Group 2:

Vendor independent PA Imaging System Enabled with Asynchronous Laser source

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Background, Specific Aims, and Significance

Photoacoustic (PA) imaging is an imaging modality that derives image contrast from the optical absorption coefficient of the tissue being imaged[1]. Owing to its deep penetration, high resolution and safety, it is intensively and widely applied in fundamental, preclinical and clinical studies[2] as a very effective optical imaging modality. However, hardware of PA imaging hinders a universal application of this technology. Implementation either relies on low-efficiency Ultrasound (US) beamformers or vender-variant PA platforms. If conventional US scanner implementing PA imaging is viable, then the cost of PA imaging will be lower so that more life will be saved. Thanks to the effort of Medical UltraSound Imaging and Intervention Collaboration (MUSiiC) Lab, an innovative photoacoustic re-beamforming approach[3] has been developed to make real-time PA implementation on conventional US platforms possible. However, this approach is applied on an ultrasound platform where frame rate and probe’s beamline sweeping rate are manually set. Whereas, conventional clinical ultrasound scanners don’t possess such “triggers” for frames and sweeping. In another word, the phase and frequency of the laser pulse are unknown, leading to a random-looking image where the transmitted signal is asynchronous with the received signal. Hence, a reconstruction method which recovers the laser frequency and the laser phase are significant and crucial for implementing PA imaging on conventional US platform.

[1] Su, Jimmy L., et al. "Advances in clinical and biomedical applications of photoacoustic imaging." Expert opinion on medical diagnostics 4.6 (2010): 497-510.
[2] Nikitin, Sergey. Laser ultrasonics in a diamond anvil cell for investigation of simple molecular compunds at ultrahigh pressures. Diss. Université du Maine, 2015.
[3] Zhang, Haichong K., et al. "Synthetic-aperture based photoacoustic re-beamforming (SPARE) approach using beamformed ultrasound data." Biomedical Optics Express 7.8 (2016): 3056-3068.

Deliverables

- Minimum
    1. Set up the environment (including visual studio, c-Make, QS Creator, Ultrasonix and OpenCV) on laptop for US platform implementation. Achieve real-time PA imaging (Howard's project last year) with US platform.
    2. Simulate in Matlab with k-wave tool box: develop a PA synchronization algorithm to recover beamline trigger and frame trigger, test with ground truth data first, then add noise.
- Expected
    1. Incorporate Matlab code in C++ and transplant it onto Ulterious.
    2. Construct of PA/US phantoms/experiments to test PA imaging system.
- Maximum
    1. Improve the algorithm to reach higher accuracy and efficiency.
    2. Combine real-time PA imaging with synchronization algorithm to entirely achieve PA imaging on conventional US platform.
    3. Summary of PA imaging using clinical US scanners in a paper for submission.
    4. An in-class domo of PA imaging using clinical US scanners.

Technical Approach

To implement PA imaging on US platforms, difference between the two should be well considered and image reconstruction methods for PA imaging are acquired.

