Photoacoustic Registration and Visualization: Project Plan

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Overview

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- Background
- Motivation
- Workflow
- Technical Approach
- Deliverables
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- Milestones
- Management Plan
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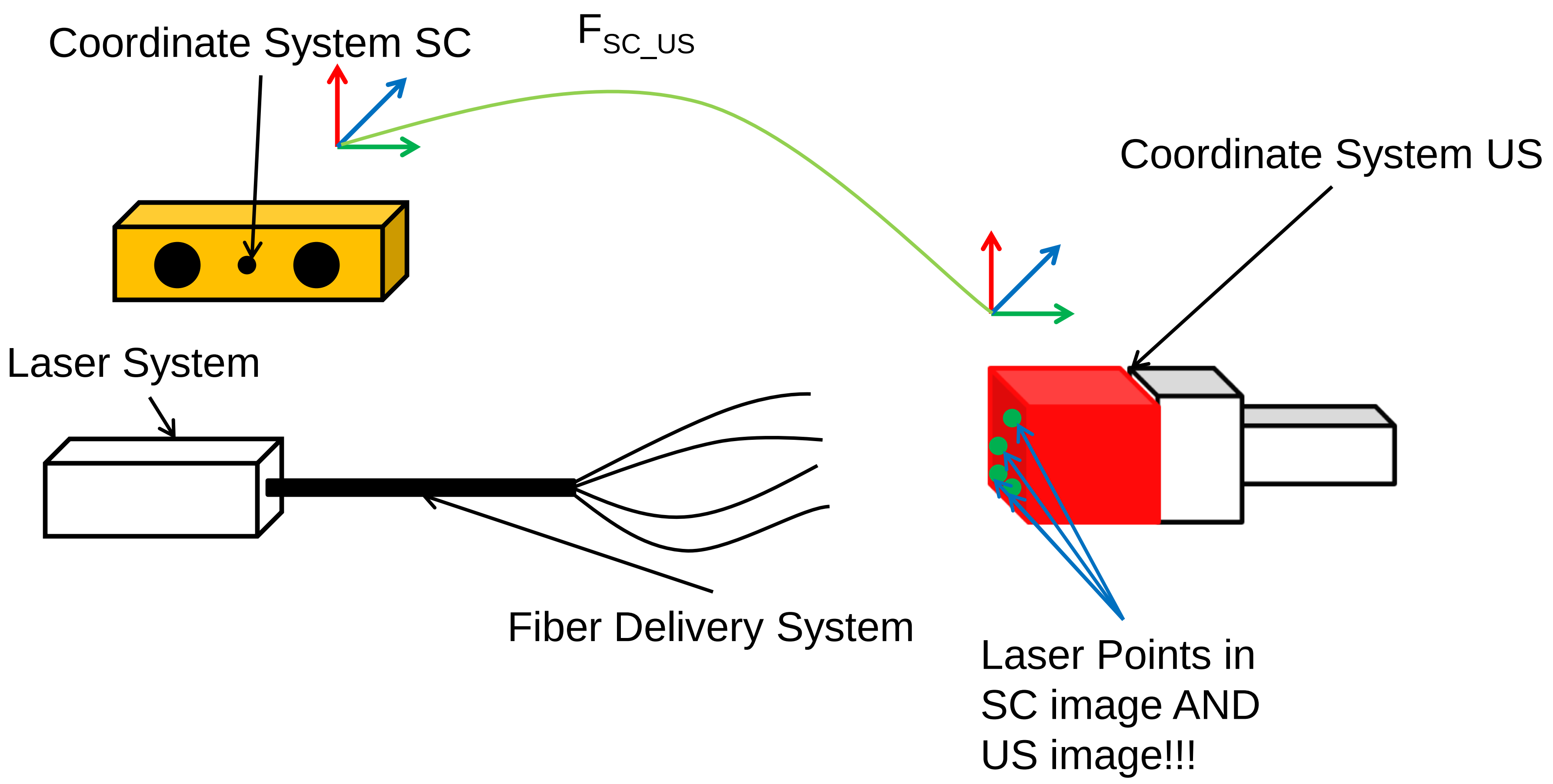
Summary

- Goal: Demonstrate automatic registration between 3D Stereocamera space and 3D Ultrasound space using Photoacoustic imaging in a system with visualization
- Team Member: Alexis Cheng
- Mentors: Emad Boctor, Russell Taylor, Jin Kang

