Synthetic Aperture Ultrasound Imaging with Robotic Tracking Technique Paper Seminar Presentation

Computer Integrated Surgery II

Project No. 2

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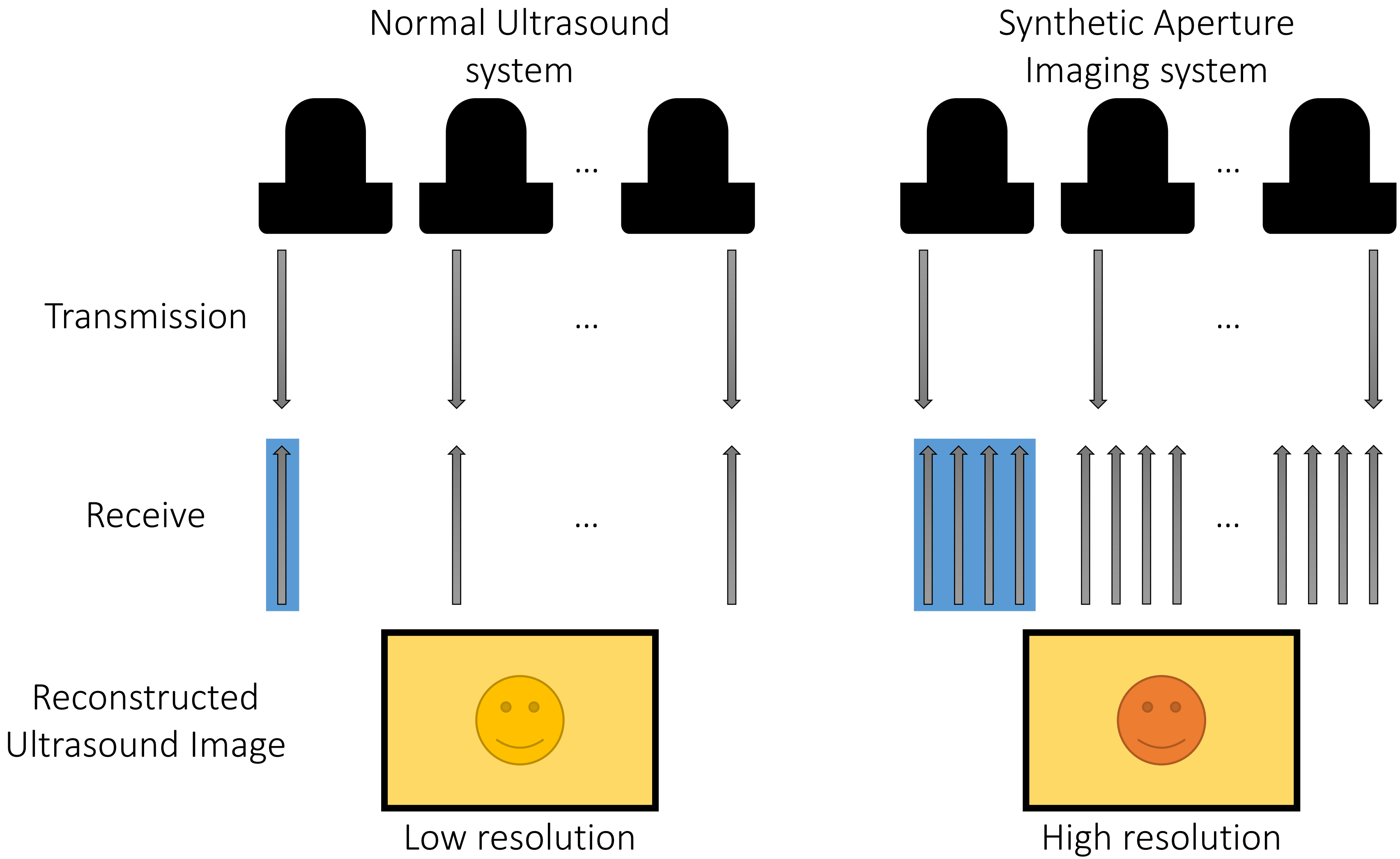
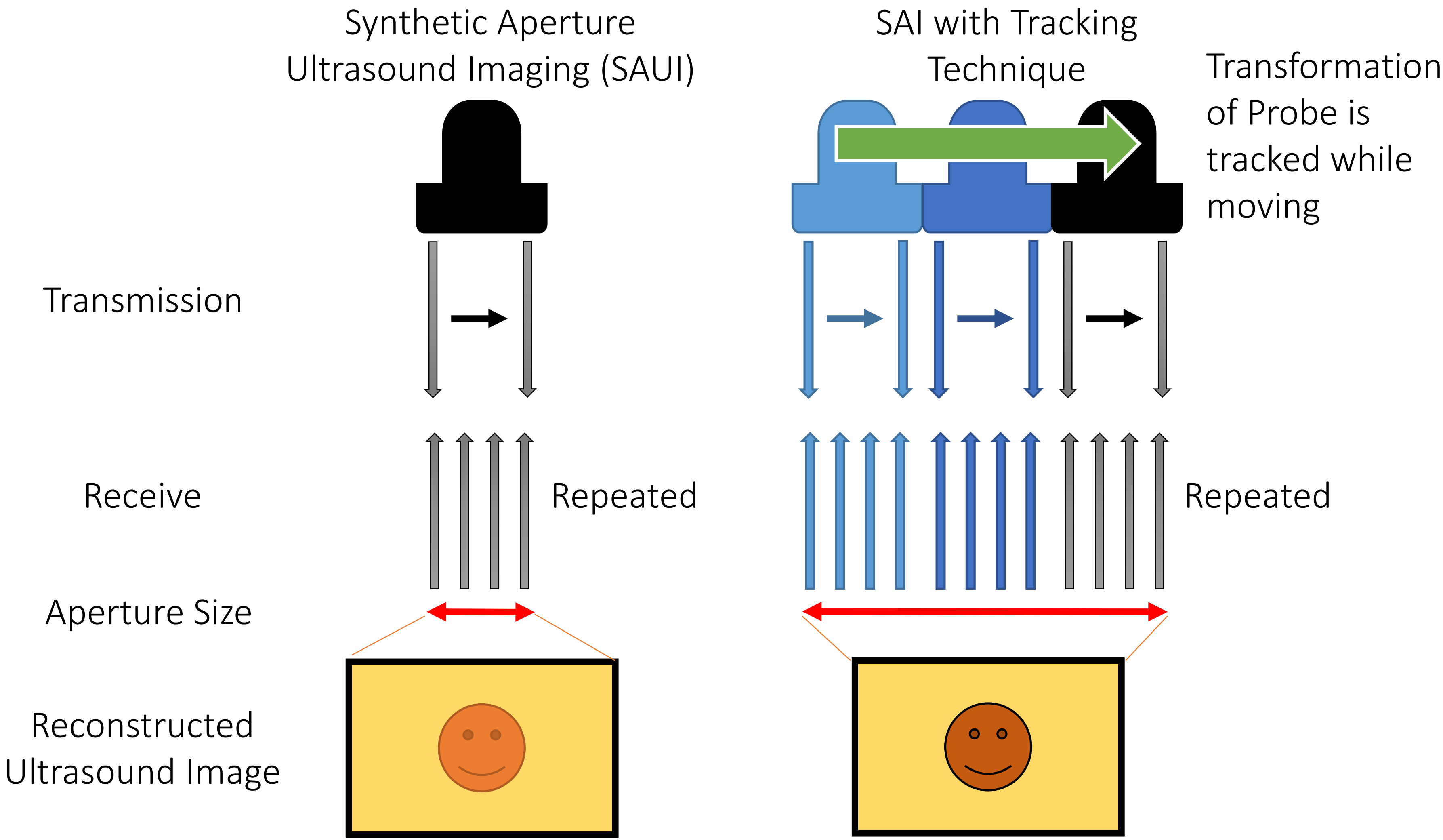
Overview

