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

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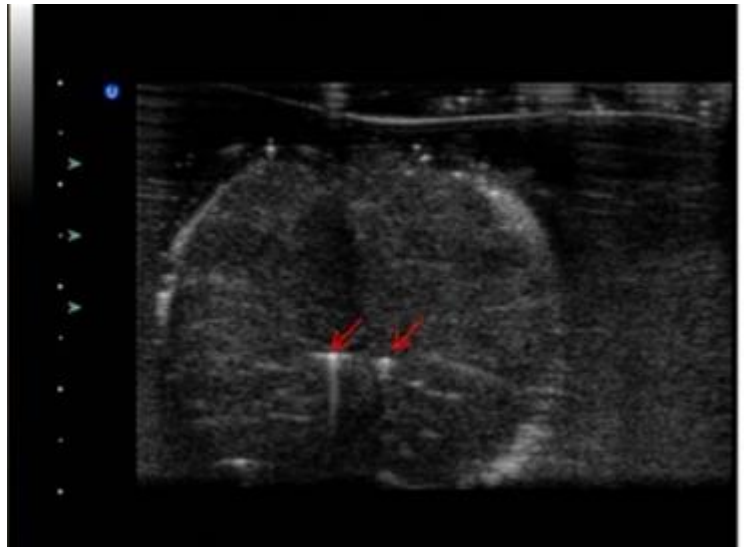
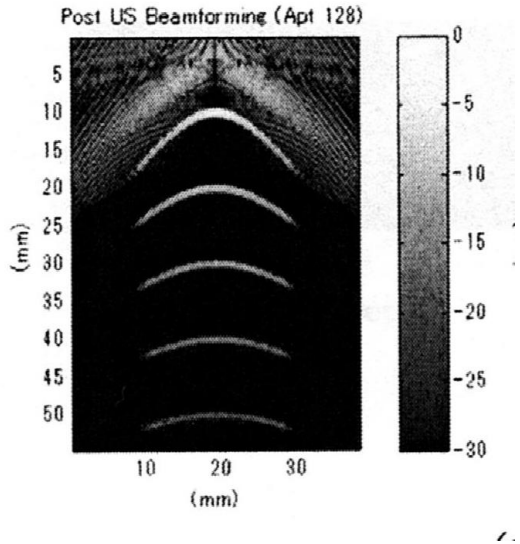
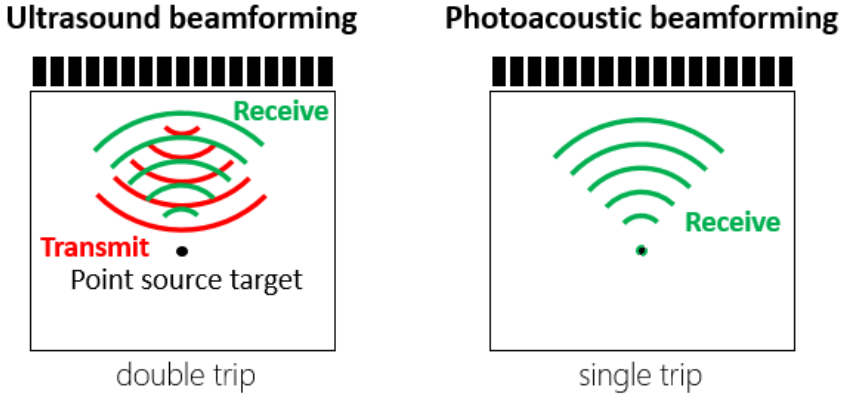
Project Summary

- Current photoacoustic (PA) imaging requires additional hardware due to incorrect beamforming on ultrasound(US) systems.
- This requirement limits the availability and flexibility of PA imaging.







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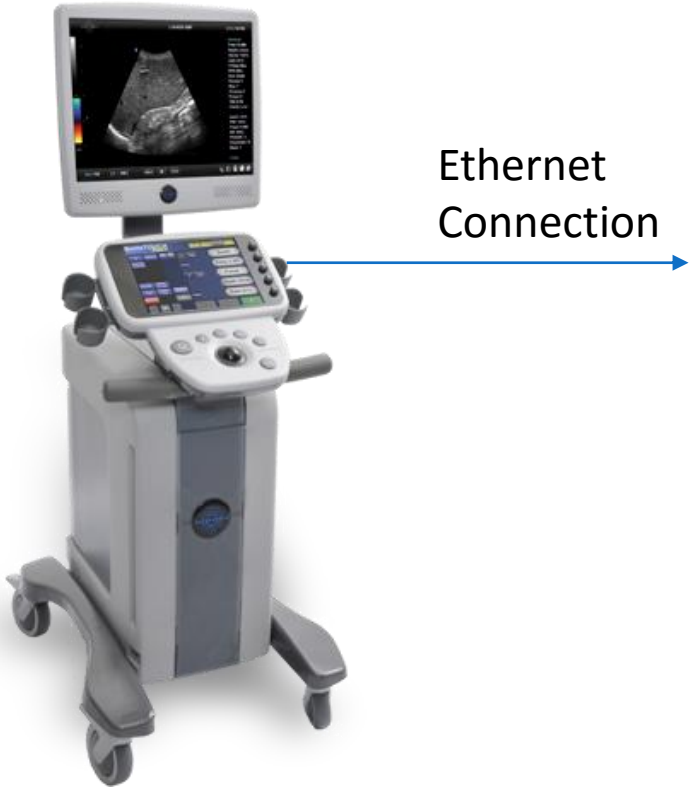
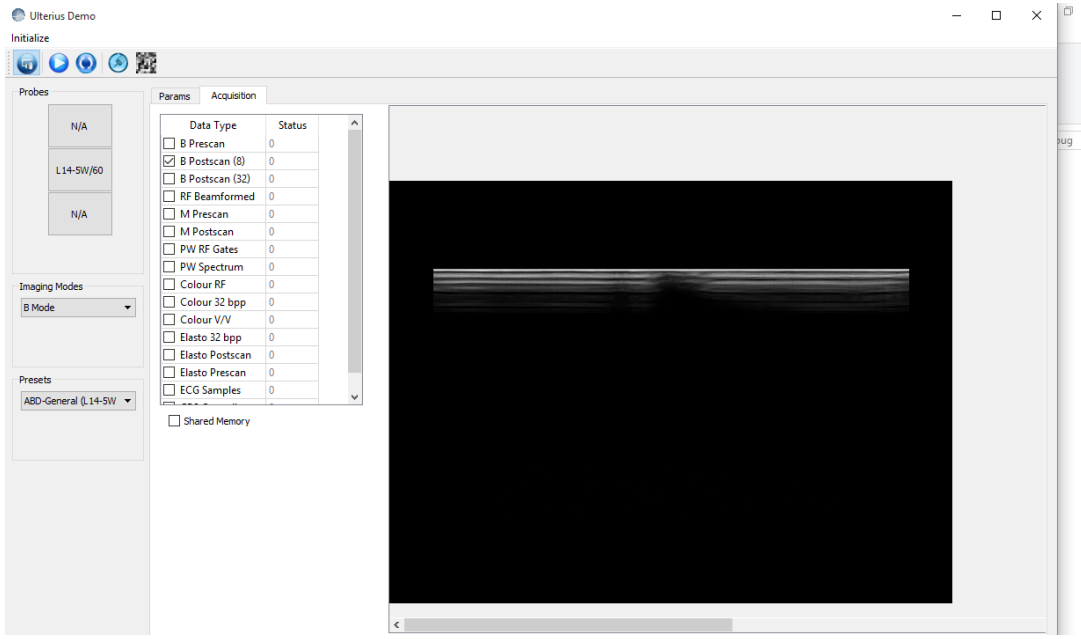
Project Goal

- Implement real-time photoacoustic (PA) imaging on an ultrasound system.



