

Seminar report

Group 2: Vendor Independent PA Imaging System Enabled with Asynchronous Laser Source

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Seminar paper: Synthetic-aperture based photoacoustic re-beamforming (SPARE) approach using beamformed ultrasound data

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1. Reason for Paper Selection

As stated in the proposal, photoacoustic (PA) imaging has the advantage of deep penetration, high resolution, and safety. However, hardware of PA imaging hinders a universal application of this technology. Implementation either relies on low-efficiency ultrasound (US) beamformers or vendor-dependent PA platforms. If conventional US scanner implementing PA imaging is viable, the cost of PA imaging will be lower. In addition, PA imaging will be more practicable for either clinical diagnoses or research.

There are several challenges encountered to achieve the goal. First, because of a different time-of-flight (TOF) of ultrasound, US systems beamform PA-derived signals incorrectly. Therefore, a new beamforming method is needed. Second, signals received from ultrasound probe are not synchronized with laser pulse. Specifically, pulse repetition frequency (PRF) and line frequency, as well as phase of laser and acquired US data, are not synchronized.

The paper selected solved the first problem, i.e., the beamforming method, which is a huge step to realize PA imaging on US systems. Additionally, it is the stepping-stone for solving synchronization problem and it provides guidance on theory of PA imaging, US data acquisition (DAQ) and beamforming.

2. Overview

- Problem

There are two critical problems to solve to develop new PA beamforming methods.

The first problem is data acquisition. Since PA imaging is an innovative modality, it is no surprise that most clinical US systems do not offer PA beamforming. In conventional beamforming methods, channel data are applied, delayed, and summed. However, conventional US probes only provide beamformed data. US systems that provide pre-beamformed channel data are expensive. Thus, we need to process the post-beamformed RF data to reconstruct the image.

The second problem is implementation. On one hand, fixed data transfer rate of US systems

prohibits high frame rate real-time imaging. On the other, we must take different TOF of US imaging and PA imaging into account when implementing beamforming.

- Goal

In conclusion, the goal of this paper is to develop a new PA image reconstruction approach based on ultrasound RF data that has already been beamformed by the system.

- Significance

Any commercially available US platform can potentially be used to create PA images.

3. Theory

- TOF

Wave propagation process reveals the fundamental difference between US imaging and PA imaging. Namely, their TOF are different. Wave propagation in US imaging includes transmitting and receiving, so it is double-trip. While PA imaging doesn't contain a process of transmitting, so it is single-trip.

Acoustic TOF can be easily derived as $t_{US}(r_F) = \frac{1}{c}(|r_T| + |r_R|)$ and $t_{PA}(r_F) = \frac{|r_R|}{c}$, for US and PA imaging respectively. If fixed focusing is applied, then $|r_T| = |r_R|$. It can be easily derived that $t_{US}(r_F) = 2t_{PA}(r_F)$. In another word, TOF of US imaging is two times of TOF of PA imaging. It is an essential relationship for synthetic-aperture based re-beamforming (SPARE) method.

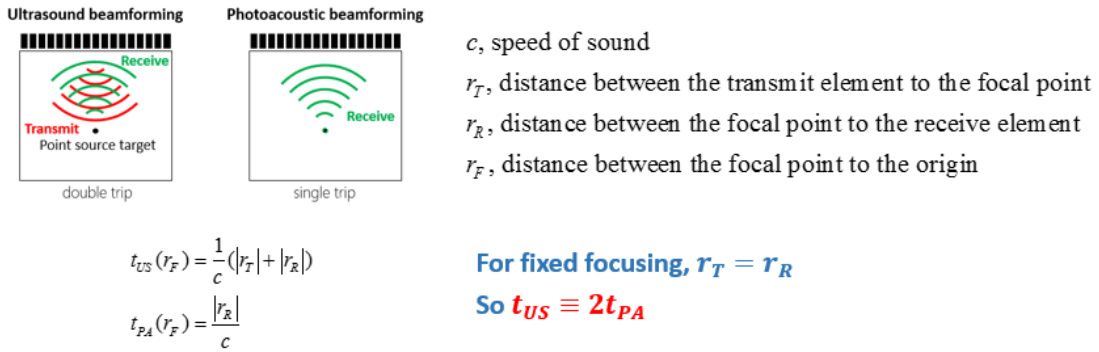


Figure 1

- Synthetic-aperture based re-beamforming (SPARE)

Conventional PA imaging needs channel data for beamforming. Since US probes only provide beamformed data, re-beamform the beamformed data becomes the potential method.