1. Background
2. Paper Summary
   Alexis Cheng et al., "*Design and development of an ultrasound calibration phantom and system*", SPIE Medical Imaging, 2014
3. Paper Analysis
4. References

Background:
Synthetic Aperture Ultrasound Imaging



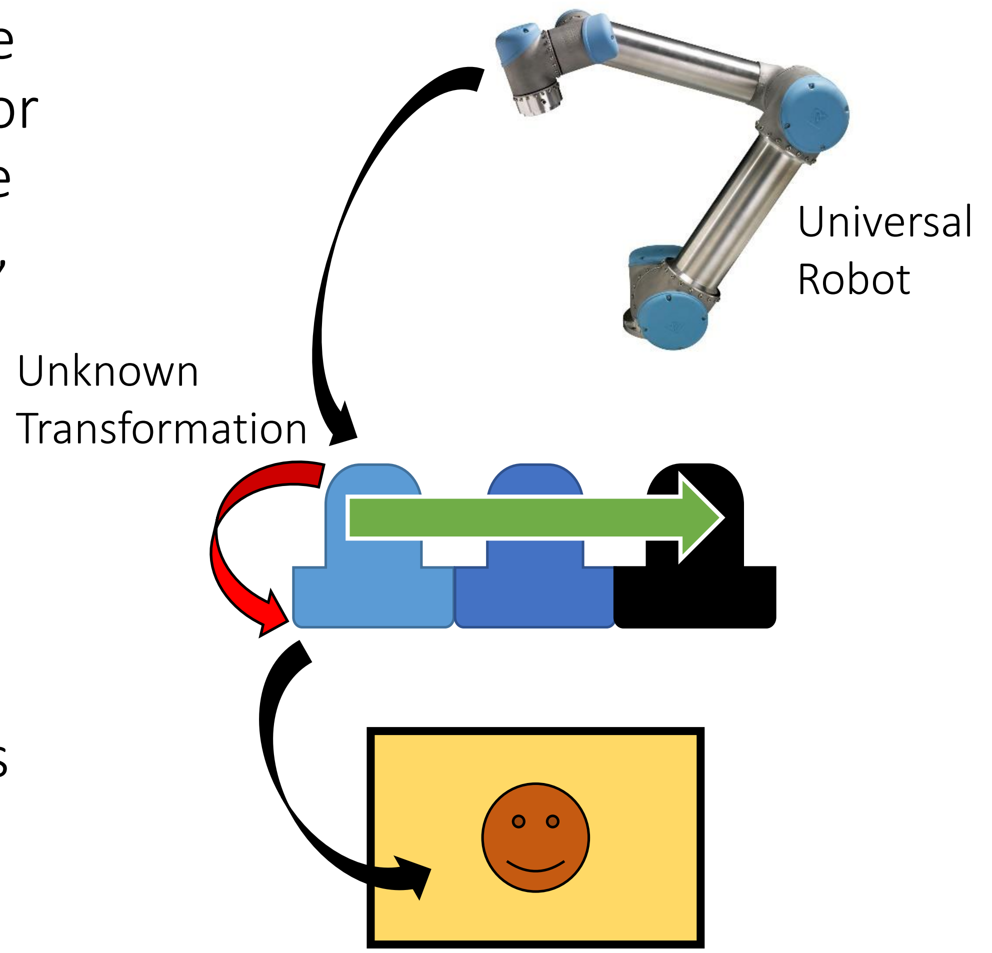
Background:
SAUI with tracking



Higher resolution can be achieved by expanding the aperture size.

Background:
Ultrasound calibration

- In order to move the probe for a designated position, or to know the location of the origin of ultrasound image, unknown rigid-body transformation on the transducer from sensor to image is needed to be calibrated.
- Process to identify this unknown transformation is called ultrasound (US) calibration.

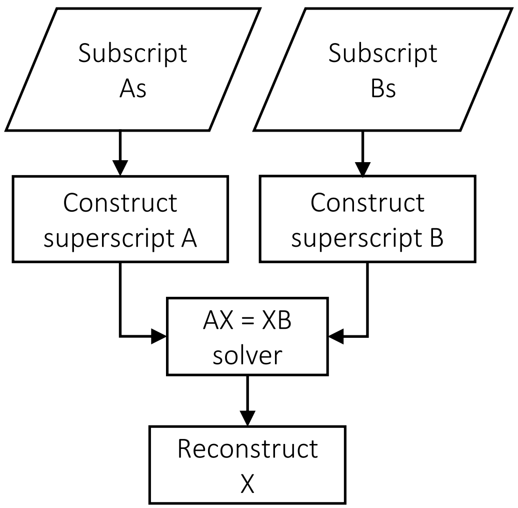


Paper Summary

Alexis Cheng et al., "*Design and development of an ultrasound calibration phantom and system*", SPIE Medical Imaging, 2014, in press

- State-of-the art solution to do ultrasound calibration
- The approach of solving AX=XB problem is applicable to our project
- Their experimental considerations are available to our project

Paper Summary



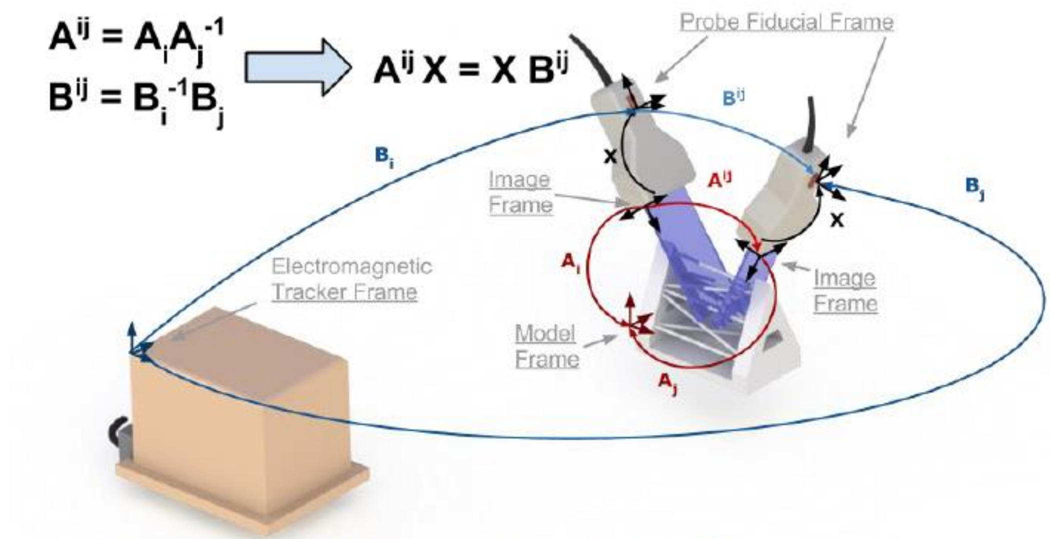


Figure 1. $AX = XB$ formulation with labeled coordinate frames

Alexis Cheng et al., "*Design and development of an ultrasound calibration phantom and system*", SPIE Medical Imaging, 2014, in press

Paper Summary
Design of calibration phantom

- This phantom is an extension of Z-fiducial phantoms
- One ultrasound image can extract homogeneous transformation from image to the phantom subscript A_i
- It is possible to get nearly perpendicular angle