Ethernet Connection

Laptop: Ultrasonix Ulterius Interface



Original Deliverables

Minimum: (Completed as of 3/26)

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

Expected: (Expected by 4/15)

1. US platform updated for real-time PA imaging.* Requires integrating our PA rebeamformer into system. ✓
2. Construction of PA/US phantoms/experiments to test PA imaging system. (PA phantoms available) ←
3. Test results of PA imaging system using real RF US data. (Results in PA-RF data or image format) ←

Maximum:

1. Implementation of additional PA image algorithms (inverse beamforming, US visual data conversion) in completed PA imaging system.
2. Summary of PA imaging system or real-time PA rebeamformer in a paper for submission.
3. An in-class live demo of real-time PA imaging system. * Additional steps required.

Updated Expected/Max Deliverables

Expected: (By 4/15-4/25)

1. Integration of our PA rebeamforming algorithm into US imaging system. (4/2)
2. Experimental setups to test PA rebeamforming. Collect PA beamformed data from system. (4/6)
3. Calibrated system that re-beamforms RF data in real-time. Confirm results by applying basic image processing (via Matlab) on data collected from system. (4/20)
4. Implementation of real-time image processing for RF data on Ulterius interface. (Depending on schedule, research data/paper may end up as the expected deliverable instead.)

Maximum: (By 5/05)

1. Summary of results in a research paper.
2. An in-class demo of the real-time PA imaging system.
3. Implementation of additional US-to-PA reprocessing algorithms (inverse beamforming, US visual data conversion) in US imaging system.

Minimum Deliverable: PA Rebeamformer

- Treats the incorrectly beamformed RF data as “raw” channel data.
- Involves dynamically refocusing the elements into a proper RF format.
- Since elements have been focused at twice the proper depth, we can dynamically refocus signals at halfway depths across the image to recover proper RF data.