Summary



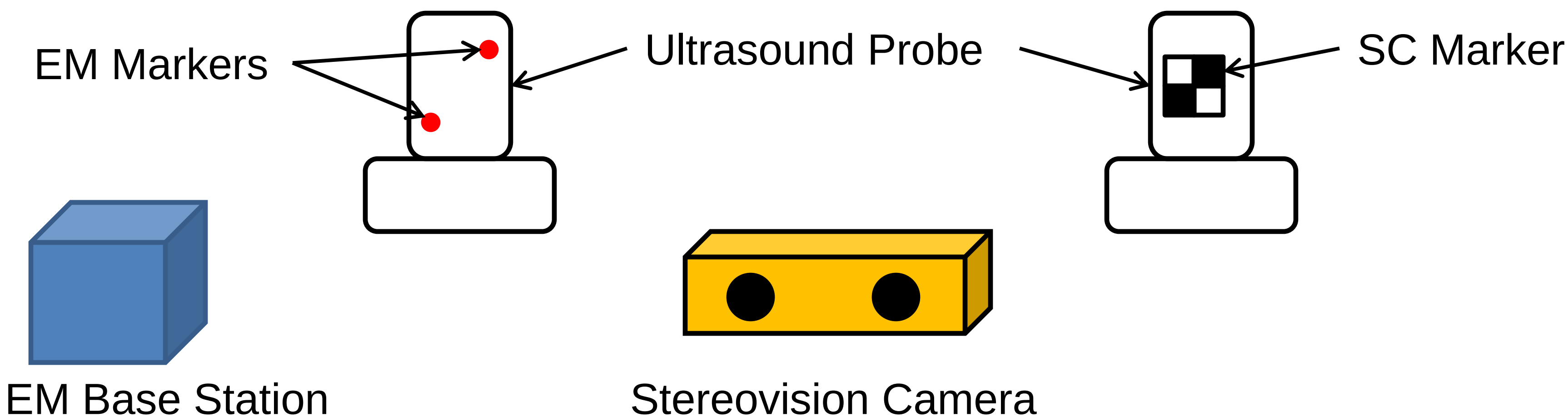
Coordinate System SC
F_{SC_US}
Coordinate System US
Laser System
Fiber Delivery System
Laser Points in
SC image AND
US image!!!

Background

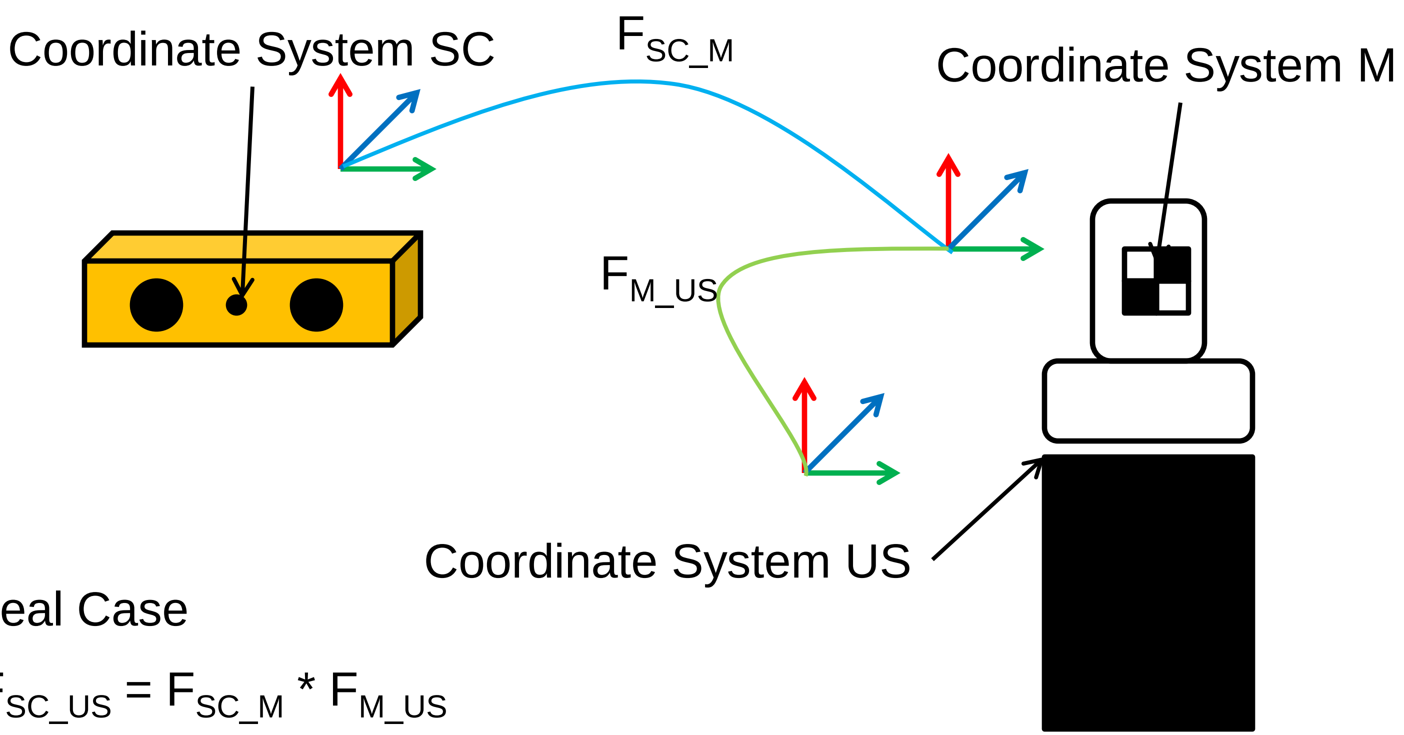
- Photoacoustic Imaging
  - Discovered in 1880 by Alexander Graham Bell
  - Light Waves are absorbed by the material, causing thermal excitation
  - Thermal excitation causes Acoustic wave
  - Acoustic waves can be detected with an Ultrasound probe