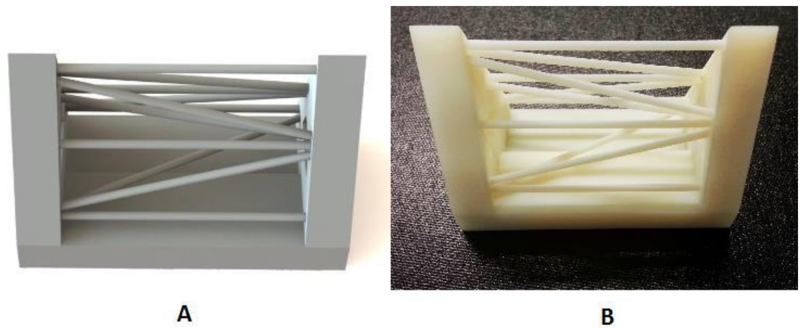


Figure 2. Calibration phantom model

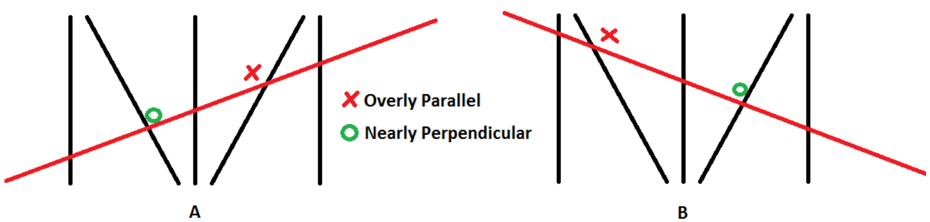


Figure 3. Z-fiducial orientations

Paper Summary
Design of calibration phantom

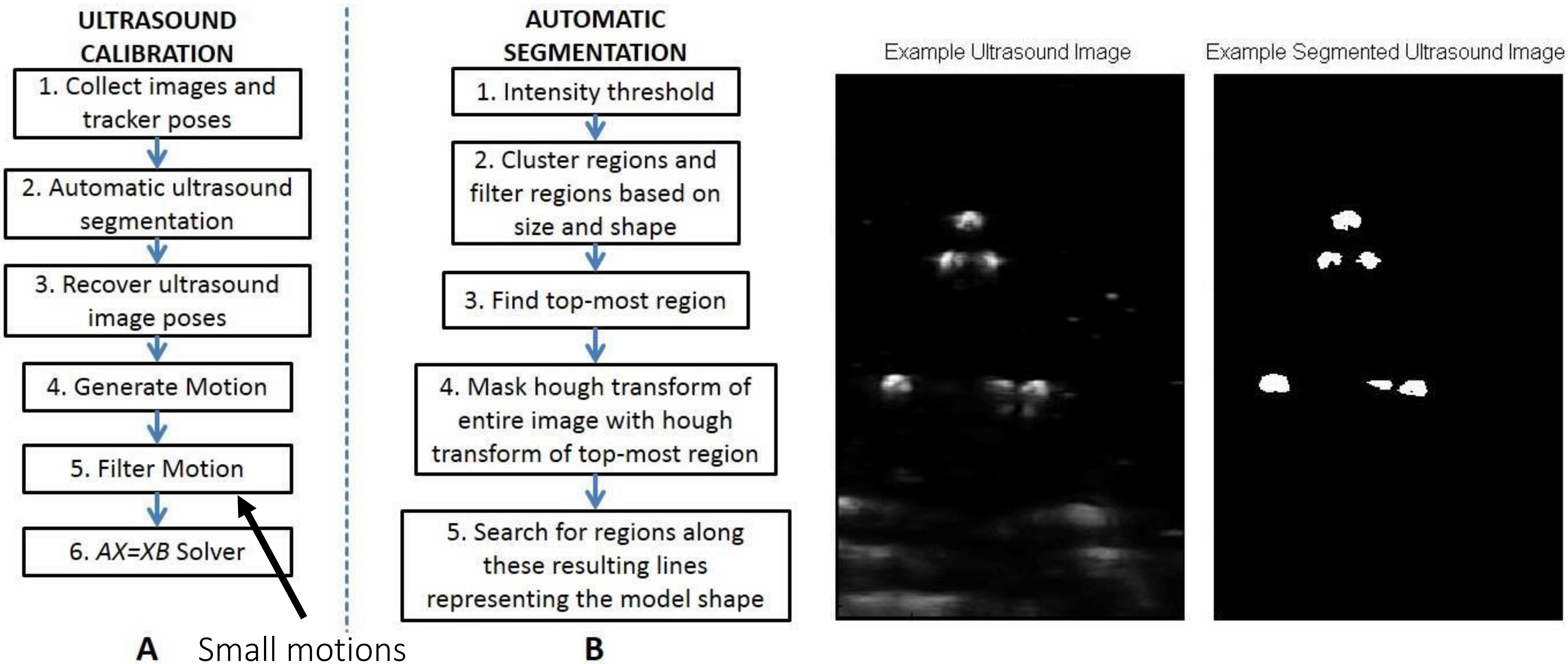
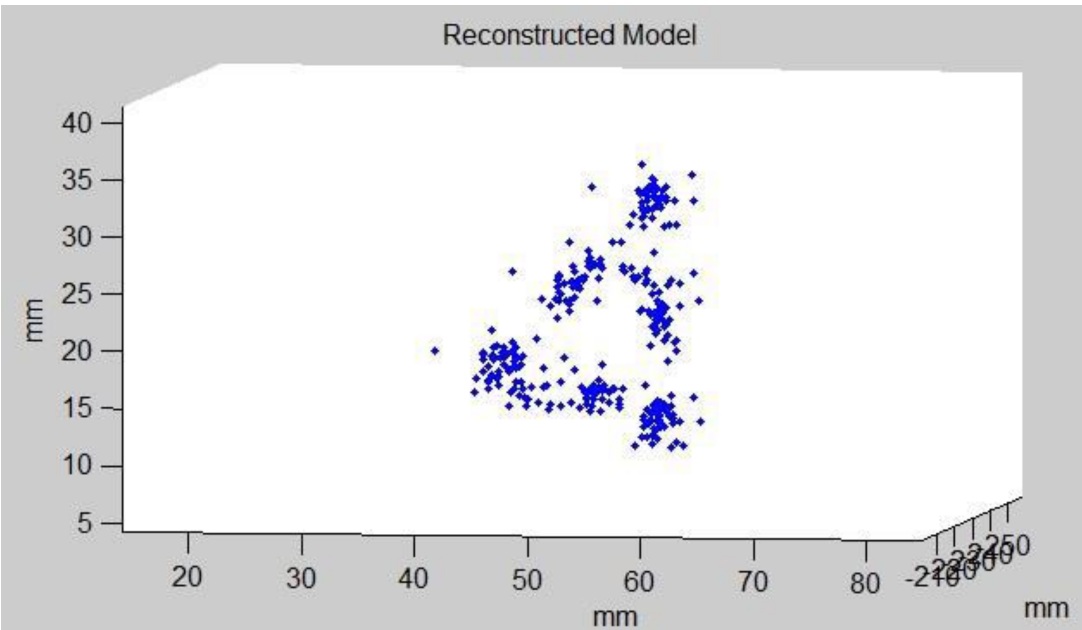