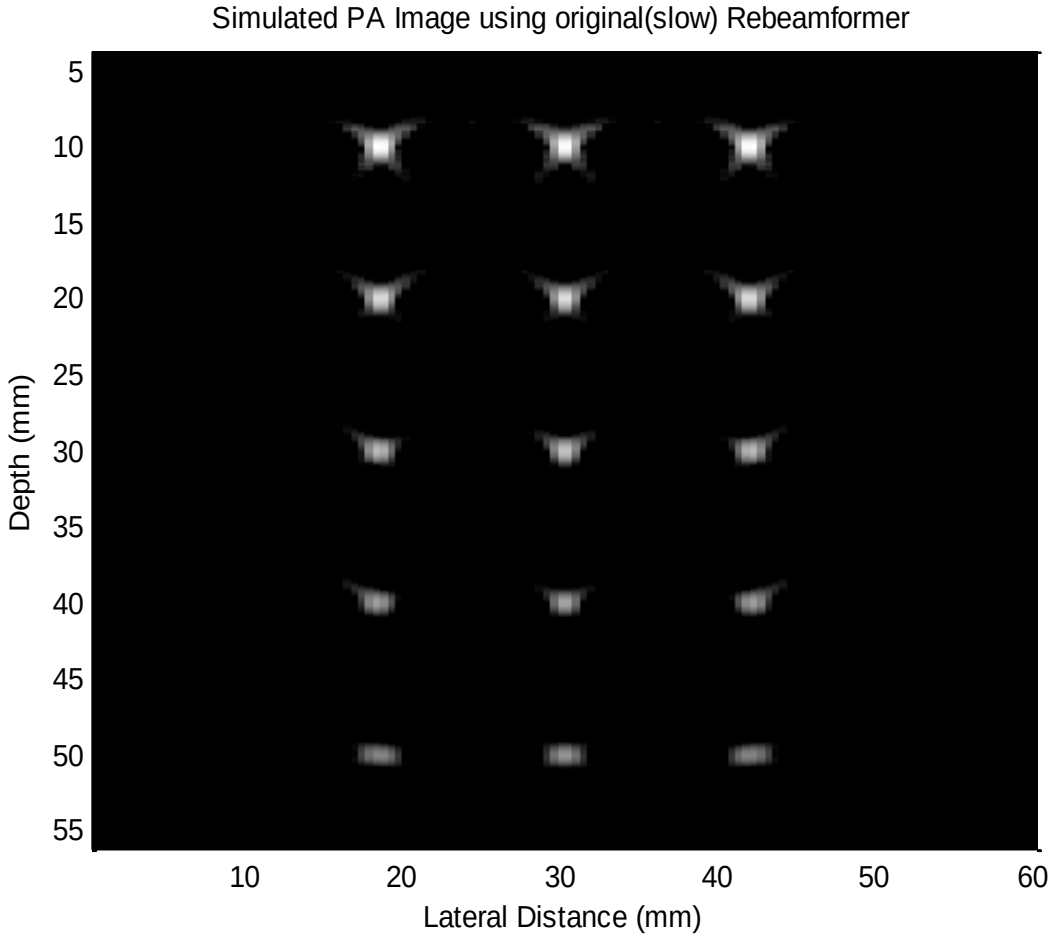
Refocusing time delay

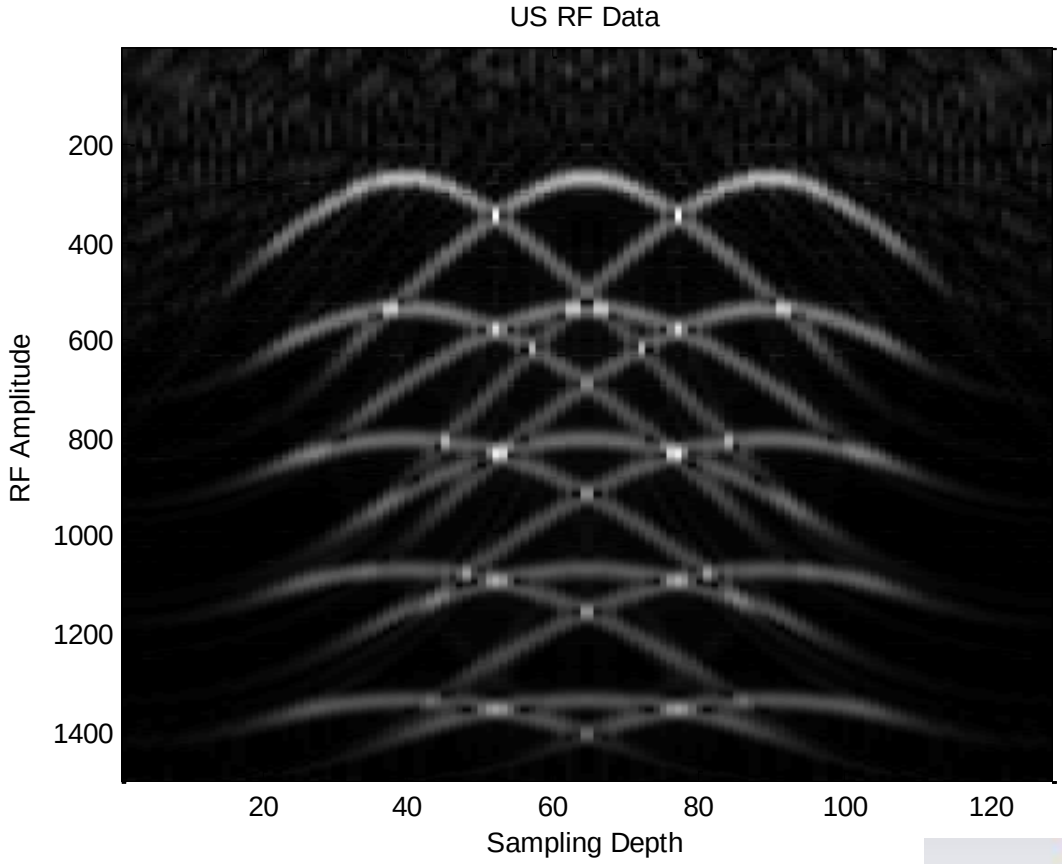
$$t = \frac{|r|}{c}$$

Refocus distance

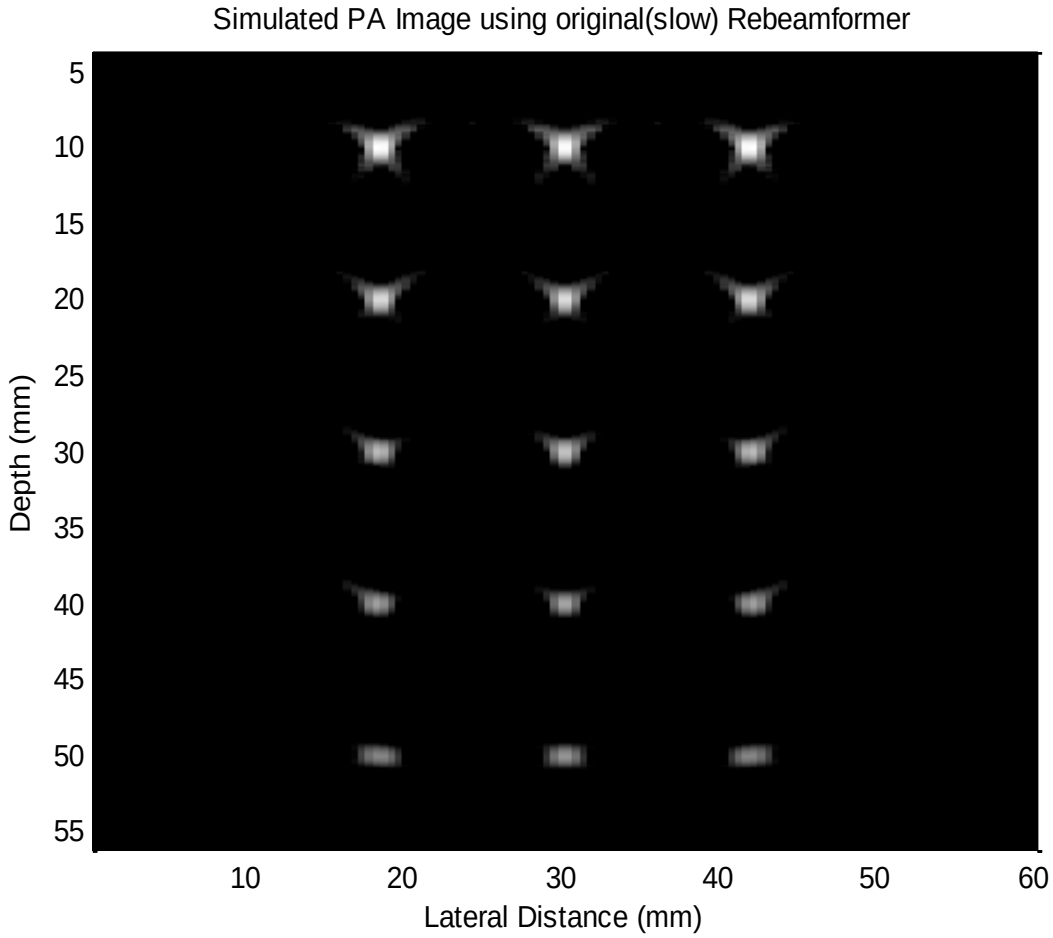
$$r = \sqrt{\left(\frac{Y_n}{2}\right)^2 + X_n^2}$$

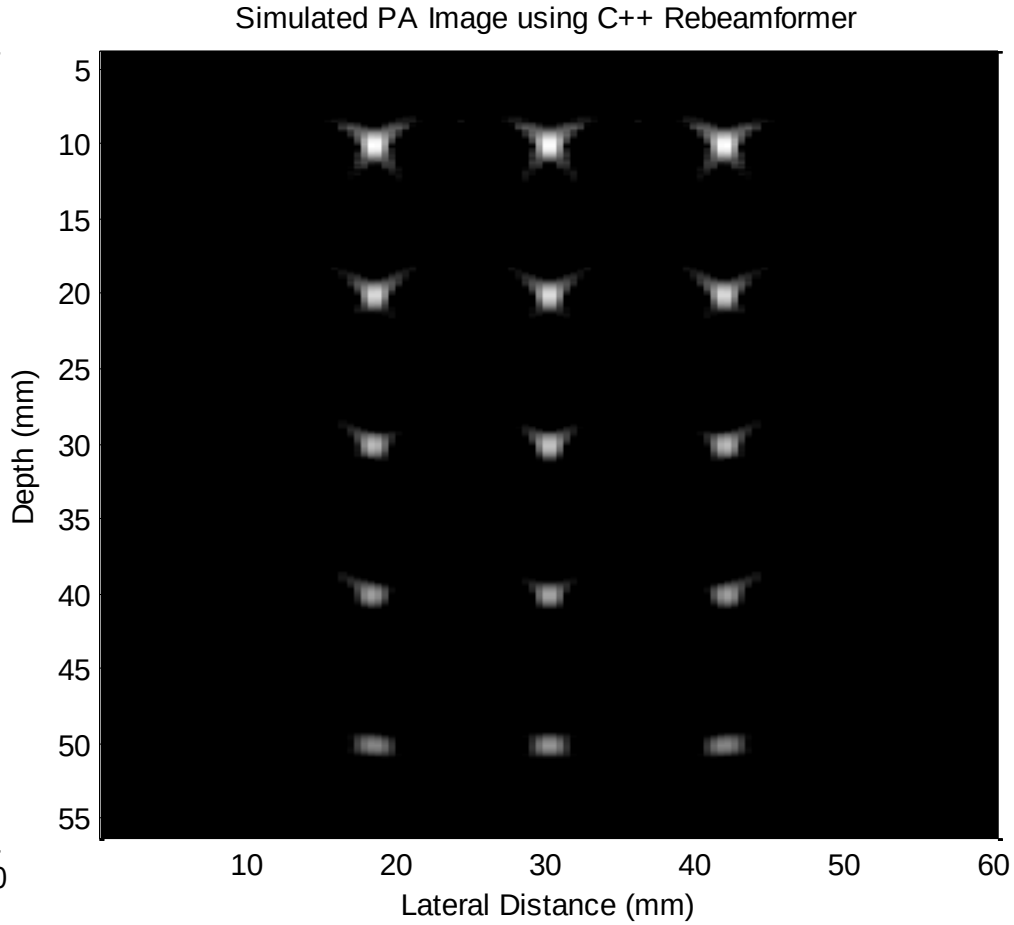
Simulation Results:



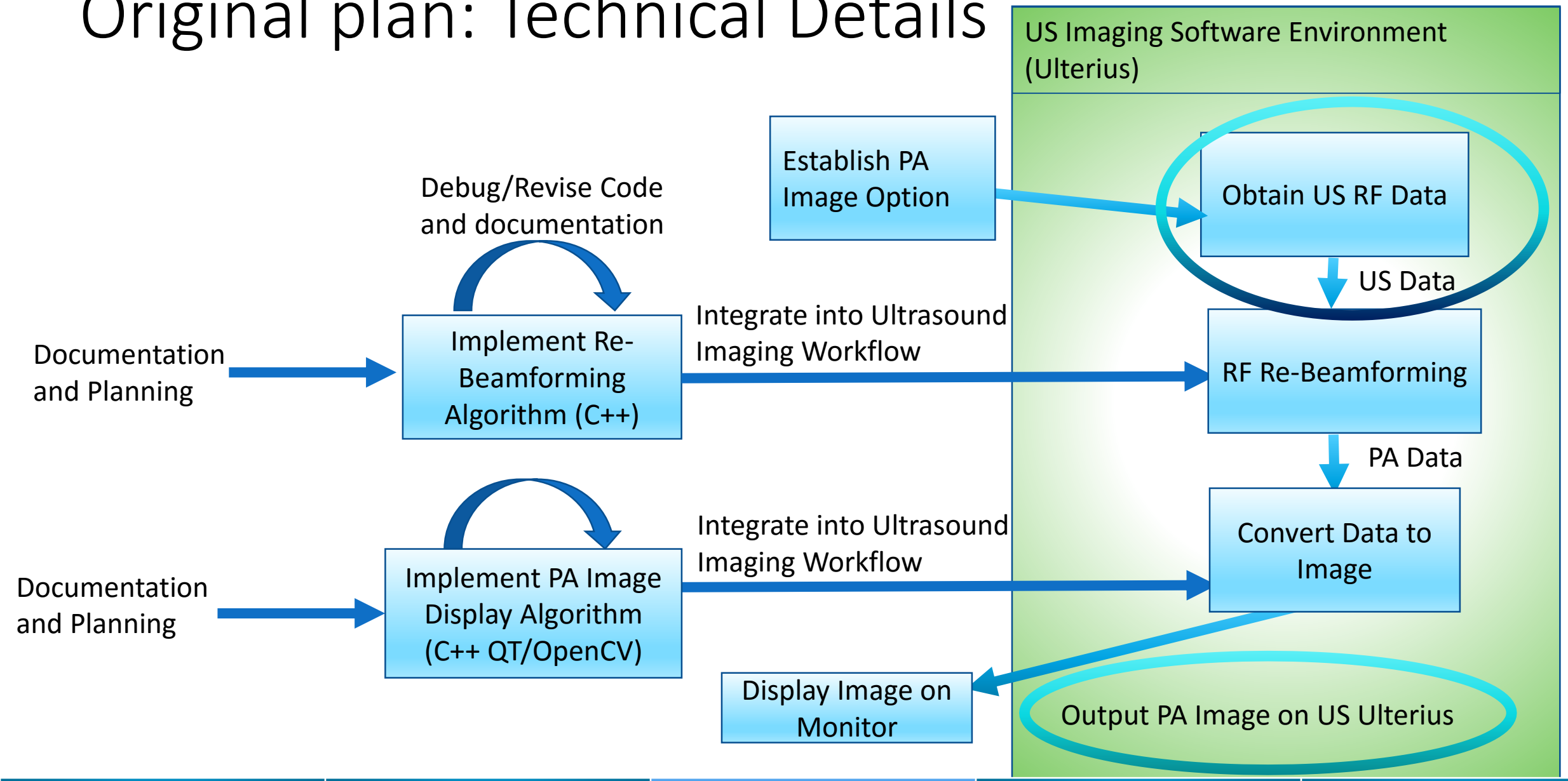


Simulation Results:





Original plan: Technical Details

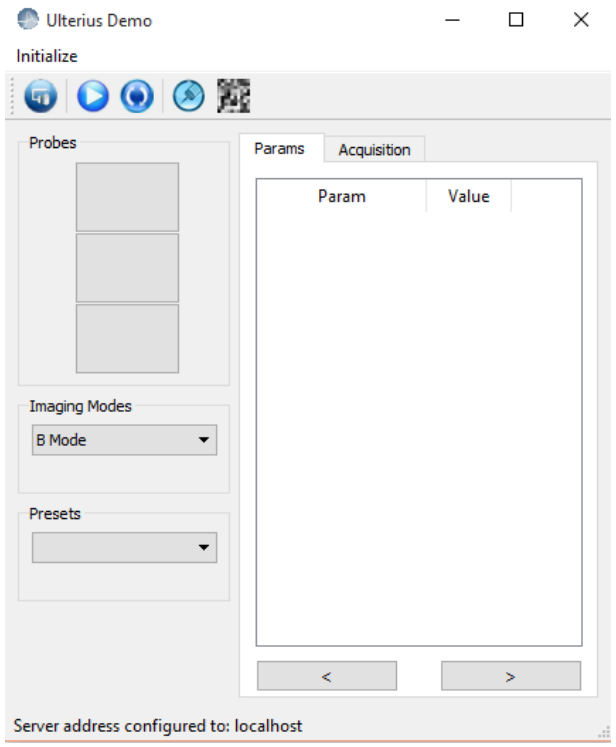


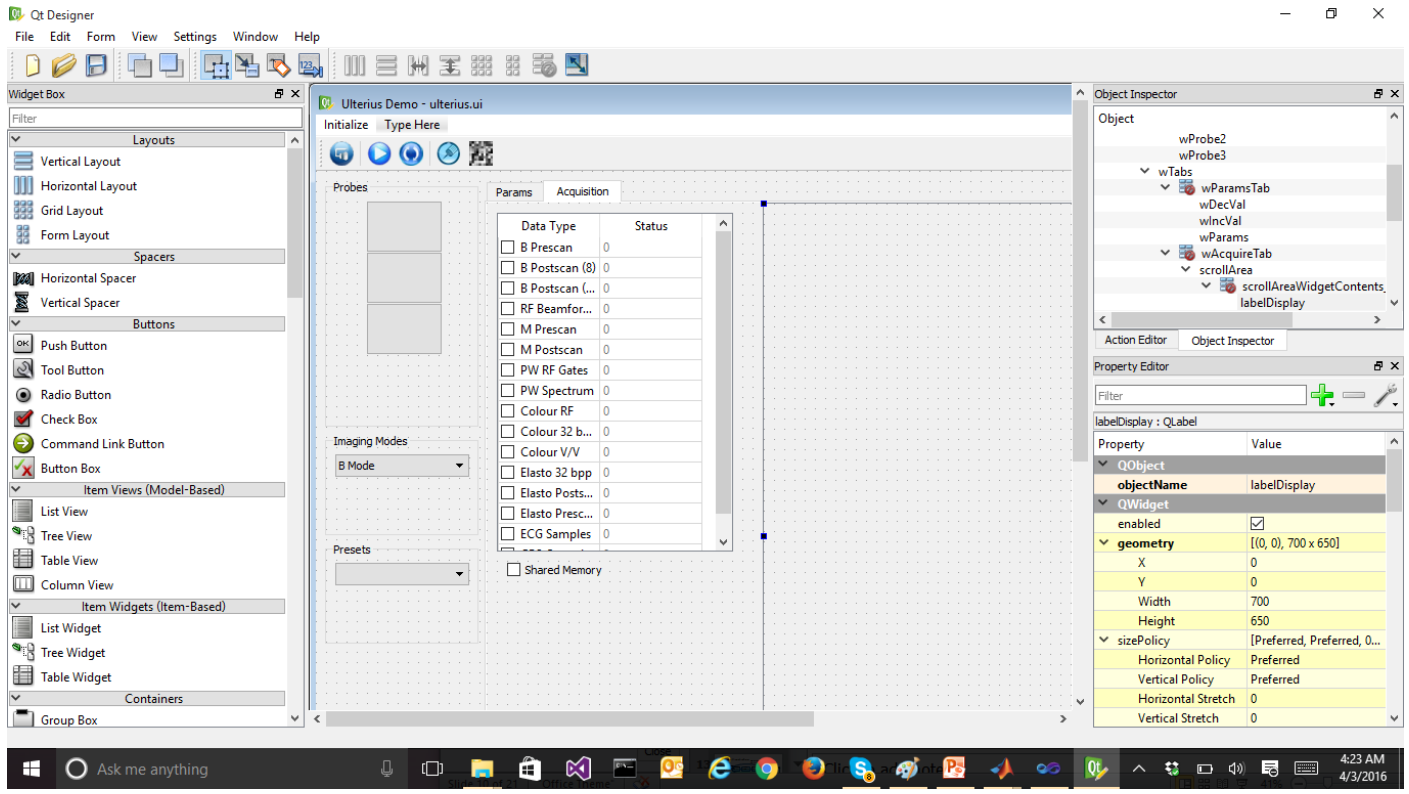
Expected Deliverable: US image platform

- Source code from Ultrasonix SDK 6.
- Built using Visual Studios 2010 (following instructions from Ultrasonix).
- Required several dependencies (QT4, OpenCV) for building US interface.
- Installation instructions and code uploaded to CIIS wiki project page as reference for future users.
- Unexpected: Needed to CREATE US image display.

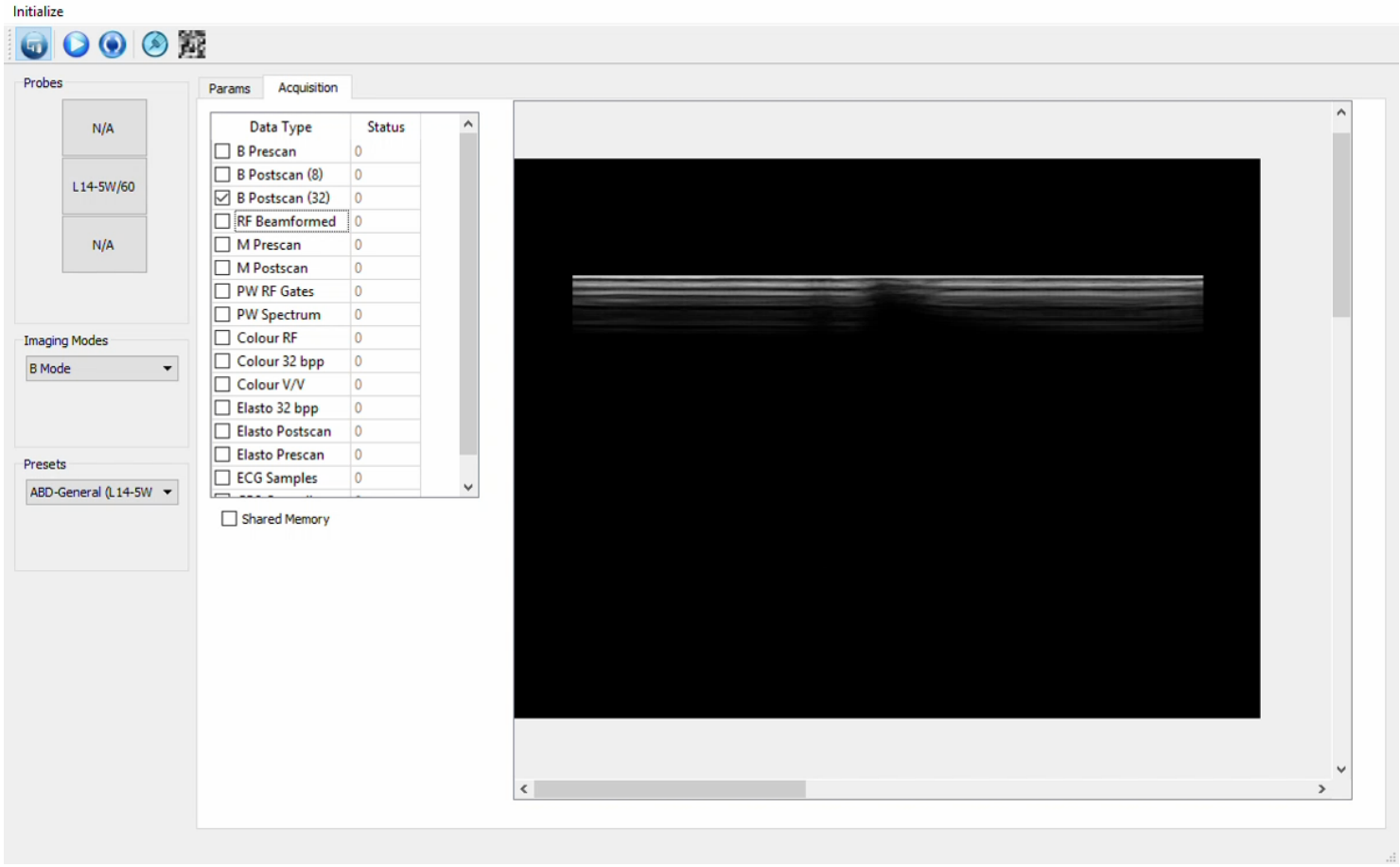
Current US/PA Imaging Interface

- Needed to implement actual image output (used reference code from MUSIIC lab).

