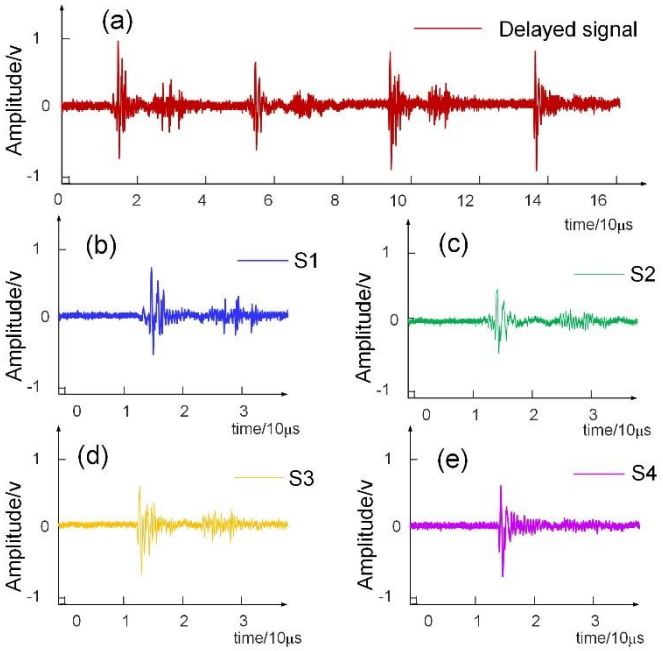

Fig. 5. The delayed signal and reconstructed signals, (a) is the delayed signal waveform, and (b) to (e) is the waveform of the reconstructed signal.

III. Results

A. Experiment Setup

In order to verify the feasibility of the acoustic delay line module. A phantom was made to be imaged by PAT system. The PAT system based on acoustic delay line module setup is shown in Fig. 6, and the phantom is a 2B pencil lead made as A shape.

In this experiment, four ultrasound detectors are applied to capture the PA wave and distribute vertically. With the step motor rotating 90 degrees, the ultrasound detectors can catch the PA signals from the phantom with full angle[15, 16].

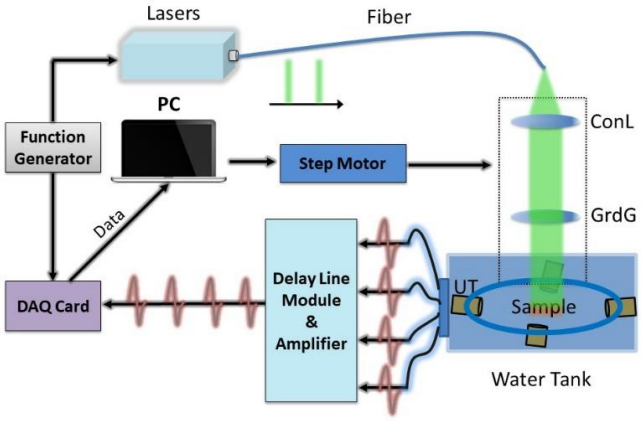

Fig. 6. The PAT system based on acoustic delay-line module setup. PC: personal computer; DAQ: data acquisition; ConL: convex lens; GrdG: ground glass; UT: ultrasound transducer.

B. Imaging Result

Some of the imaging results are shown in Fig. 7, Fig. 7(a) is the photograph of the phantom. The reconstructed image in Fig. 7(b) is by using a single detector with traditional sampling method, while Fig. 7(c) is by using four detectors with the proposed delay line module. The experimental results in Fig. 7. (b) and 7(c) show that the multi-channel acoustic delay-line module can reduce the DAQ channel consumptions and get a high quality imaging result of the PAT system[17].

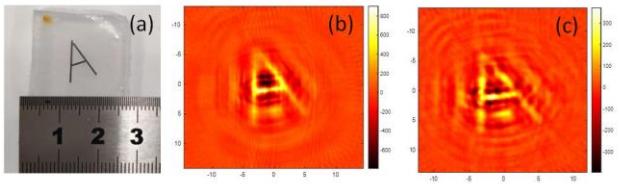

Fig. 7. The acoustic delay line measurement results, (a) phantom, (b) reconstructed images with traditional sampling method and (c) four detectors scanning with acoustic delay line.

C. Result and Discussion

The acoustic delay-line module could compact multi-channel PA signals into one output that reduce the DAQ consumptions and reduce the PAT system cost. However, there are also some limitations for the acoustic delay-line module. Because the signal time delay is based on the ultrasound transmission, the acoustic delay-line is not able to delay a continuous analog signal, whose time duration is more than the ultrasound transmission in the delay media. Therefore, the application of the acoustic delay-line is restricted to deal with the pulse signals, such as the PA signals in the PAT system and the ultrasound imaging system. Additionally, the signal transformed by the piezoelectric ceramics will induce distortion, which is related to the piezoelectric ceramics transmission characteristic. As a consequence, after sampling the delayed signal, it should be separated, and deconvolution in the digital domain and additional calculation are needed to process the signals.

IV. Conclusion

In this study, an acoustic delay line module based on water delay-line units is proposed. The delay-line unit contains two ceramic piezoelectric plates to transmit and receive ultrasound, and water as the propagation medium. It transforms the signal from electric mode into ultrasonic mode, and back to electric mode, which can easily achieve dozens and hundreds of microseconds' delay. The four-in-one acoustic delay line module can compact four simultaneous PA signals into one output and distinguish with different time delay. The imaging result shows that the low-cost of PAT system based on the water made acoustic delay line module is promising to apply in biomedical imaging research.

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