Figure 2. Workflows for A) the overall US calibration and B) the automatic segmentation algorithm

Paper Summary
Result



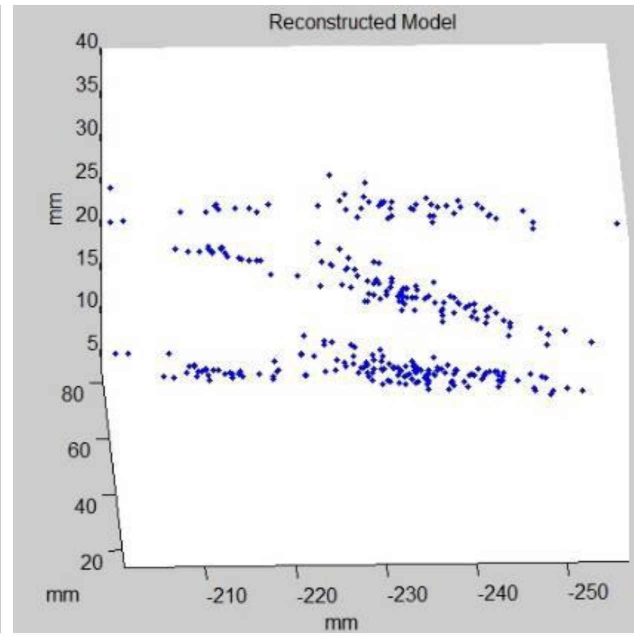


Table 1. Normalized error metric for different combinations of motion generation and filtering

Motion Generation	Filtering	Error Metric (mm)
A^i	Without	2.75 ± 1.67
A^i	With	1.74 ± 1.00
A^{ij}	Without	2.36 ± 1.49
A^{ij}	With	1.56 ± 1.02

Paper Summary
Discussion

- Filter of motions are effectively working to eliminate bad motions combinations.
- US images are difficult to segment and the US image quality will cause the automatic segmentation algorithm to fail.
- This phantom takes advantage of US physics and can be easily printed without user modifications.

Table 1. Normalized error metric for different combinations of motion generation and filtering

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A^{ij}	With	1.56 ± 1.02

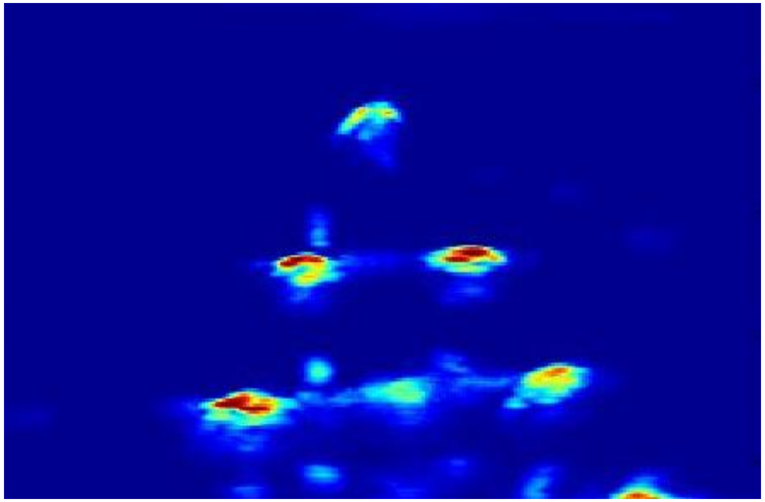
Paper Analysis

Pros

- Well describe the overview of AX=XB problem based on segmentation.
- A approach to automatically segment region is presented, and compensation method such as Hough transform is used.
- The advantage of the phantom and the 1.56 mm accuracy is shown.