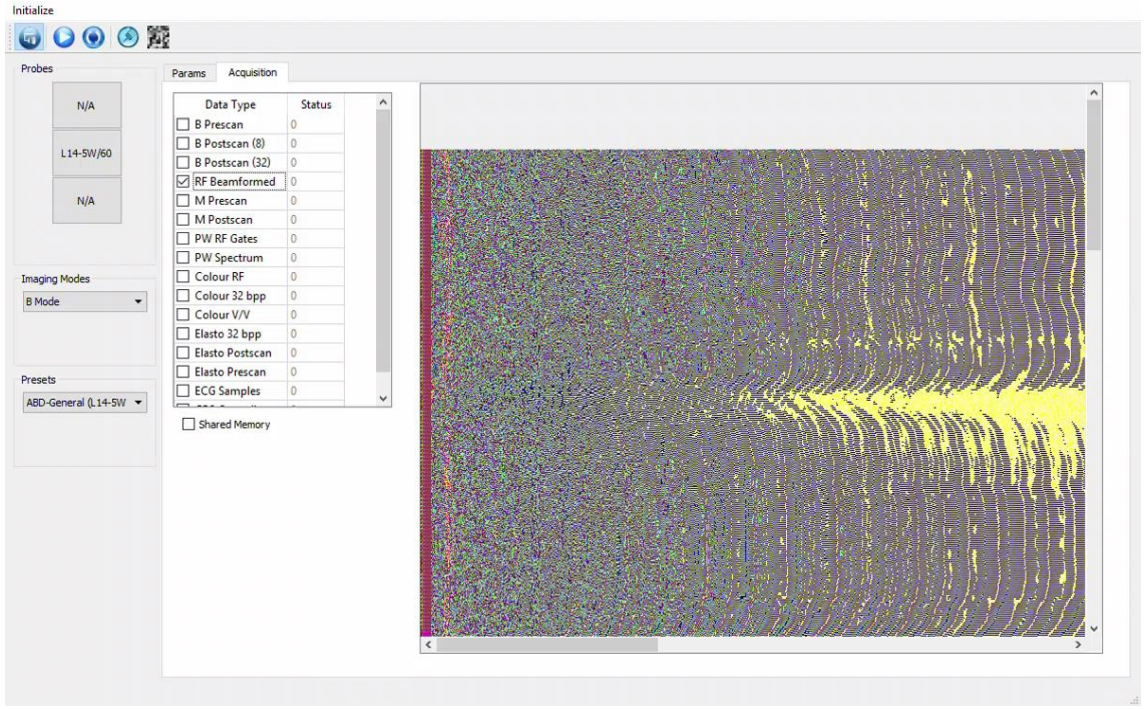


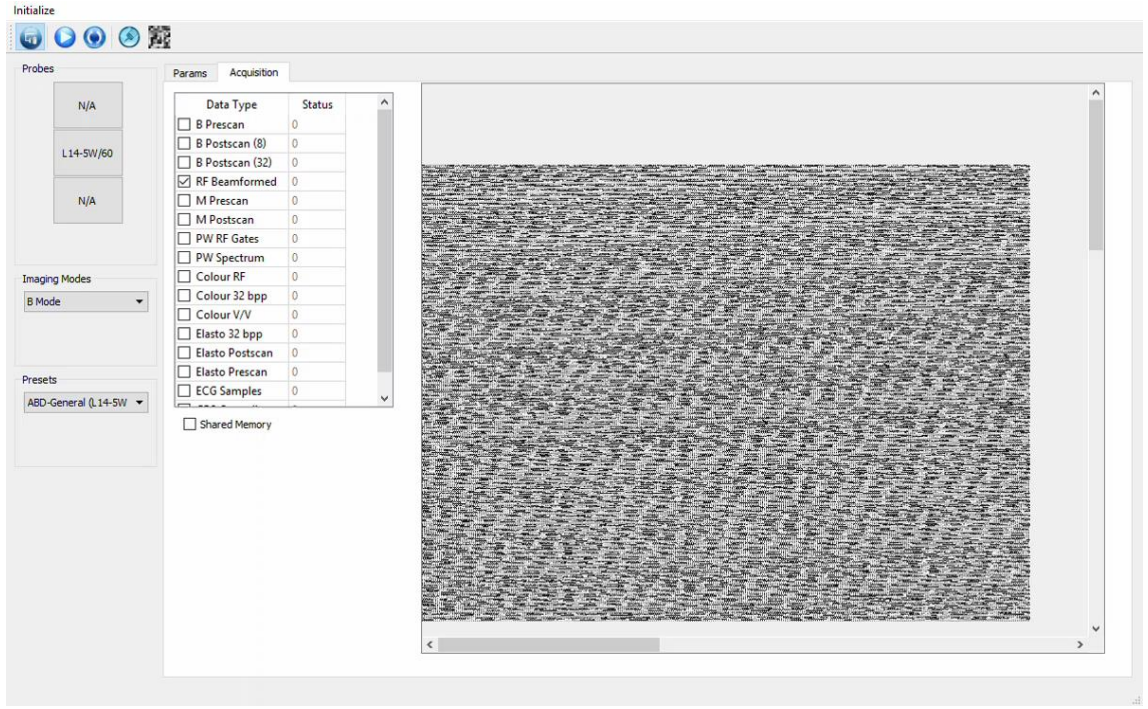


Result:


Initialize
Probes
N/A
L14-5W/60
N/A
Imaging Modes
B Mode
Presets
ABD-General (L14-5W
Params
Acquisition
Data Type
Status
B Prescan
B Postscan (8)
B Postscan (32)
RF Beamformed
M Prescan
M Postscan
PW RF Gates
PW Spectrum
Colour RF
Colour 32 bpp
Colour V/V
Elasto 32 bpp
Elasto Postscan
Elasto Prescan
ECG Samples
Shared Memory

