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● *Original Contribution*

PHOTOACOUSTIC IMAGING WITH A COMMERCIAL ULTRASOUND SYSTEM AND A CUSTOM PROBE

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Abstract—Building photoacoustic imaging (PAI) systems by using stand-alone ultrasound (US) units makes it convenient to take advantage of the state-of-the-art ultrasonic technologies. However, the sometimes limited receiving sensitivity and the comparatively narrow bandwidth of commercial US probes may not be sufficient to acquire high quality photoacoustic images. In this work, a high-speed PAI system has been developed using a commercial US unit and a custom built 128-element piezoelectric-polymer array (PPA) probe using a P(VDF-TrFE) film and flexible circuit to define the elements. Since the US unit supports simultaneous signal acquisition from 64 parallel receive channels, PAI data for synthetic image formation from a 64- or 128-element array aperture can be acquired after a single or dual laser firing, respectively. Therefore, two-dimensional (2-D) B-scan imaging can be achieved with a maximum frame rate up to 10 Hz, limited only by the laser repetition rate. The uniquely properties of P(VDF-TrFE) facilitated a wide –6 dB receiving bandwidth of over 120% for the array. A specially designed 128-channel preamplifier board made the connection between the array and the system cable, which not only enabled element electrical impedance matching but also further elevated the signal-to-noise ratio (SNR) to further enhance the detection of weak photoacoustic signals. Through the experiments on phantoms and rabbit ears, the good performance of this PAI system was demonstrated. (E-mail: xdwang@umich.edu) © **2011 World Federation for Ultrasound in Medicine & Biology.**

Key Words: **Photoacoustic imaging, P(VDF-TrFE) transducer, Broad bandwidth, Real-time imaging, Vasculature.**

INTRODUCTION AND LITERATURE

Photoacoustic imaging (PAI), which is also referred to as optoacoustic imaging or thermoacoustic imaging, is an emerging technology combining the merits of both light and ultrasound. In PAI, a short-pulsed laser source is used to illuminate a biologic sample. The laser-generated photoacoustic signals, which are excited by thermoelastic expansion resulting from a small transient temperature rise, are measured by a wide-band ultrasonic transducer(s). The acquired signals can then be used to rebuild the distribution of optical energy deposition within the acoustically imaged region of the sample. Although photoacoustic signal propagation in biologic tissues is intrinsically high-speed, to achieve signal acquisition fast enough for real-time imaging is still technologically challenging. Many pioneering studies on PAI are based on home-fabricated signal acquisition systems that employ a single transducer or an array with only limited receiving channels (Wang et al. 2003; Karabutov et al. 2003; Manohar et al. 2005; Wang et al. 2007; Xiao et al. 2010). Therefore, the mechanical or electrical scan of signals for tomographic imaging is time consuming, especially when the laser repetition rate is also limited. Researchers have recently made efforts on accelerating the imaging speed of PAI drastically by developing custom designed systems powered with large amount of channels (Ermilov et al. 2009; Kruger et al. 2003; Li et al. 2010; Song et al. 2010; Yang et al. 2009). Most of these imaging systems, however, are very costly and also difficult to be duplicated by other groups when fabrication of sophisticated data acquisition circuits is involved.

By combining with commercial medical ultrasound (US) systems, the development of PAI can be accelerated by taking advantage of the state-of-the-art US image processing, management and display technologies (Erpelding et al. 2010; Kolkman et al. 2008; Wang et al. 2008; Yaseen

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et al. 2010). For example, the imaging speed of PAI can be significantly improved by acquiring data from the parallel ultrasound channels each with commercial-grade receiver sensitivity and noise figures. Moreover, PAI results can be more easily reproduced between laboratories when realized with commercially available US. PAI is a natural complement to established US techniques and may significantly enlarge the scope of application of medical US in diagnostic imaging and therapeutic monitoring. An US and PAI dual-modality system may allow nonionizing and noninvasive visualization of both ultrasonic and optical contrast in a biologic sample as well as tissue physiologic properties including blood flow, volume and oxygen saturation. By presenting comprehensive structural and functional information of a biologic sample, the sensitivity and specificity in diagnosis and characterization of a variety of disorders can be substantially improved in comparison with conventional US alone. In comparison with PAI, US is a more established imaging modality. Therefore, interpretation of US images of an object may help guide the PAI procedure and interpretation. The morphologic and tissue acoustic information provided by US, *e.g.*, tissue boundaries, acoustic attenuation and speed of sound, may also be used to improve the reconstruction of PAI images, which may elevate the accuracy in quantitative PAI imaging of tissue optical properties and hemodynamic parameters.