Cons

- Segmentation error affects the calibration result
- Hard to achieve sub-milimeter accuracy

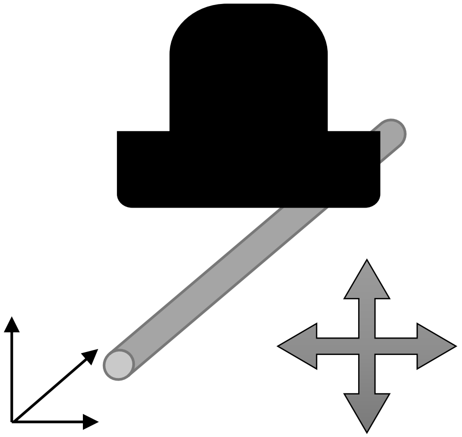


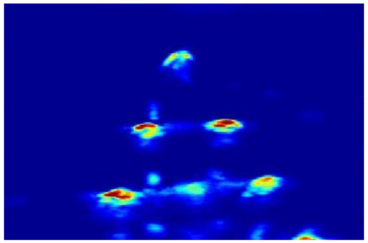
Idea from Paper

Idea to improve the accuracy:

US Calibration Using Moving Phantom

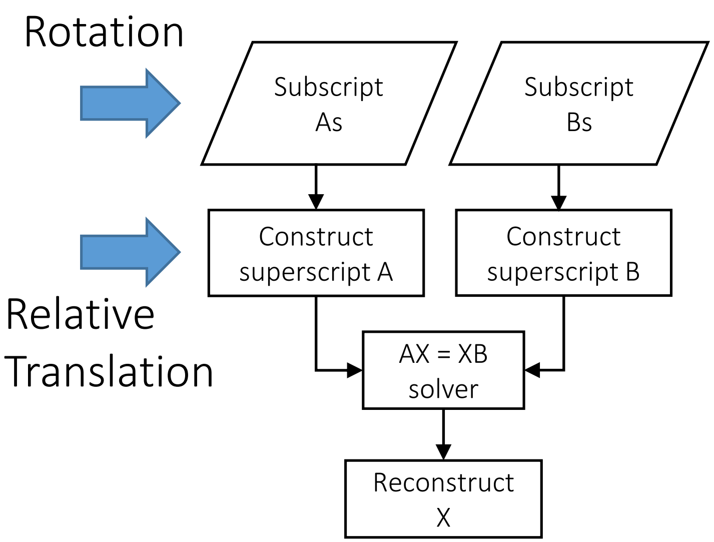
- Moving the phantom toward x and y axis, from the coordinate of phantom.
- Normalized cross correlation (NCC) is used to identify the displacement of phantom in image.
- The goal of this project is to reconstruct X only using moving information.





Idea from Paper

Ultrasound calibration utilizing moving phantom trajectory



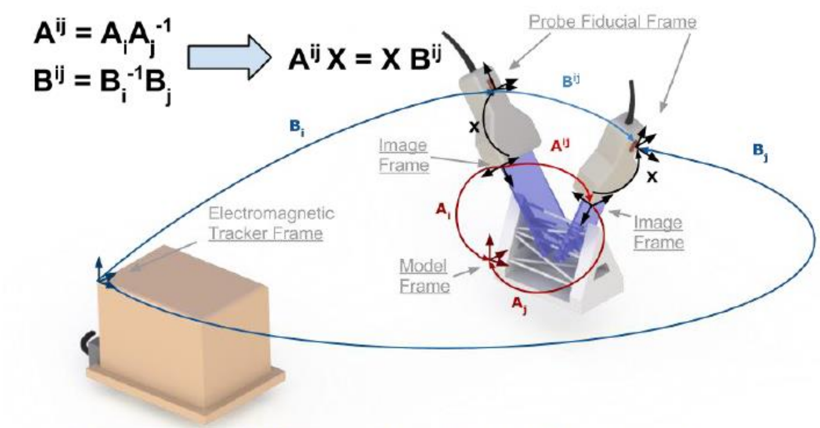
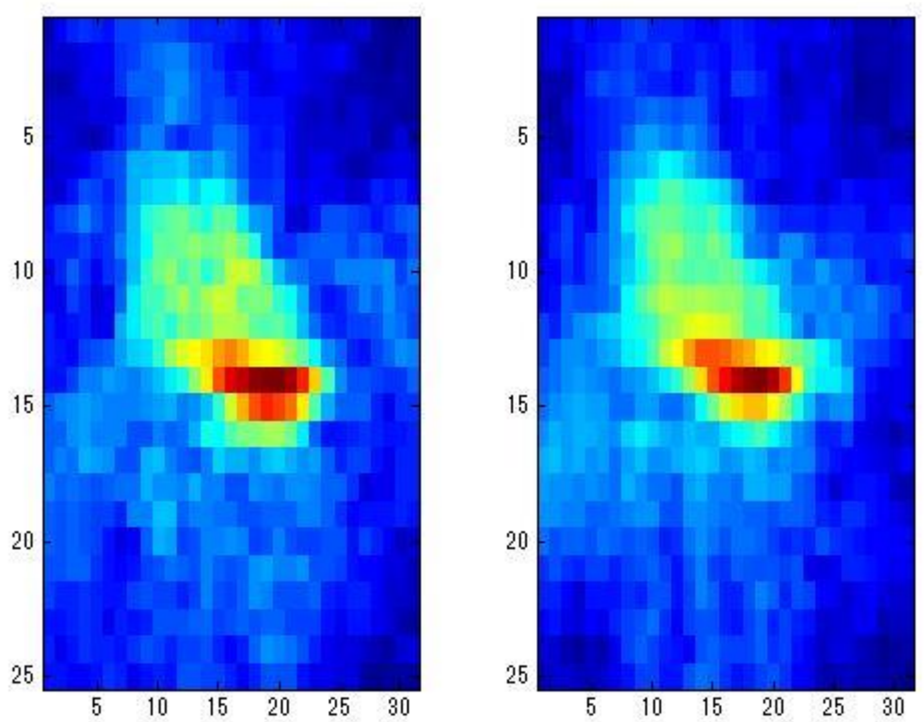