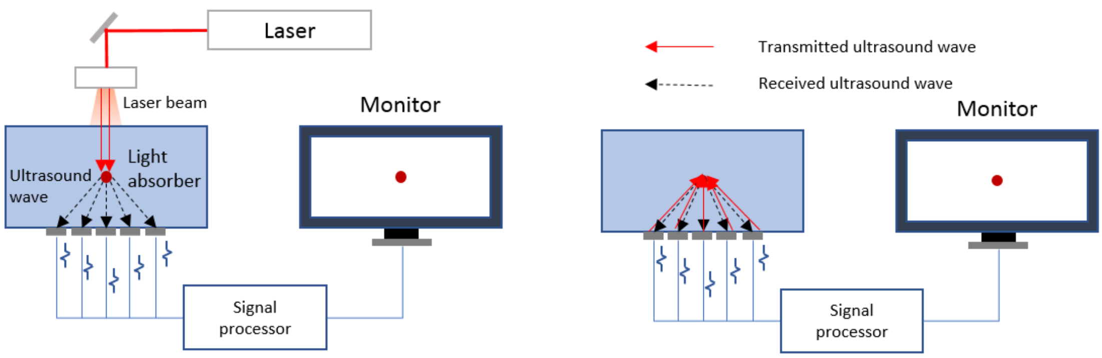
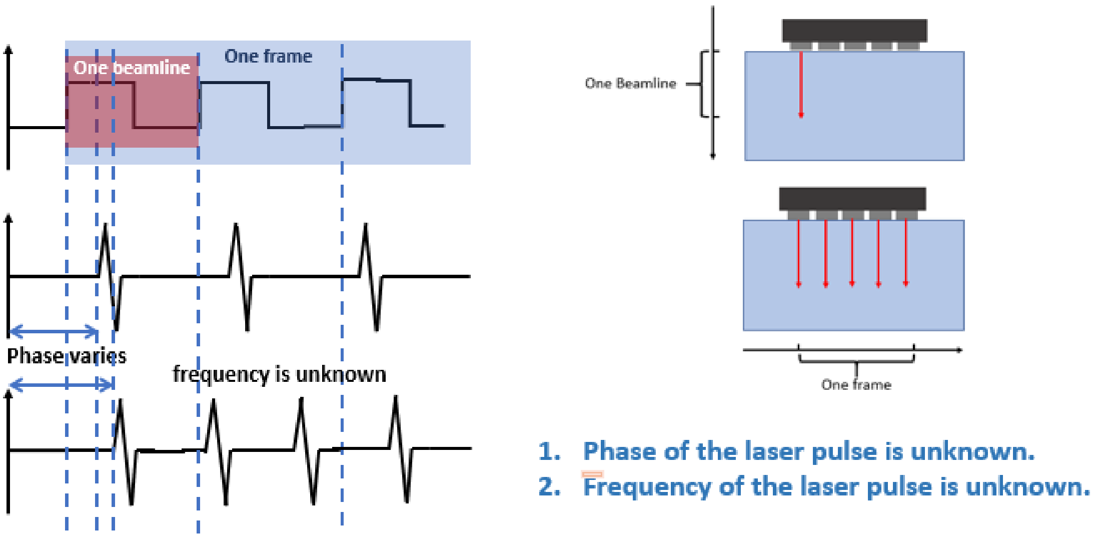
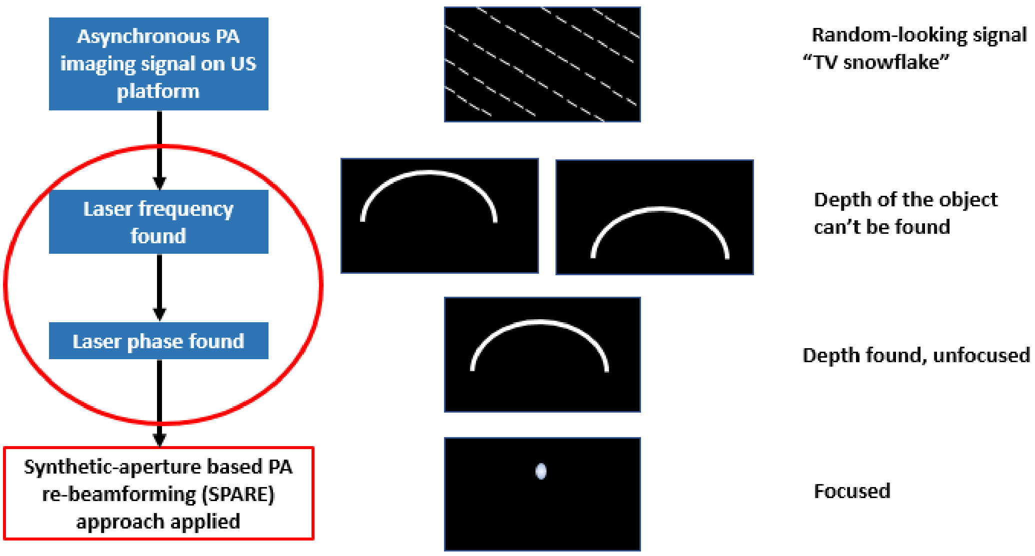


Figure.1 Comparison between PA and US platforms

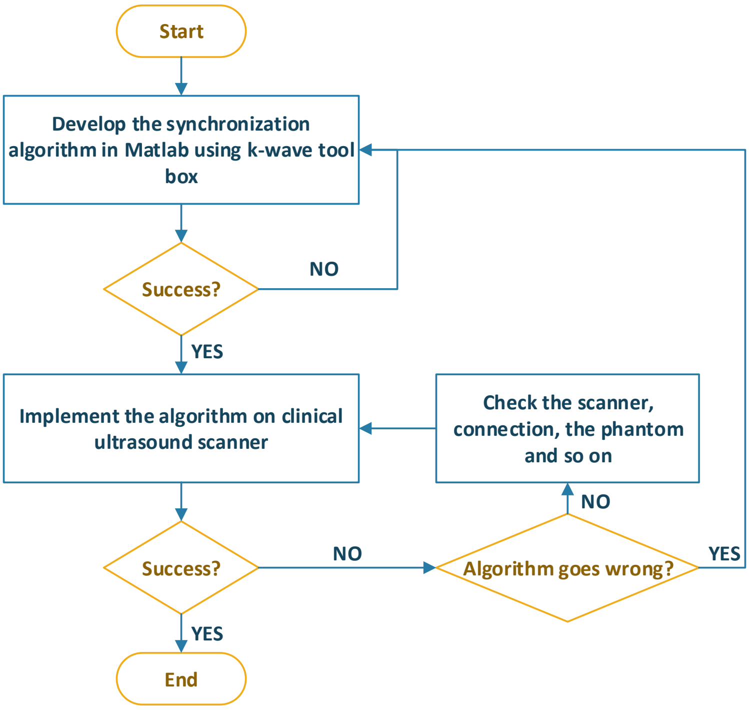
One critical problem that must be solved before PA imaging can be totally applied onto conventional US scanners is the synchronization. Since conventional US platforms don't have laser trigger, when does each frame starts (phase of the laser) and when does the frequency of the laser are unknown.