Direct use of a commercial US unit to achieve high quality PAI, however, is challenging. Since the signal level in US is typically much higher than those in PAI and most commercial US systems do not have a high enough signal-to-noise ratio (SNR) nor low enough digitizer threshold for the recovery of weak photoacoustic signals from expected subsurface tissues. Unlike PAI, US involves both ultrasonic signal transmission and receiving; hence, piezoelectric or piezoelectric-composite transducers with both good transmission and reception efficiencies are employed to build most US probes. Using piezoelectric arrays, typical US systems have only limited detection bandwidths (*e.g.*, usually less than 80%), which are not sufficient for high quality PAI, especially when realized in a tomographic manner. The photoacoustic signals generated in biologic tissues have intrinsically broad bandwidth. It has been demonstrated that the spatial resolution achievable in a tomographic PAI system is highly dependent on its detection bandwidth (Xu and Wang 2003). More importantly, with a broad spatial frequency response, a PAI system will be sensitive to imaging a reasonably broad range of spatial frequencies in the target area, *i.e.*, the broadband system can present the optical absorption distribution in a reasonably wide range of object sizes accurately, without strong edge enhancement or blurring. Moreover, broader detection bandwidth also leads to reduced side lobes.

In this work, a high-speed PAI data acquisition system was developed using a commercial US unit (z.one, Zonare Medical Systems, Inc., Mountain View, CA, USA) and a custom built 128-element piezoelectric-polymer array (PPA). Since the US unit supports simultaneous signal acquisition from 64 parallel receive channels, PAI radio-frequency (RF) data from a 64-element array aperture can be acquired after a single laser firing. For complete data acquisition with the 128 elements, a minimum of two laser pulses are needed. Unlike in some other previously developed photoacoustic imaging systems where Poly(vinylidene fluoride) (PVDF) arrays were employed (Ermilov et al. 2006; Kozhushko et al. 2004), the custom built probe developed for this system was using P(VDF-TrFE) film and, for the first time, was integrated with a commercial US machine. Although piezoelectric-polymers are not efficient transmitters, their receiving sensitivity is excellent for competitive detection of weak photoacoustic signals. More importantly, an array fabricated using piezoelectric-polymer elements provides uniquely broad detection bandwidth, which allows satisfactory image quality for PAI. To further elevate the SNR and also realize impedance matching to the 2-meter cable, the signals received by the PPA are sent to a specially designed 128-channel preamplifier board before digitization in the US unit. That is, the preamplifier board provides a much lower capacitance load for the PPA, efficiently drives the coaxial cables and further amplifies the signal prior to the digitizers to allow recovery of signals well below the noise level by averaging. Validating the feasibility of PAI imaging by using a commercial US machine and array probes optimized for photoacoustic signal receiving, as completed in this work, should accelerate the development of PAI and US dual-modality imaging and its application in preclinical and clinical settings.

MATERIALS AND METHODS

Imaging system

A PAI data acquisition system assembled using a commercial US unit is shown in Figure 1. A Nd:YAG laser (Powerlite, Continuum, Santa Clara, CA, USA) is employed to provide laser pulses with repetition rate of 10 Hz, wavelength of 532 nm, pulse energy up to 0.8 J, and pulse length of 5 ns. The synchronization between the US unit receive cycle and the laser firing is achieved using a frame-trigger signal tapped from the probe connector. To acquire laser-generated photoacoustic signals, the US unit can operate in receive-only mode (with the transmitter turned off) at a frame rate triggered by the 10-Hz repetition rate of the pulsed laser. For each laser pulse, 64 channels of 16-bit I/Q data are acquired from a selectable 64-element sub-aperture of the array.