Figure 1. $AX = XB$ formulation with labeled coordinate frames

Idea from Paper

Invent a decent ultrasound calibration method



Progress

Ultrasound Calibration utilizing moving phantom trajectory

Rotation	Error from GT	STD	Translation	Error from GT	STD	Repeatability
Yaw	0.0924	0.0578	X	0.3722	0.2612	0.4619
Pitch	0.0966	0.0734	Y	0.2099	0.12	0.217
Roll	0.0712	0.0399	Z	0.1646	0.1467	0.2142
Norm	0.151455	0.101589	Norm	0.457913	0.322717	0.553464

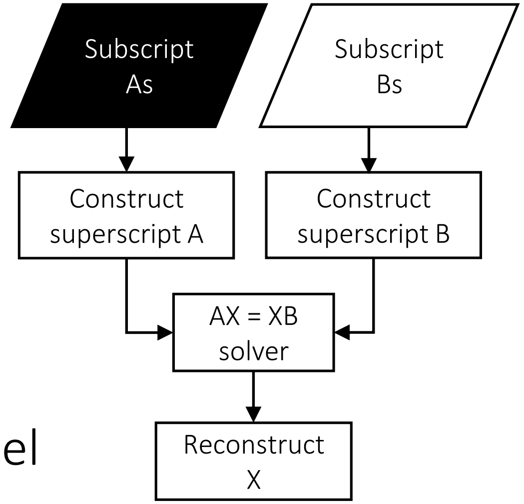
1. Error form GT = closeness to the grand truth
   Subtract each result with grand truth and took the average of absolute value. STD is also calculated
2. Repeatability: repeat reconstructing X loop times and see the stability of result

References

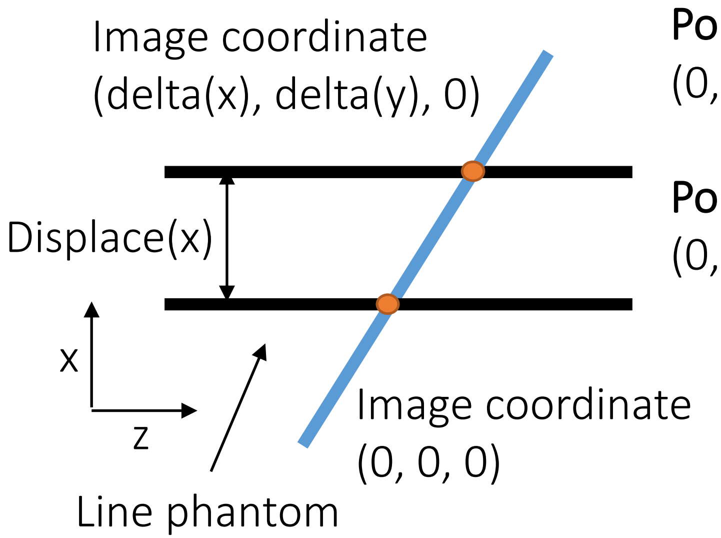
- Boctor, E.M., Viswanathan, A., Choti, M.A., Taylor, R.H., Fichtinger, G., Hager, G.D., “A Novel Closed Form Solution for Ultrasound Calibration,” IEEE Int Symp. On Biomedical Imaging, 527-530, 2004
- Andreff, N., Horaud, R., Espiau, B., “Robot Hand-Eye Calibration Using Structure-from-Motion” The International Journal of Robotics Research, 2001.

Thank you for your attention.

Idea from Paper
STEP1 - Rotation



- The rotation (of subscript A) is reconstructed through point cloud registration between three points on model coordinate and image coordinate.