The re-beamforming process for SPARE approach is demonstrated below. First, the US probe receives US waves and generate channel data. Then, it beamforms the channel data into pre-beamformed data, which can be achieved from the platform. Finally, SPARE approach is applied to re-beamform the data.

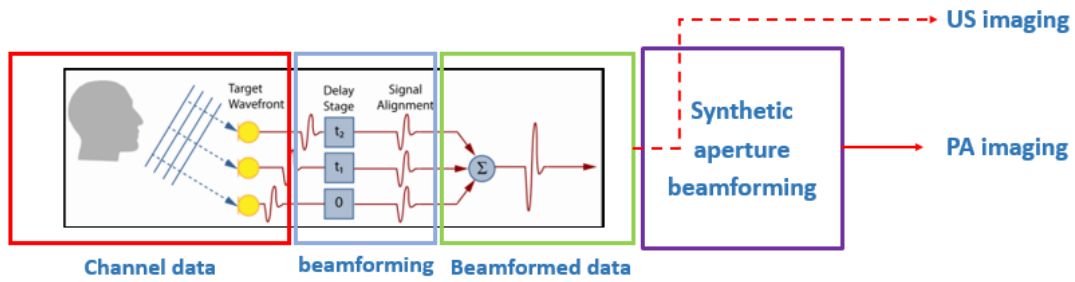


Figure 2

More specifically, the shapes of two point sources are illustrated in the figure to show the process of SPARE beamforming. The wave front of received RF signal is shown as the green curve in (a). After applying the fixed focusing delay as red dashed curves in (a), it becomes somewhat more but not totally focused in (b). Regard the focal point in (b) as a virtual point source and apply inverse and forward delay and sum, the signal is fully focused as shown in (c). (d) illustrates the situation for dynamic focusing, in which the virtual element depth z_F is the half distance of re-beamforming focal depth z_R .

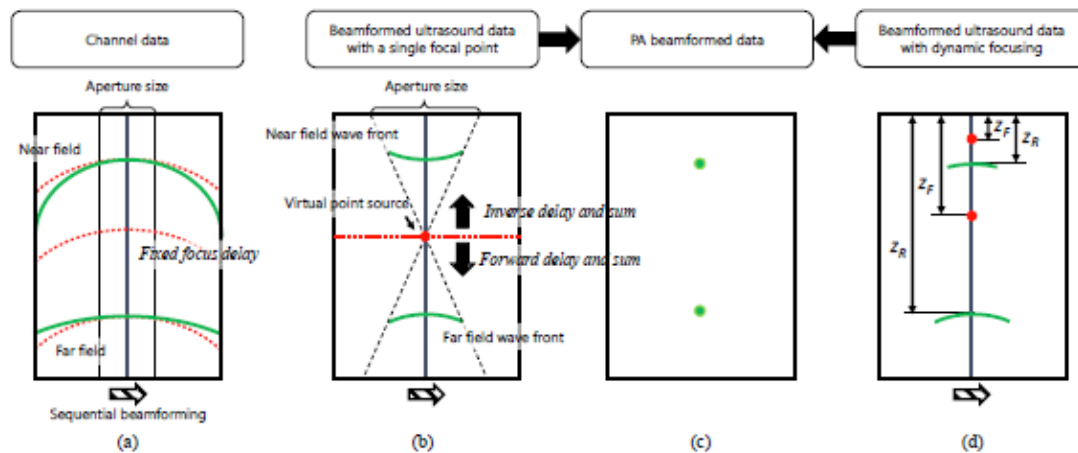


Figure 3

4. Methods

Simulation:

- Software: field II, which is a ultrasound Matlab program system that uses the concept of spatial impulse responses.
- Settings:
 - (1) five PA point sources placed at 10 mm, 20 mm, 30 mm, 40 mm, and 50 mm depth
 - (2) 128-element, 0.3 mm pitch, linear array transducer
 - (3) Sampling rate: 40MHz
- Parameter to be controlled:

The fixed focal depth, the SPARE beamformer focal depth, the fixed focusing aperture size, the aperture size for the SPARE beamforming

Experiment:

Setup:

- (1) A 905-nm wavelength pulsed laser diode (PLD)
- (2) A plastisol phantom with black ink
- (3) Function generator
- (4) 0.3 mm pitch, 128-element, linear array ultrasound transducer
- (5) Channel data collection device (Sonix DAQ) via a clinical US machine (Sonix Touch, Ultrasonix)

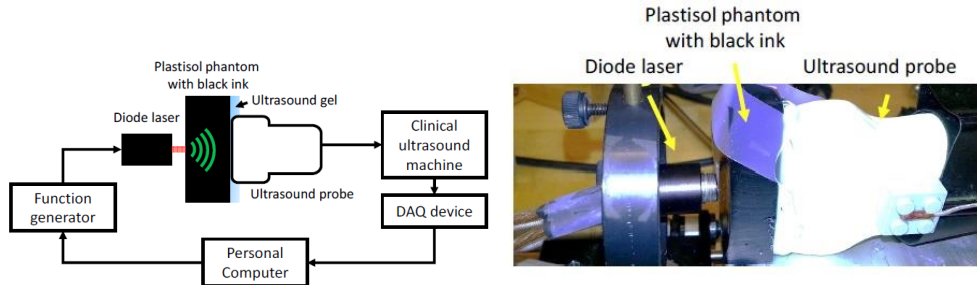


Figure 4

5. Key Results

I. Simulation

Different photoacoustic waveforms, resolution and SNR of corresponding images are tested. In addition, dynamic focusing method is also tested. All results indicate good image quality comparing to ground truth. It proves a universality of SPARE approach.

- (1) Results of different waveforms in the simulation are shown in figure 5. SPARE algorithm does not depend on the impulse responses determined by the absorber size and the ultrasound probe, which means it can be applied on all kinds of ultrasound probes.
- (2) Result of resolution test is shown in figure 6. The resolution of the proposed method agrees well with the ground truth values with a correlation coefficient of 99.87%.
- (3) Result of SNR test is shown in figure 7. The correlation coefficient of conventional ultrasound beamforming and proposed method is 91.56%.
- (4) Result of dynamically focused beamformed ultrasound RF data is shown in figure 8. Grating lobe artifacts are visible in the near field. It is drastically reduced when a small aperture size is used.