Motivation

- Surgical Tracking Systems are widely used in Computer Assisted Interventions
- Common Tracking Systems include Electromagnetic and Stereo Camera



Motivation



Ideal Case

$F_{SC\_US} = F_{SC\_M} * F_{M\_US}$

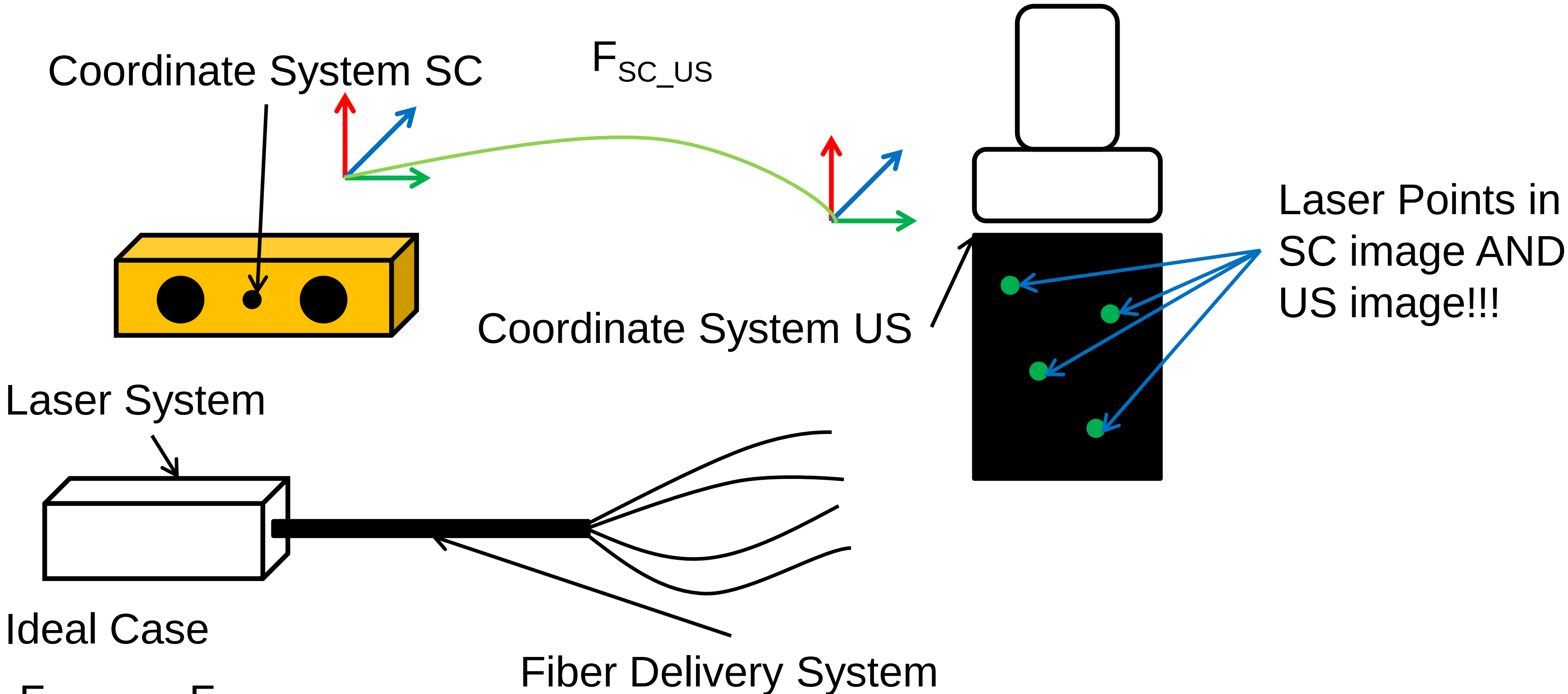
Real Case with Errors

$F_{SC\_US} * \Delta F_{SC\_US} = F_{SC\_M} * \Delta F_{SC\_M} * F_{M\_US} * \Delta F_{M\_US}$

