Group 13 Project: Real-time Photoacoustic Imaging Using Clinical Ultrasound Systems

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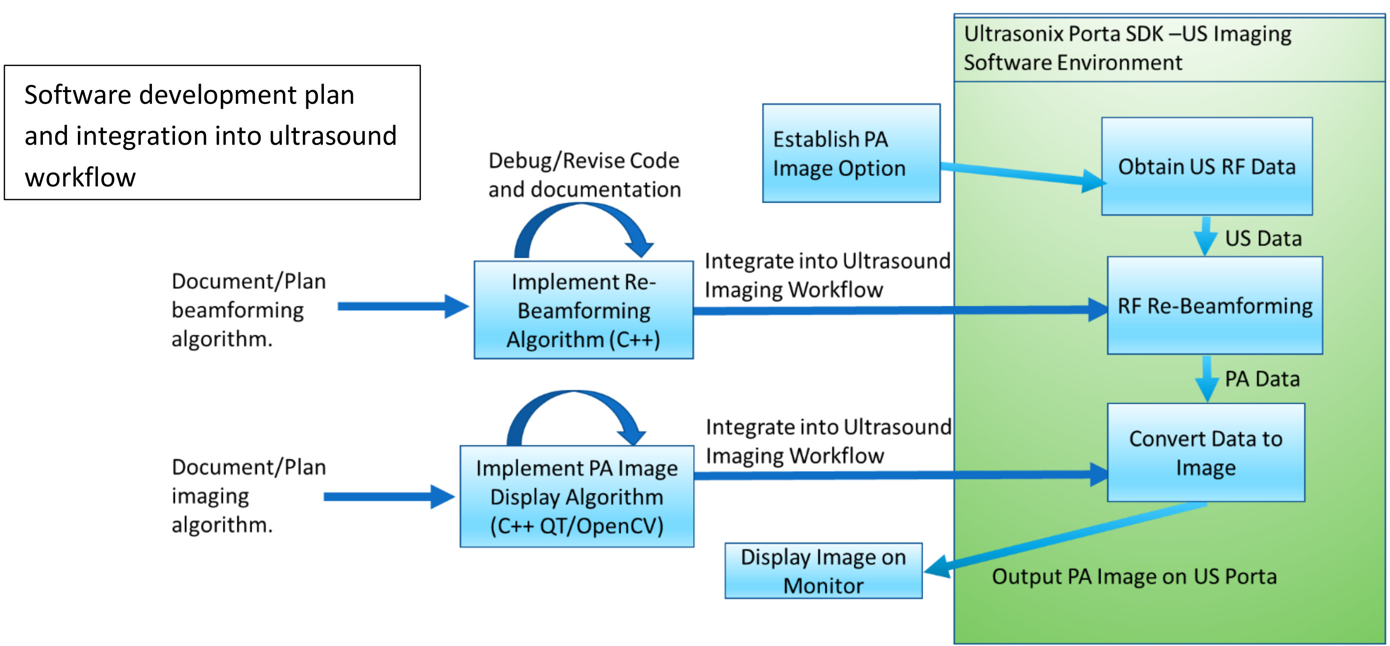
Project Goal: Incorporate a real-time photoacoustic imaging algorithm into a clinical ultrasound platform.

Relevance in Medical Imaging: Photoacoustic (PA) imaging is a medical imaging modality whose uses include blood vessel visualization, cancer detection, and tracking of surgical tools in the body (e.g. brachytherapy seeds in prostate). Current PA imaging systems require specialized hardware to process PA signals. Even though conventional ultrasound (US) systems can receive PA signals, they beamform the data incorrectly as pulse-echo signals, resulting in distorted PA images. This limitation raises the overall cost of PA imaging and reduces its availability. By incorporating PA imaging into existing clinical US systems, this project hopes to reduce PA imaging costs and increase its usage in clinical settings.

Technical Approach: As most US systems have real time access to beamformed RF data, Dr. Boctor's lab has developed several approaches to process US RF data back into a PA image. Since the RF data is beamformed incorrectly, one approach would be to invert the US beamforming to reconstruct "raw" channel data, which is then correctly PA beamformed and processed into an image. An alternative approach is to treat the US beamformed data itself as pre-beamformed data, and apply synthetic aperture re-beamforming. This approach skips the inverse beamforming step, allowing for faster data processing and frame rate. US video data itself can also be reprocessed and fed into either approach, but this is the least accurate method as the B-mode image data is highly processed and compressed.



To develop a real time PA imaging system, my first priority is to document and build the PA re-beamforming algorithm in C++. Once the beamforming algorithm has been debugged, I will then integrate this algorithm into the ultrasound imaging software (Porta SDK) to allow for fast PA imaging. To do this, I will need to implement a PA imaging option in the US software interface. When this option is selected, the US workflow should then transfer real-time RF data into the integrated beamforming algorithm to be processed into PA data. I will then need to document and create a PA display algorithm using QT or OpenCV, to convert the PA data into a PA image that is displayed in the ultrasound program interface.