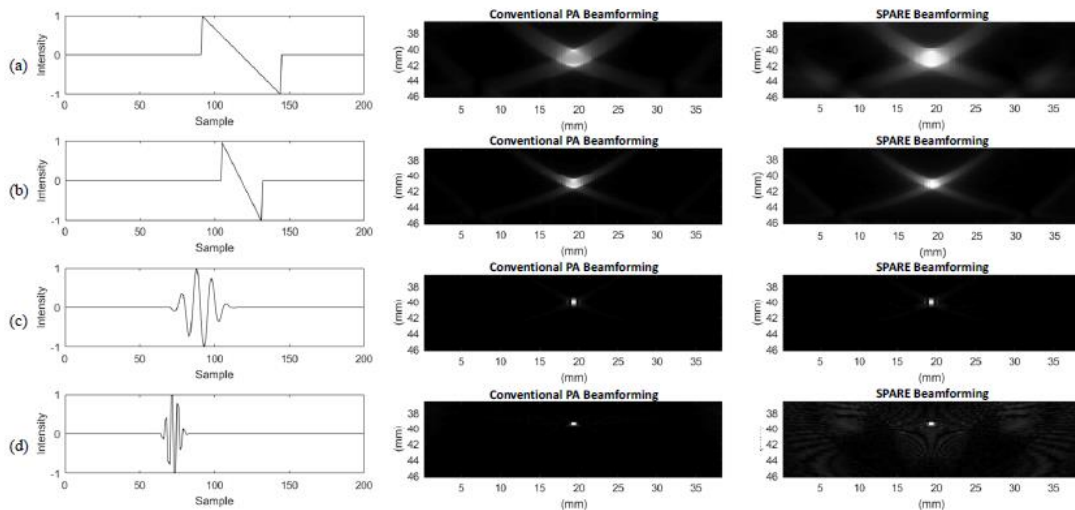


Figure 5 Simulated photoacoustic waveforms, PA images from channel data, and PA images using SPARE beamformer are shown. Fixed focusing at 20 mm depth was used for SPARE beamforming. (a) 1 mm and (b) 0.5 mm diameter objects with N-shape impulse responses were simulated. For a point source, (c) 2 MHz, (d) 5 MHz center frequency waves were simulated assuming that a band-limited ultrasound transducer was used to receive these signals.

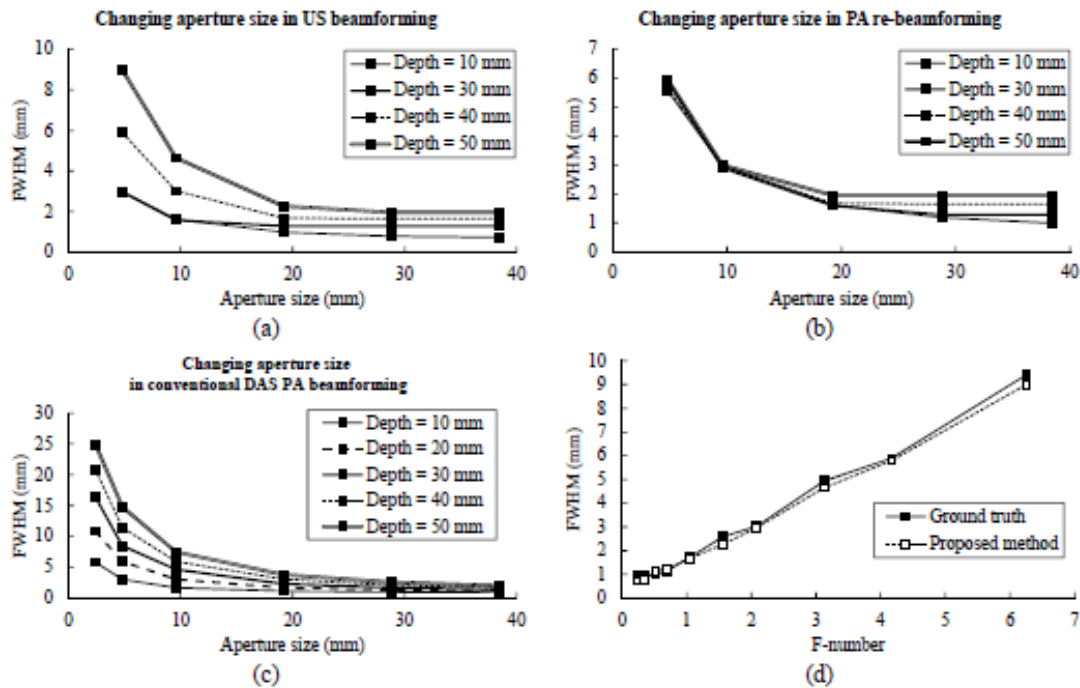


Figure 6 The FWHM of the proposed re-beamforming for the designated focusing depth