Real Time RF Data Acquisition





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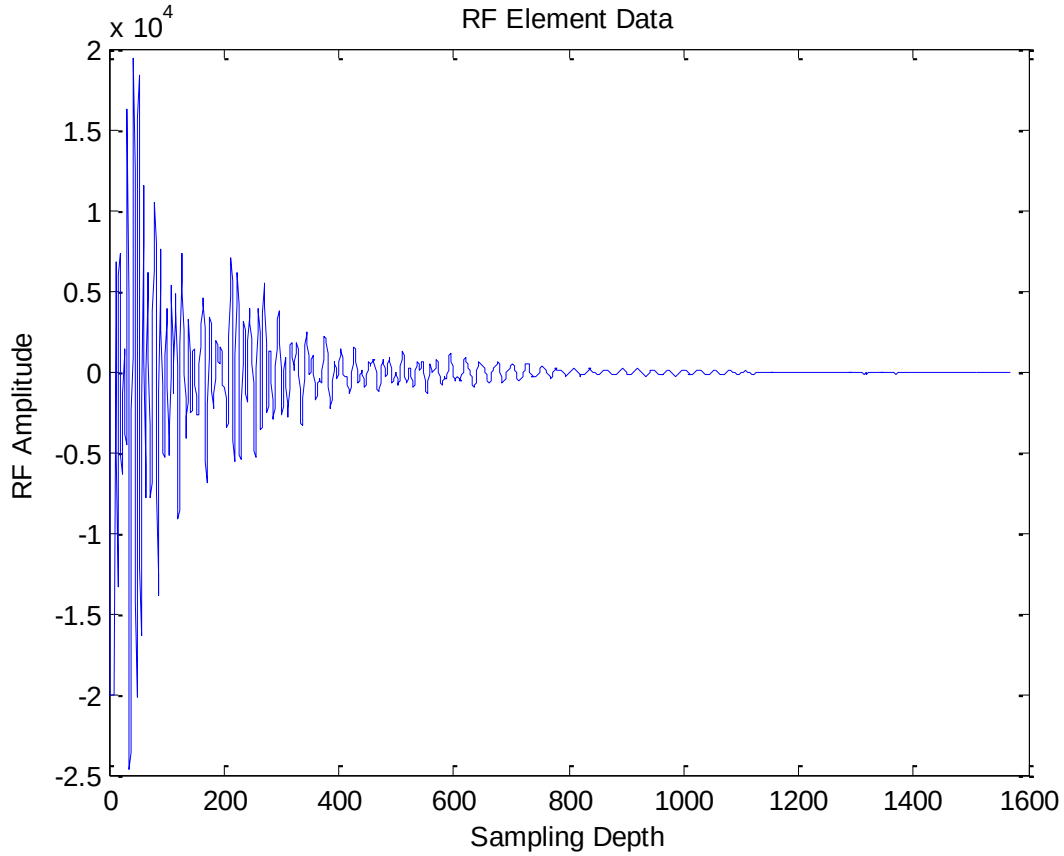
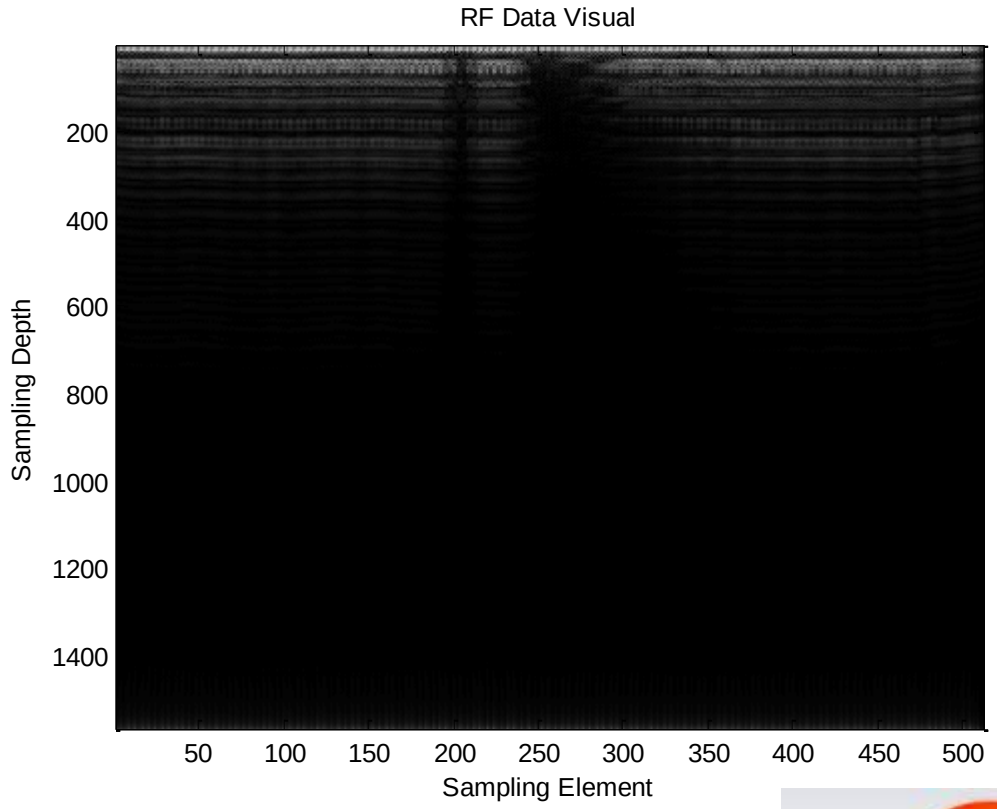
Verifying RF Data Format

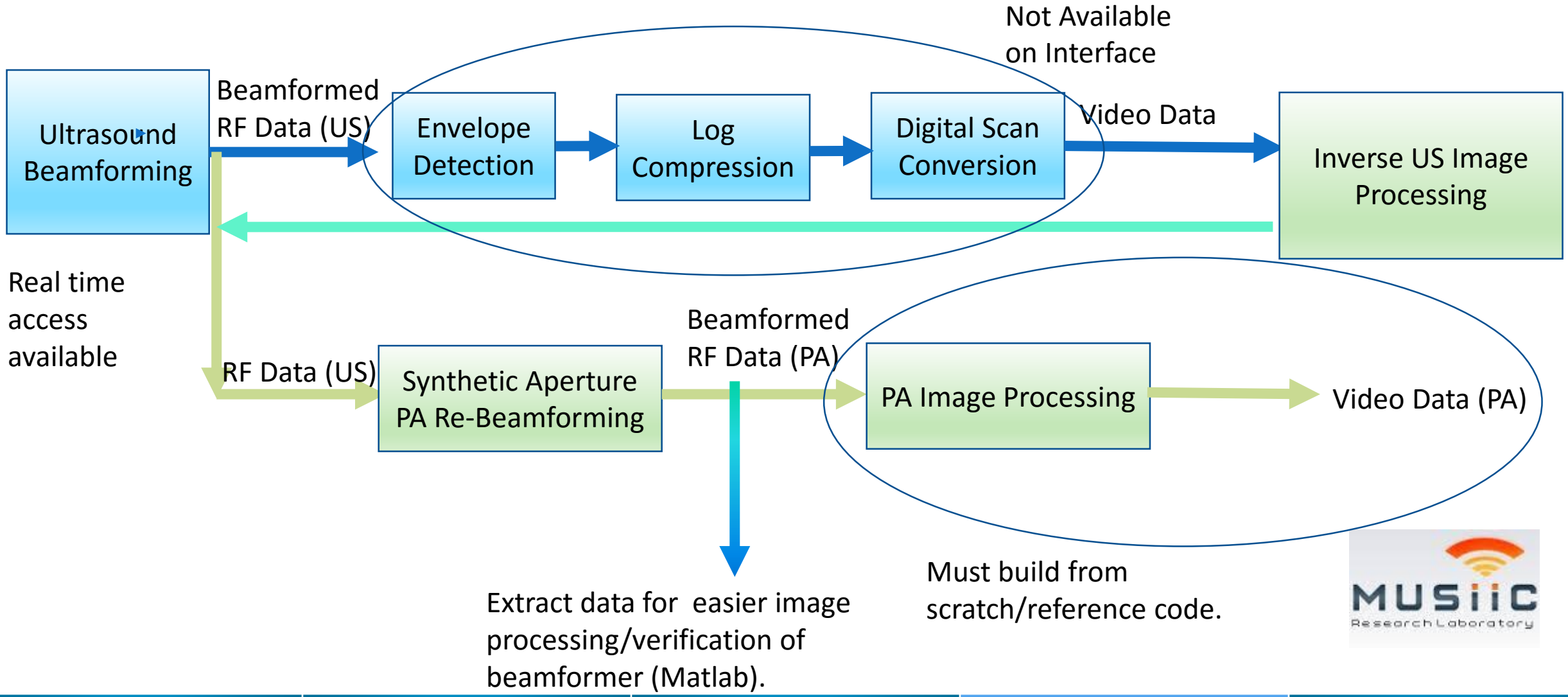




Remaining Challenges

- Implementation of RF rebeamforming needs to be calibrated for real RF data.
- Implementation of real-time RF image processing needed as well (Envelope detection, signal compression) to visualize RF data.
- US system can still process RF data without the second component.