A summary of what the image will look like is demonstrated as figure below if laser phase and laser frequency are recovered step by step.

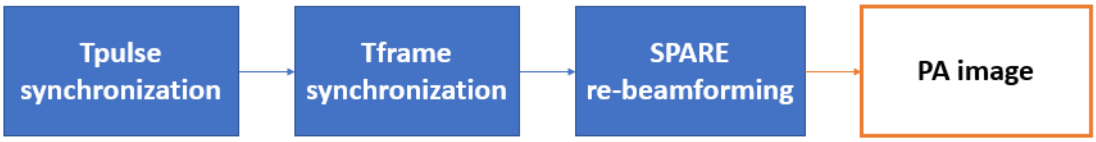


The way to solve the problem is to first simulate the whole process in Matlab, with assistance of k-wave tool box. Then transplant the algorithm in C++ onto Ulterius, construct phantoms and validate on clinical ultrasound platforms. The workflow is demonstrated below.



Simulation and real tests may go back and forth until the expected result is achieved.

One very initial and intuitive though about the algorithm is to set bounds and intervals for T_{frame} and T_{pulse}, and search the optimal one by brute-force. Other approaches may include solving optimization problems to get the best image quality.



Instead of synchronization, image reconstruction has also to be real-time. This has been achieved by group 13 in Computer Integrated Surgery II 2016. The technical approach here is to combine the real-time imaging part with data obtained after synchronization to make PA imaging on US platform viable.

Milestones and Status

Milestone name	Planned date	status
Acquire PA real time re-beamforming algorithm + US Imaging SDK	Before 2/1	Done
Reading on PA imaging and document methods and	Before 2/1	Done

algorithms		
k-wave installation and manual reading	2/1 – 2/15	In progress
Develop brute-force searching algorithm to synchronize frames and laser pulses. Simulate PA imaging with k-wave tool box in Matlab.	2/10 – 3/5	In progress
Validate the algorithm and get ground truth data	3/6 – 3/12	Not started
Add noise to frames and beamlines, validate in Matlab	3/12-3/19	Not started
Milestone.1 Simulation		
Set up Ultrosonix SDK, QT creator and open CV.	2/15 – 3/26	Already tried May start over
Incorporate Matlab programs into C++	3/6 – 4/9	Not started
Milestone.2 C++ algorithm		
Construct phantoms to test the synchronization algorithm on clinical US scanner.	4/9-4/16	Not started
Validate the synchronization algorithm via clinical US data	4/9 - 4/16	Not started
Combine synchronization part and real-time part to achieve PA imaging on US platform	4-16– 5/1	Not started
Milestone.3 Combination of synchronization algorithm and real-time imaging		
Prepare demo and final report/paper	5/1 – 5/18	Not started
End of project		

Backup plan:

1. If delays are encountered in milestone 1, keep focusing on developing the synchronization algorithm. Make incorporation of Matlab program in C++ as a maximum deliverable.

2. As previous experience from group 13 last year, hardware problems may occur on US platform. If delays occur in milestone 3, leave more time to tests and put off integration of synchronization and real-time imaging.

Task Management

- Weekly meeting with Kai.
- Documentation on reading materials, programming diagrams, work status and so on.
- Regularly check code and project status

- Backup codes frequently

Dependencies

Software:

- Matlab k-wave tool box – for PA imaging simulation (Acquired)
- Visual studio 2010 (Acquired, but may reinstall)
- QT creator (Acquired)
- OpenCV 2.4.11 (Acquired)

Hardware:

- The Ultrasonix SonixTouch US imaging machine
- US phantom (basic phantoms available)

Reading List

1. Su, Jimmy L., et al. "Advances in clinical and biomedical applications of photoacoustic imaging." Expert opinion on medical diagnostics 4.6 (2010): 497-510.
2. Nikitin, Sergey. Laser ultrasonics in a diamond anvil cell for investigation of simple molecular compunds at ultrahigh pressures. Diss. Université du Maine, 2015.
3. Bae, Moo-Ho, and Mok-Kun Jeong. "A study of synthetic-aperture imaging with virtual source elements in B-mode ultrasound imaging systems." IEEE transactions on ultrasonics, ferroelectrics, and frequency control 47.6 (2000): 1510-1519.
4. Zhang, Haichong K., et al. "Synthetic-aperture based photoacoustic re-beamforming (SPARE) approach using beamformed ultrasound data." Biomedical Optics Express 7.8 (2016): 3056-3068.
5. Prince, Jerry L., and Jonathan M. Links. Medical imaging signals and systems. Upper Saddle River, New Jersey: Pearson Prentice Hall, 2006.
6. Singh, Mithun KA, and Wiendelt Steenbergen. "PhotoAcoustic-guided Focused UltraSound imaging (PAFUSion) for reducing reflection artifacts in photoacoustic imaging." European Conference on Biomedical Optics. Optical Society of America, 2015.
7. Muyinatu A. Lediju Bell, lecture notes for Ultrasound and Photoacoustic beamforming
8. Toennies, Klaus D. Guide to medical image analysis: methods and algorithms. Springer Science & Business Media, 2012.