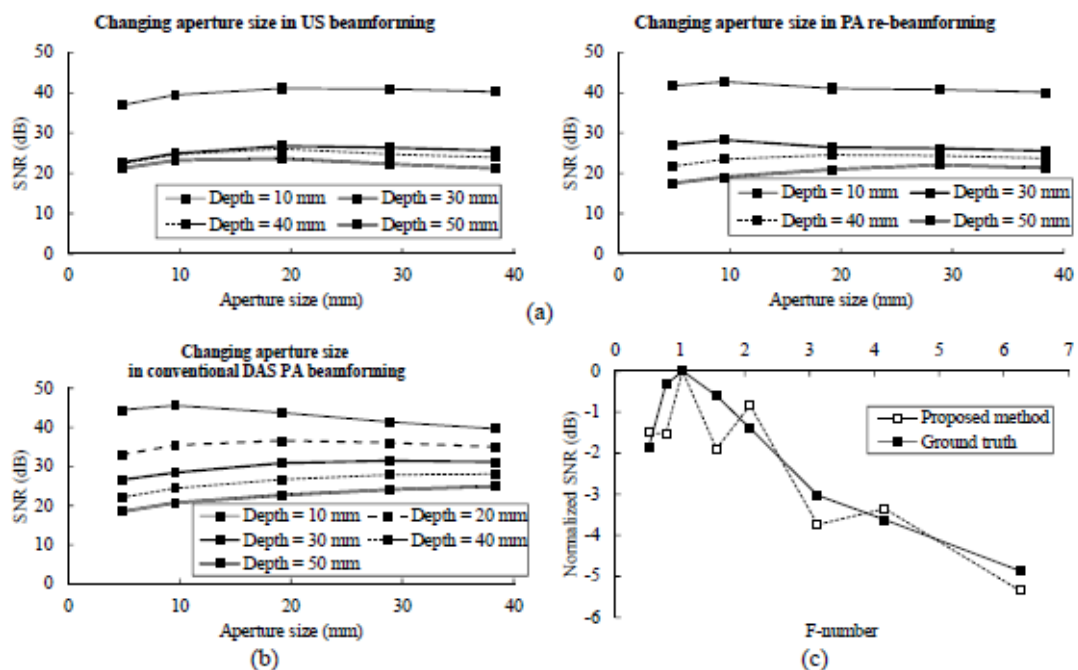


Figure 7 The measured SNR of proposed beamformer varying the aperture size

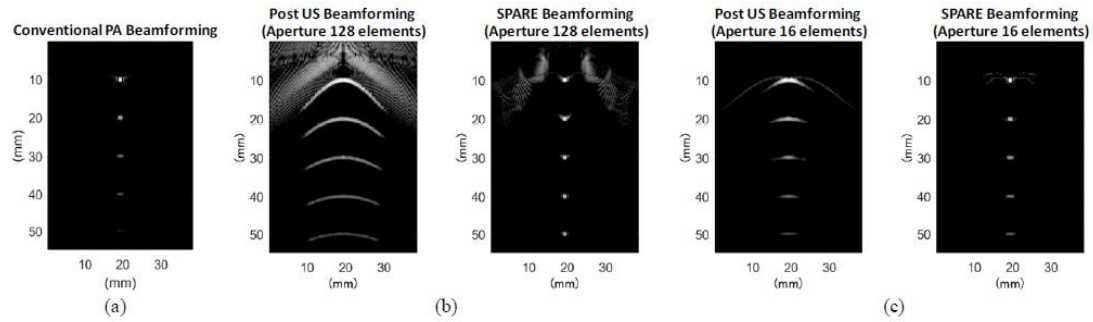


Figure 8 (a) The reconstructed PA image from channel data as a ground truth. (b-c) The reconstructed images through ultrasound and SPARE beamforming.

II. Experimental evaluation

Ultrasound beamforming with fixed focusing and dynamic focusing was applied to experimental channel data to produce two types of ultrasound post-beamformed data.

(1) Experimental SPARE beamforming results are indicated in figure 9. The FWHM was similar to that of the ground truth when the fixed focusing was applied from 9 mm to 21 mm. However, the reconstructed point was degraded in the lateral direction when the fixed focal depth was far from the target.

(2) Experimental SPARE beamforming results from dynamically focused ultrasound beamforming are shown in figure 10. The single source point is well focused.