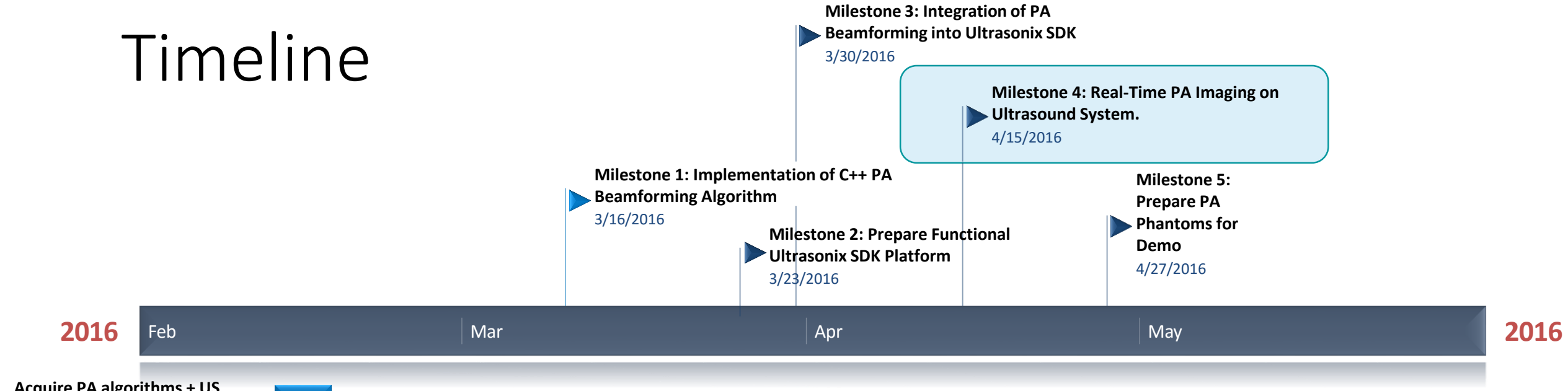
Next Step: PA Image Visualization



Current Dependencies

- SonixTouch US Device + US Probe (Available for use)
- Software: Visual Studios 2010, QT4, OpenCV (Acquired)
- Functional Ulterius Build + Reference Build (Achieved/Provided)
- PA Beamforming Algorithm (Acquired and implemented in C++)
- Inverse Beamforming Algorithm (Available)
- Envelope Detection/Compression Algorithm (Provided by mentor)
- Alternatively: Fast Fourier Transform Library (Available)
- Pseudo-PA(PZT) Phantoms (Available for setup and use)

Timeline



Acquire PA algorithms + US imaging SDK — 2/15/2016 - 2/19/2016

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

Contingency Plan: If delays are encountered in Milestones 2-3, change focus to developing and testing PA beamforming algorithms. Make research paper into an expected deliverable and shift milestones to PA algorithm tests/PA phantom preparation.

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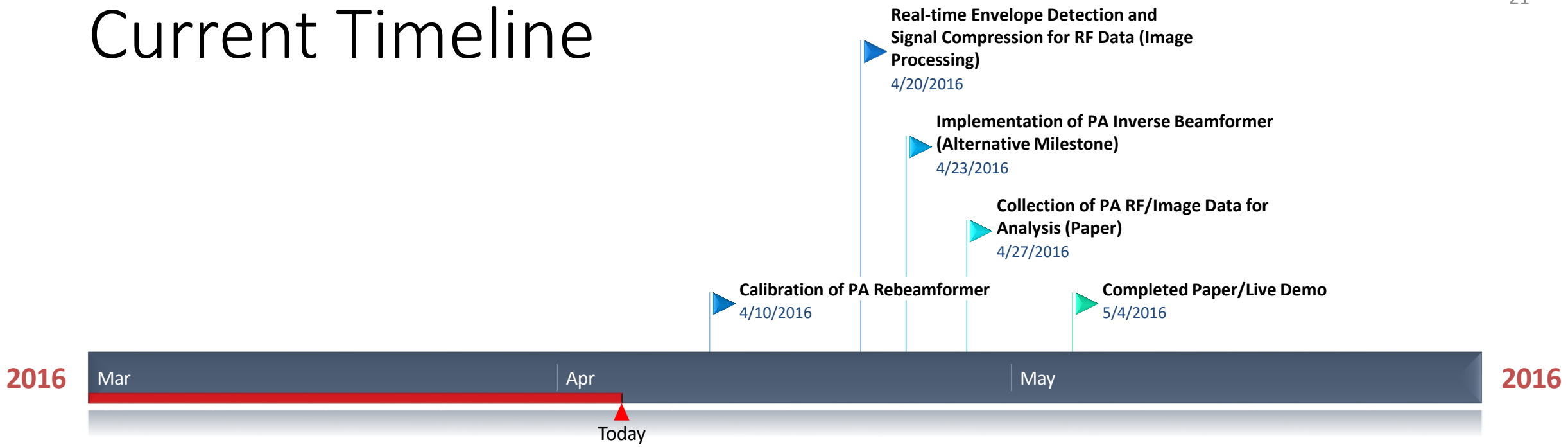
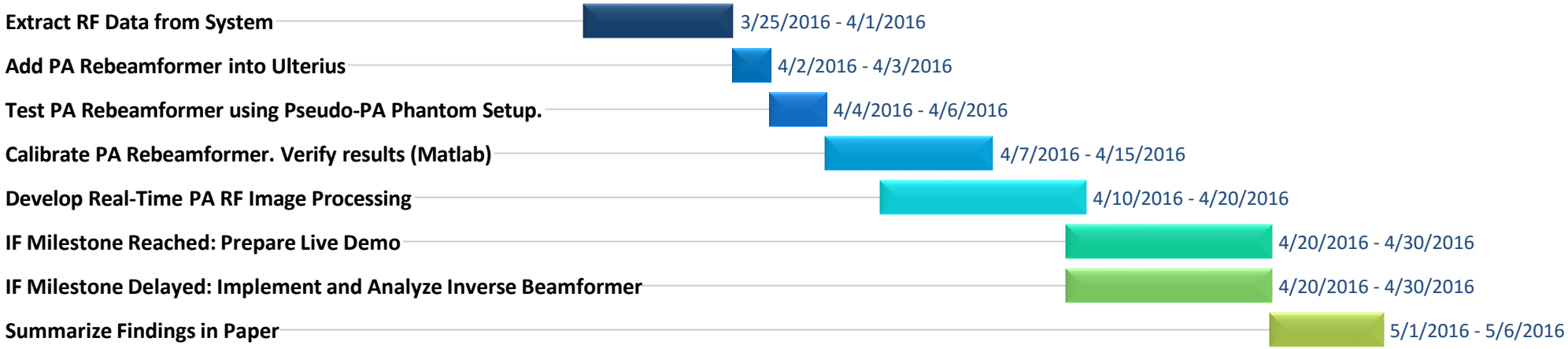
Current Timeline





Milestones:

1. April 10 – Calibration of PA re-beamformer for real-time PA signals.
2. April 15-20 – Implementation of real-time PA imaging (envelope detection and signal compression).
3. If milestone 2 not reached: April 23 – Implementation of PA inverse beamformer.
4. April 27 – Collection of PA RF/image data for paper analysis.
5. May 5 – Completion of paper or live demo for presentation.

Questions?

Reference/Reading List

- Zhang, Kai, et. al. “Synthetic Aperture Based Photoacoustic Image Re-beamforming From Ultrasound Post-beamformed RF Data”. Unpublished Manuscript (will be submitted for publication).
- Park, Suhyun, et al. "Adaptive beamforming for photoacoustic imaging using linear array transducer." *Ultrasonics Symposium, 2008. IUS 2008. IEEE*. IEEE, 2008.
- 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.
- 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.
- 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.
- 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.
- J. Kortbek, J. A. Jensen, K. L. Gammelmark, “Synthetic Aperture Sequential Beamforming,” *Proc. in IEEE Int. Ultrasonics Symp*., 966-969 (2008).
- 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.