Motivation

- $\Delta F_{SC\_M} = [I + sk(a_{SC\_M}), e_{SC\_M}]$
- $\Delta F_{M\_US} = [I + sk(a_{M\_US}), e_{M\_US}]$
- $\Delta F_{SC\_US} = [I + sk(a_{SC\_US}), e_{SC\_US}]$
- [2] $a_{M\_US} = 3.26$ degree, $e_{M\_US} = 3.08$ mm
- [3][4] $a_{SC\_M} = 0.11$ degree, $e_{SC\_M} = 0.5$ mm
- 90% Confidence Intervals
- $a_{SC\_US} = R_{M\_US} * a_{SC\_M} + a_{M\_US}$, $a_{SC\_US} \leq 3.37$ degree
- $e_{SC\_US} = e_{SC\_M} - R_{SC\_M} * sk(p_{M\_US}) * a_{SC\_M} + R_{SC\_M} * e_{M\_US}$, $e_{SC\_US} \leq 3.58$ mm

Motivation



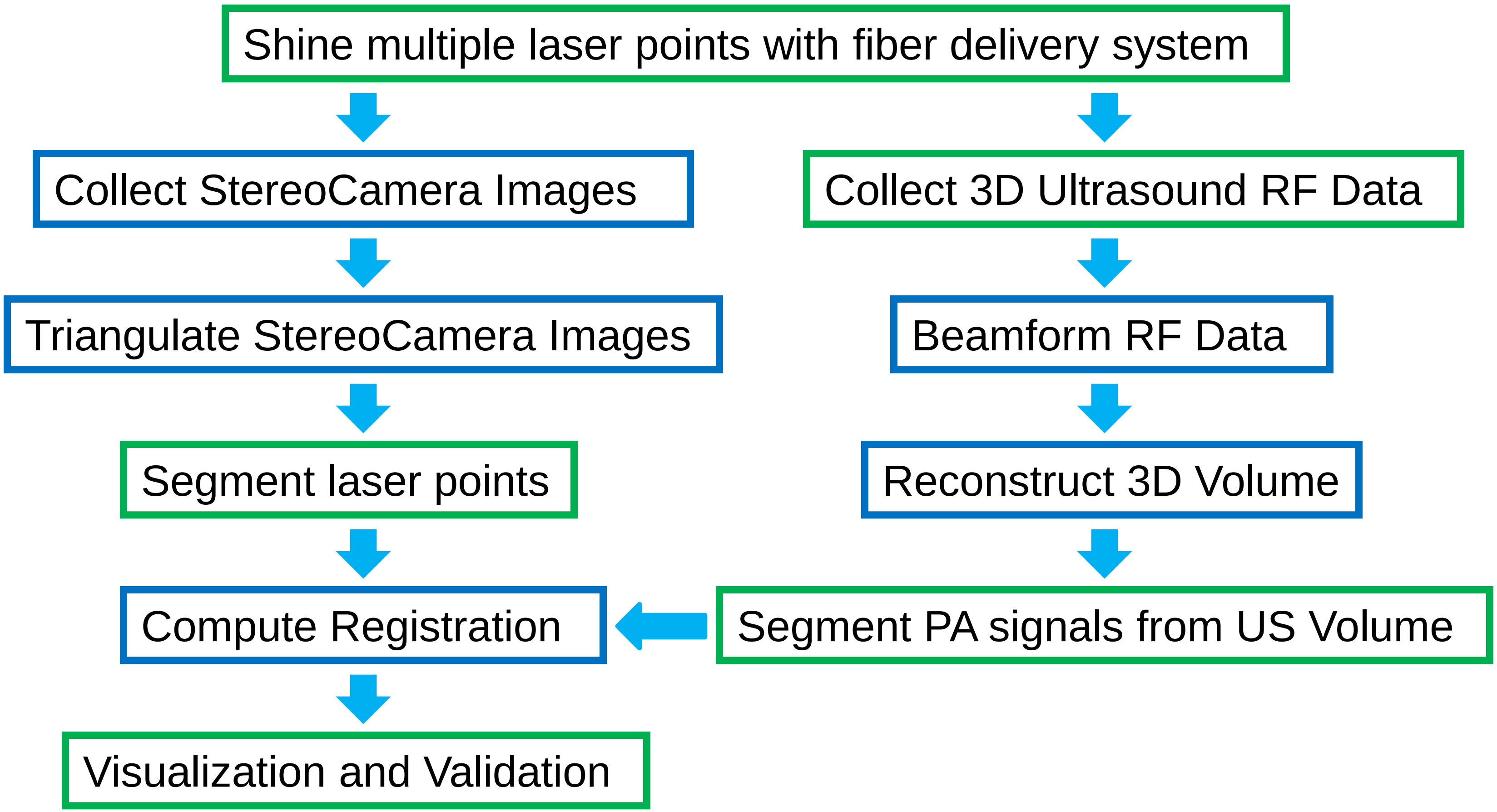