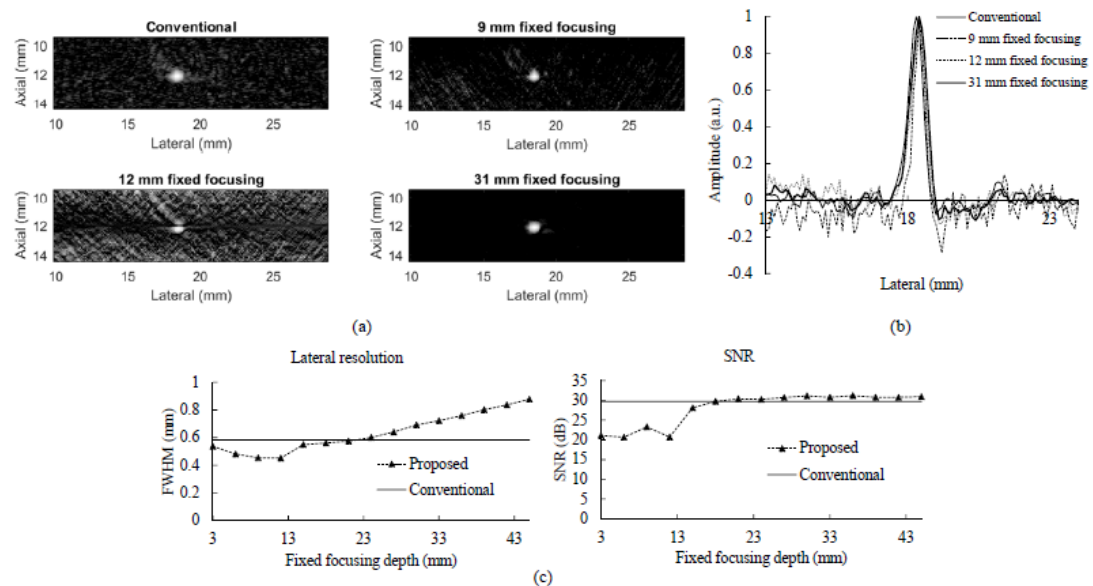


Figure 9 Experimental SPARE beamforming results

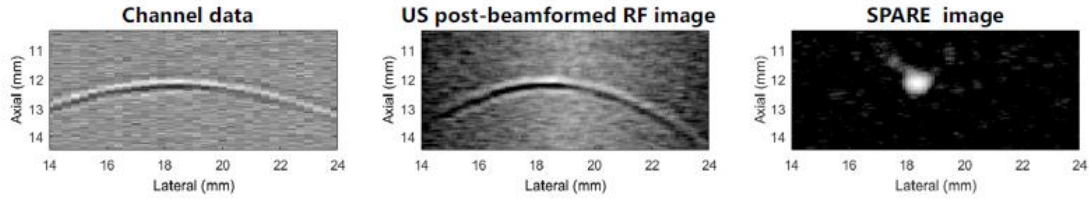


Fig. 10. Experimental SPARE beamforming results with dynamic focusing. Original channel data, intermediate ultrasound post-beamformed result, and final SPARE post-beamformed result are shown from left to right, respectively. The dynamic range of 20 dB was used for display.

Figure 10 Experimental SPARE beamforming results with dynamic focusing

6. Conclusion

A synthetic-aperture based PA beamforming method utilizing ultrasound post-beamformed RF data is proposed. It is validated through simulation, and experiments with different parameter definitions.

SPARE method is a big step to realize PA imaging on US systems. The next step is to overcome the synchronization between laser and signal received by US probe.

7. Assessment

(1) About This paper

This paper demonstrates convincing and significant results of the feasibility of SPARE approach under practical data acquisition. It is an important step to realize PA imaging on conventional US probes. Future work includes implementing the algorithm in real time, which has been done by Howard Xu, Kai etc. in CIS II 2016 project.

Some improvement may include get higher SNR of the image. In addition, this paper focused on beamforming, while there are problems in synchronization of acquired US pre-beamformed data and the PA laser pulse, which would be solved in my project.

(2) About my project

This paper provides theory guidance on PA imaging on US platform.

This paper demonstrates simulation methods and experimental approaches for testing.

The difference is I will focus on synchronization, where the sampling process will be considered and new algorithms will be developed.