Points in model coordinate

(0,0,0), (displace(x), 0, ±sqrt(norm(delta)^2 – displace(x)^2))

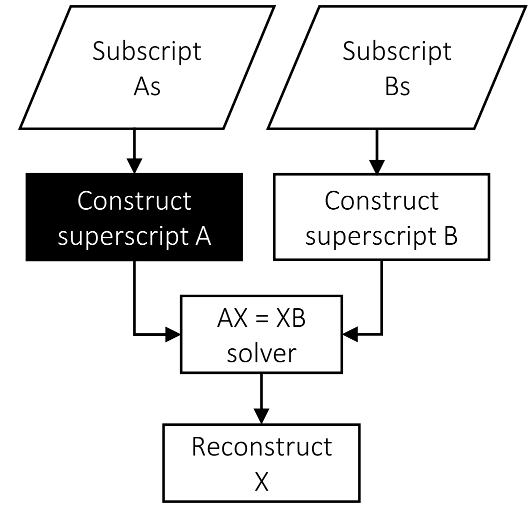
Poinsts in image coordinate

(0,0,0), (delta(x), delta(y), 0)

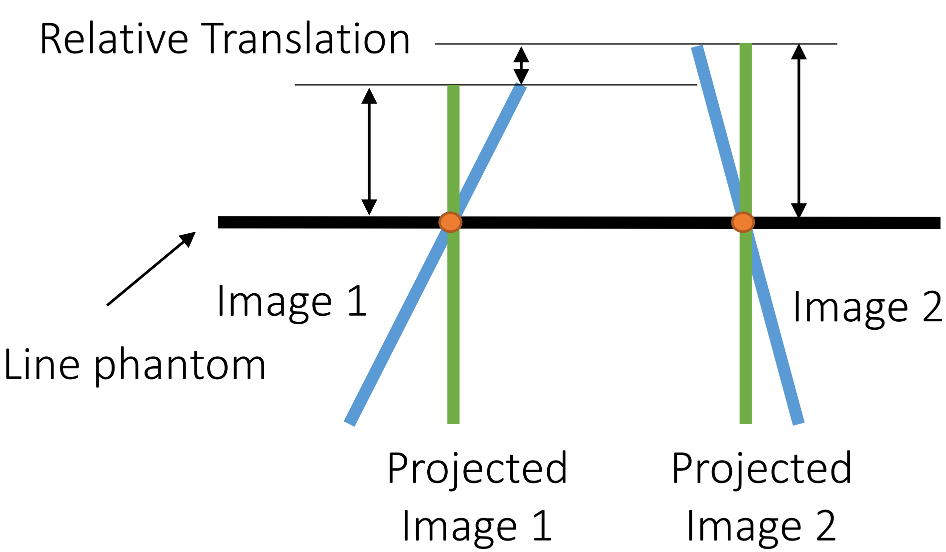
STEP 1 $\quad {}^{\text{USimage}}p = R_i \cdot {}^{\text{Model}}p$

Idea from Paper

STEP2 – Translation (partial)



- Translation of two images from the coordinate of model can be obtained by getting displacement of points in the images which is projected to the model coordinate.



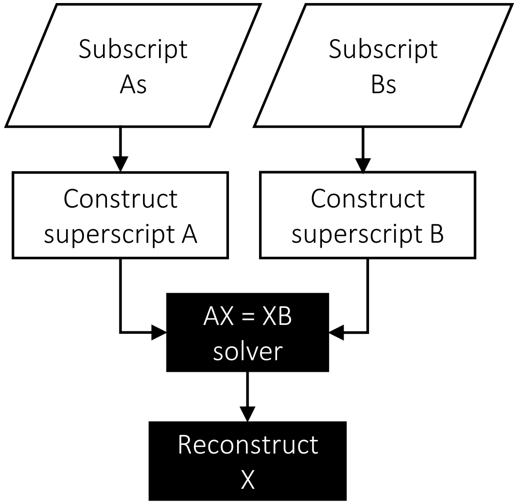
STEP 2

$$^{\text{Model}}I_i(x,y,0) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} \cdot {}^{\text{Model}}I_i(x,y,z).$$

$$\Delta t^{ij}(x,y) = {}^{\text{Model}}I_i(x,y) - {}^{\text{Model}}I_j(x,y)$$

Idea from Paper

STEP3 – Reconstruction of X



STEP 3

Rotation

- ${}^{A}R^{ij}\,{}^{X}R = {}^{X}R\,{}^{B}R^{ij}$

Translation

- $${}^{A}R^{ij}\,{}^{X}\boldsymbol{P} + \begin{bmatrix} R_i^T(1,1)x + R_i^T(1,2)y + R_i^T(1,3)\boldsymbol{Z} \\ R_i^T(2,1)x + R_i^T(2,2)y + R_i^T(2,3)\boldsymbol{Z} \\ R_i^T(3,1)x + R_i^T(3,2)y + R_i^T(3,3)\boldsymbol{Z} \end{bmatrix} = {}^{X}R\,{}^{B}P^{ij} + {}^{X}\boldsymbol{P}$$

- Three equations and four unknowns for one relative pose
- Nine equations for six unknowns for three relative poses

Progress: Simulation

Ultrasound Calibration utilizing moving phantom trajectory

Defined X

- Rotations: -87.94(row) -17.99(pitch) -0.91673(yaw)
- Translation: 97(x) -365(y) -20(z)
  from experimental result using active-echo

Grand truth subscript As

- Group 1: [20:40 10 60 60 60 60]
- Group 2: [10 20:40 60 60 60 60]
- Group 3: [20:40 20:40 60 60 60 60]
  *[row pitch yaw x y z]

Error

- Normalized cross correlation[0.05mm]
- Subscript B[0.1mm].

Loops for assessment = 20

Progress: Result

Ultrasound Calibration utilizing moving phantom trajectory

Rotation	Error from GT	STD	Translation	Error from GT	STD	Repeatability
Yaw	0.0924	0.0578	X	0.3722	0.2612	0.4619
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