Ideal Case

$F_{SC\_US} = F_{SC\_US}$

Real Case with Errors

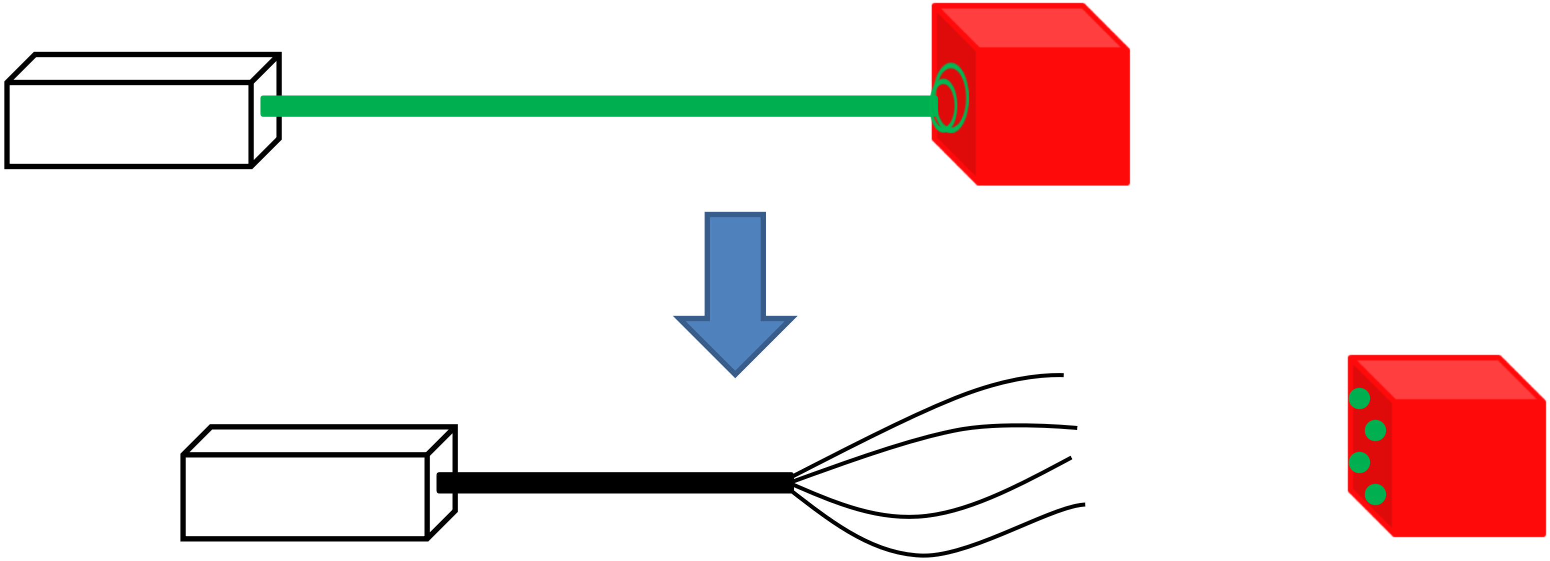
$F_{SC\_US} * \Delta F_{SC\_US} = F_{SC\_US} * \Delta F_{SC\_US}$

Workflow


Shine multiple laser points with fiber delivery system
Collect StereoCamera Images
Triangulate StereoCamera Images
Segment laser points
Compute Registration
Visualization and Validation
Collect 3D Ultrasound RF Data
Beamform RF Data
Reconstruct 3D Volume
Segment PA signals from US Volume

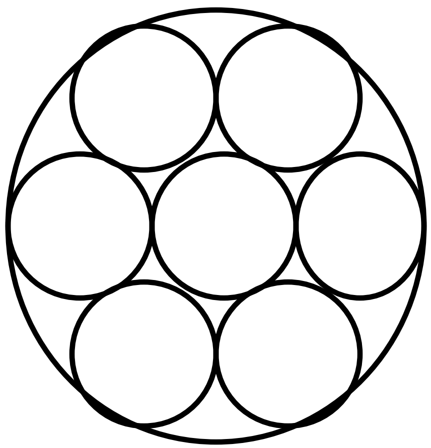
Technical Approach (1)