Deliverables: Here is a list of our deliverables in order of expected completion:

Minimum:

1. Documentation of PA re-beamforming algorithm and its integration into an US visualization platform.
2. Implementation of re-beamforming algorithm (C++ code).
3. Scripts to debug algorithm with simulation data sets (basic results + code).

Expected:

1. Adapt existing US platform to allow for PA imaging. Integrate our PA software into system (finished code).
2. Construct PA/US phantoms. Set up experiments to test PA imaging system.
3. Test PA imaging system using real RF US data (more detailed results).

Maximum:

1. Implement additional PA image algorithms (inverse beamforming, US visual data conversion) in completed PA imaging system if there is sufficient time.
2. Summarize findings in a paper for submission.
3. An in-class live demo of real-time PA imaging system.

Status of Dependencies:

- Access to Robotorium and lab (Submitted Permission Form)
- PA re-beamforming algorithm (Acquired from Mentor)
- PA inverse beamforming and video processing algorithm (Available)
- US Ultrasonix Porta SDK Software (Acquired)

- PA Image Setup (Laser system, PZT element as source) (Available for setup)
- US System and Probe (Present)
- US Phantom (Basic phantoms Available)

Key dates:

Task	Expected Start and End Data
Acquire PA algorithms + US imaging SDK	2/15/2016 - 2/19/2016 (Completed)
Read existing PA literature. Document PA algorithms.	2/22/2016 - 3/3/2016
Read Ultrasonix SDK, QT, OpenCV manuals. Document Ultrasonix implementation.	2/22/2016 - 3/16/2016
Implement PA Re-beamforming Algorithm in C++	3/3/2016 - 3/16/2016
Set up Ultrasonix SDK environment. Begin work on PA imaging	3/3/2016 - 3/23/2016
Incorporate PA Beamforming into Ultrasonix SDK	3/16/2016 - 3/20/2016
Enable PA Image Processing on Ultrasonix SDK	3/20/2016 - 4/6/2016
Finish Implementing PA Imaging on Ultrasonix SDK. If possible, incorporate other US to PA algorithms	4/6/2016 - 4/20/2016
Collect RF test data on PA beamforming and imaging	4/6/2016 - 4/20/2016
Prepare demo and final report/paper on results	4/20/2016 - 5/5/2016

Major Milestones:

1. Implementation of C++ PA beamforming algorithm by spring break (3/16).
2. Set up a functional Ultrasonix SDK platform (3/23).
3. Integration of PA Beamforming into Ultrasonix workflow (3/30).
4. Successful Real-Time PA Imaging in Ultrasonix SDK (4/15).
5. PA imaging demo and final paper on results of beamforming algorithm (4/27 for demo preparation, 5/5 for paper).

Responsibilities and Management Plan: Since I am the only member of group 13, I am fully responsible for completing project deliverables. I will meet regularly with my mentors for guidance and ask questions whenever I become stuck.

C++ is a programming language I am familiar with and I have taken Computer Graphics last semester. However, I will need to read and familiarize myself with Ultrasonix SDK and QT/OpenCV programming in order to integrate the PA beamforming algorithm into the ultrasound system.

Management of PA beamforming and US code will be done through regular backups and storage of code on a separate hard drive and cloud file storage services (JHU box, dropbox).

<u>Reading List</u>

1. Zhang, Kai, et. al. "Synthetic Aperture Based Photoacoustic Image Re-beamforming From Ultrasound Post-beamformed RF Data". Unpublished Manuscript (will be submitted for publication).
2. Park, Suhyun, et al. "Adaptive beamforming for photoacoustic imaging using linear array transducer." *Ultrasonics Symposium, 2008. IUS 2008. IEEE*. IEEE, 2008.
3. Kuo, Nathanael, et al. "Real-time photoacoustic imaging of prostate brachytherapy seeds using a clinical ultrasound system." *Journal of biomedical optics* 17.6 (2012): 0660051-0660057.
4. Kang, Hyun-Jae, et al. "Software framework of a real-time pre-beamformed RF data acquisition of an ultrasound research scanner." *SPIE Medical Imaging*. International Society for Optics and Photonics, 2012.
5. Harrison, Travis, and Roger J. Zemp. "The applicability of ultrasound dynamic receive beamformers to photoacoustic imaging." *Ultrasonics, Ferroelectrics, and Frequency Control, IEEE Transactions on* 58.10 (2011): 2259-2263.
6. Frazier, Catherine H., and William Brien. "Synthetic aperture techniques with a virtual source element." *Ultrasonics, Ferroelectrics, and Frequency Control, IEEE Transactions on* 45.1 (1998): 196-207.
7. J. Kortbek, J. A. Jensen, K. L. Gammelmark, "Synthetic Aperture Sequential Beamforming," *Proc. in IEEE Int. Ultrasonics Symp*., 966-969 (2008).
8. Wilson, Thaddeus, et al. "The ultrasonix 500RP: A commercial ultrasound research interface." *Ultrasonics, Ferroelectrics, and Frequency Control, IEEE Transactions on* 53.10 (2006): 1772-1782.