- From sequential single point firing to multi-point firing
  - Develop fiber delivery system



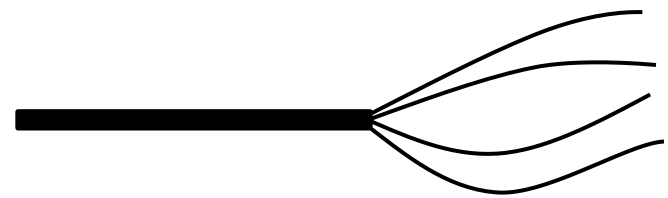
Technical Approach (1)

Fiber Bundle



Laser Light IN

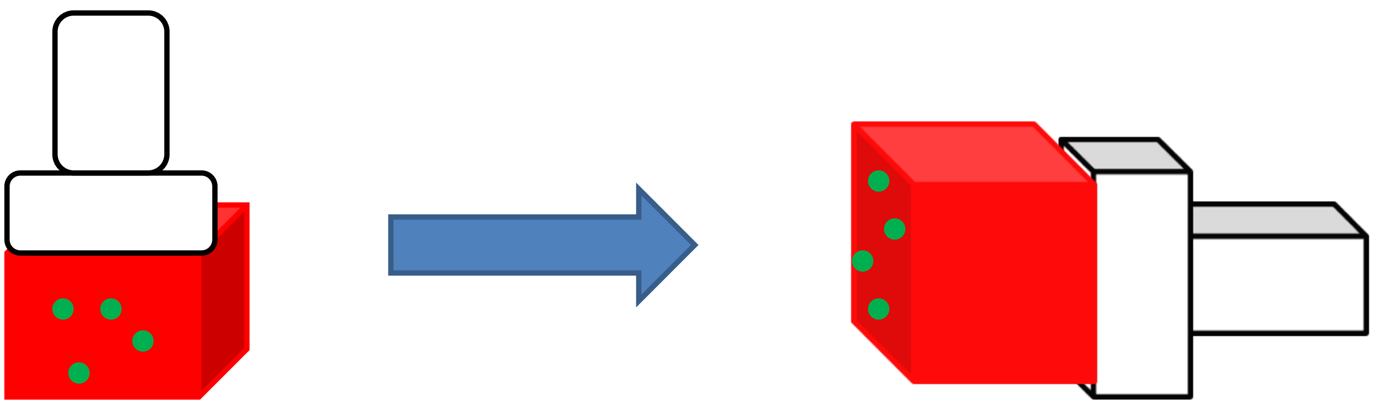
Split Bundle at end



Laser Light OUT

Technical Approach (2)

- From 2D Ultrasound to 3D Ultrasound
  - Previous Issues
    - Required accurate placement of ultrasound probe to receive superficial acoustic waves



Technical Approach (2)

- Use existing 2D RF acquisition software

Collect 2D Ultrasound RF Data

↓

Actuate motor in 3D Probe to move a certain step size

Repeat until the motor is actuated from start to finish

Technical Approach (3)

- From Manual Segmentation to Automatic Segmentation
  - Previous Issues
    - Results could not be reliably recalculated from data
    - Cumbersome to find intensity thresholds with trial and error
    - Inability to extend to real-time

Technical Approach (3)

StereoCamera Images

Ultrasound Volume

Determine intensity threshold based on intensity histogram

↓

Use threshold to make volume binary

Use color to make images binary

↓

Determine points based on characteristics of each high intensity region

Technical Approach (4)

- Arun's Method [1]

$$\bar{\mathbf{a}} = \frac{1}{N}\sum_{i=1}^{N}\vec{\mathbf{a}}_i$$

$$\tilde{\mathbf{a}}_i = \vec{\mathbf{a}}_i - \bar{\mathbf{a}}$$

$$\bar{\mathbf{b}} = \frac{1}{N}\sum_{i=1}^{N}\vec{\mathbf{b}}_i$$

$$\tilde{\mathbf{b}}_i = \vec{\mathbf{b}}_i - \bar{\mathbf{b}}$$

$$\mathbf{H} = \sum_i \begin{bmatrix} \tilde{a}_{i,x}\tilde{b}_{i,x} & \tilde{a}_{i,x}\tilde{b}_{i,y} & \tilde{a}_{i,x}\tilde{b}_{i,z} \\ \tilde{a}_{i,y}\tilde{b}_{i,x} & \tilde{a}_{i,y}\tilde{b}_{i,y} & \tilde{a}_{i,y}\tilde{b}_{i,z} \\ \tilde{a}_{i,z}\tilde{b}_{i,x} & \tilde{a}_{i,z}\tilde{b}_{i,y} & \tilde{a}_{i,z}\tilde{b}_{i,z} \end{bmatrix}$$

$$H = U * S * V^t$$

$$R = V * U^t$$

$$T = b^{\sim} - R * a^{\sim}$$

F = [R, T]

Technical Approach (5)

- Validation of calculated Transformations
  - Visualization of Ultrasound points in Camera Space
- Given that $SC_k = F_{SC\_US} * US_k$ for k points
  - Target registration error (TRE) of points not used in registration
    - $TRE = SC_{test} - F_{SC\_US} * US_{test}$
    - Where F_{SC_US} is computed with k-1 points

Technical Approach (5)

- Given that $SC_k = F_{SC\_US} * US_k$ for k points
  - Fiducial registration error (FRE) of points used in registration
    - $FRE = SC_k - F_{SC\_US} * US_k$ for all k
    - Where F_{SC_US} is computed with k points
  - Fiducial localization error (FLE) of points used in registration
    - $FLE = SC_k - TRUE\ SC_k$ for all k
    - $FLE = US_k - TRUE\ US_k$ for all k

Deliverables

- Minimum
  - Phantom and Ex-vivo Experimental Results with 3D Ultrasound
  - Ability to project multiple laser points concurrently
  - Visualization only shows points overlaid together
  - Automatic Segmentation working on 2D Ultrasound images or each individual 3D Ultrasound slice

Deliverables

- Expected
  - Minimum Deliverables
  - Visualization overlays points and representation of 3D Ultrasound volume
  - Automatic Segmentation working on 3D Ultrasound volume

Deliverables

- Maximum
  - Expected Deliverables
  - Ability to collect 3D RF data without manually actuating motor
  - Complete system integrated together

Dependencies

- Access to Laboratories
  - Dr. Kang's Lab
    - Have access to key already
  - Dr. Boctor's Lab area
    - Have access to pass code already
- Access to Equipment
  - Laser and Optics
    - Have access to Dr. Kang's lab already
  - Ultrasound Machine
    - Have access to Dr. Boctor's Lab area already
- Access to Phantom materials
  - Have access to Dr. Boctor's lab area already

Milestones

- Phantom Construction
  - Date: February 27
  - Criteria: Create phantom suitable for 3D PA imaging
- 3D Ultrasound
  - Date: February 27
  - Criteria: Be able to manually segment the PA signal from a 3D volume

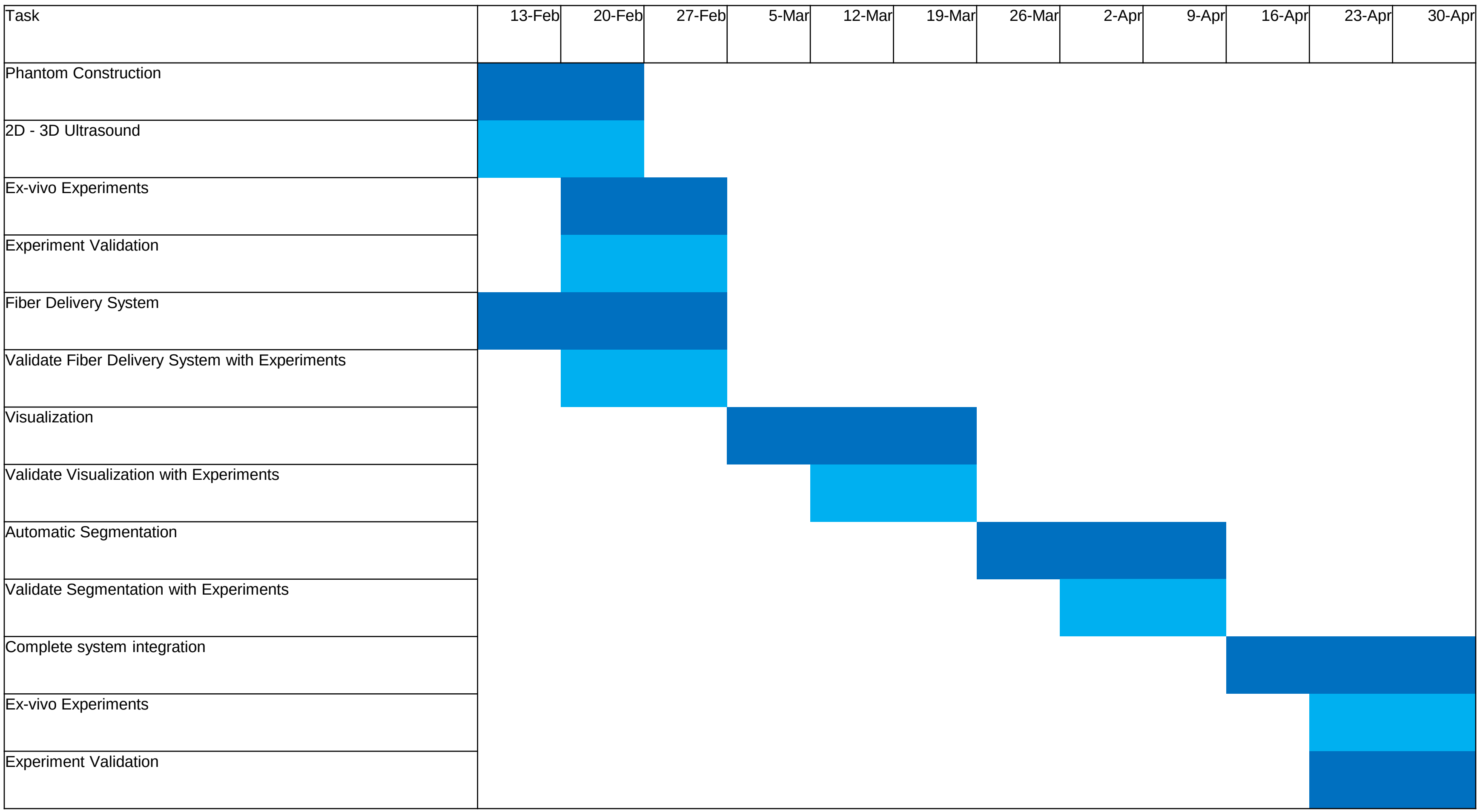
Milestones

- Fiber Delivery System
  - Date: March 5
  - Criteria: Develop a fiber that can shine multiple laser spots at once
- Visualization
  - Date: March 26
  - Criteria: Be able to display SC and US points in the SC space

Milestones

- Automatic Segmentation
  - Date: April 16
  - Criteria: Able to segment desired PA signal from a set of images
- System Integration
  - Date: May 7
  - Criteria: Pieces fit together

Milestones


Task
13-Feb
20-Feb
27-Feb
5-Mar
12-Mar
19-Mar
26-Mar
2-Apr
9-Apr
16-Apr
23-Apr
30-Apr
Phantom Construction
2D - 3D Ultrasound
Ex-vivo Experiments
Experiment Validation
Fiber Delivery System
Validate Fiber Delivery System with Experiments
Visualization
Validate Visualization with Experiments
Automatic Segmentation
Validate Segmentation with Experiments
Complete system integration
Ex-vivo Experiments
Experiment Validation

Management Plan

- Schedule weekly meetings with mentors
- Review timeline and milestones weekly
- Adjust timeline accordingly weekly

Reading List

- Hoelen C. et al. “Three-dimensional photoacoustic imaging of blood vessels in tissue”. Optics Letters 1998. Vol. 23-8:648-650
- Kuo N. et al. “Photoacoustic imaging of prostate brachytherapy seeds in ex vivo prostate”. SPIE 2011
- Oberhammer P. et al. “Optimization and Quantification for Rigid Point Based Registration for Computer Aided Surgery”. Advances in Medical Engineering 2007. Vol. 114-3:230-235
- Pham D. et al., “Current Methods in Medical Image Segmentation”. Annual Review of Biomedical Engineering 2000. Vol. 2:315-337
- Vyas S. et al., “Intraoperative Ultrasound to Stereocamera Registration using Interventional Photoacoustic Imaging”. SPIE 2012
- Xu M. et al. “Photoacoustic Imaging in Biomedicine. Review of Scientific Instruments”. Review of Scientific Instruments 2006, 77

Future Work

- Low power high frequency laser diodes
  - Replace expensive laser!
- Pre-operative Model Registration with Fiducials
- Move to DaVinci System
- Tool tracking
- Sub-surface imaging

References

- [1] Arun K. et al., “Least-Squares Fitting of Two 3-D Point Sets”. IEEE PAMI, 9-5:698-700, September 1987.
- [2] Boctor E. et al., “A Novel Closed Form Solution for Ultrasound”. ISBI 2004
- [3] Navab N. et al., “Camera-Augmented Mobile C-Arm (CAMC) Application: 3D Reconstruction using Low Cost Mobile C-Arm”. MICCAI 1999, 688-697
- [4] Wiles A. et al., “Accuracy assessment and interpretation for optical tracking systems”. Medical Imaging 2004, vol. 5367: 421-432

Questions?