

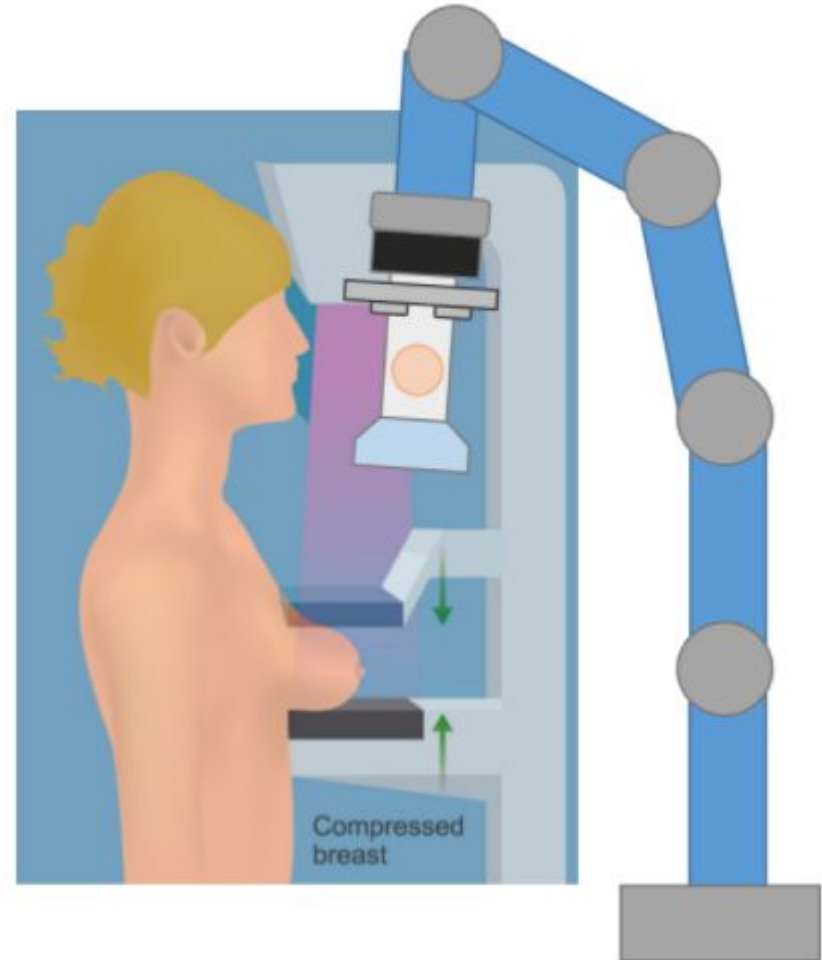
# Background Reading Presentation: *Phantom with Multiple Active Points for Ultrasound Calibration*

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# Project Summary

- We are seeking to develop a robotic device for augmenting current mammography with ultrasound imaging
  - Calibration
    - UR5
    - Cameras
    - Hand-Eye
    - Ultrasound ←
  - Motion Planning
    - Hand-Over-Hand Integration
    - Movement Algorithm



# Key Results

- Proposed a US calibration concept and associated mathematical framework enabling fast and accurate US calibration using multiple “active” points.

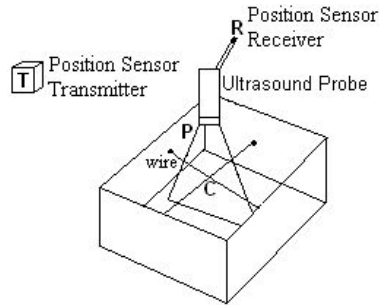
## Significance:

- Ultrasound calibration method can help us achieve high accuracy transformation bridging the tracking sensor and the US image coordinate systems
- Evaluation methods could be used to assess our calibration accuracy

# Theory - Phantoms

## Point Based

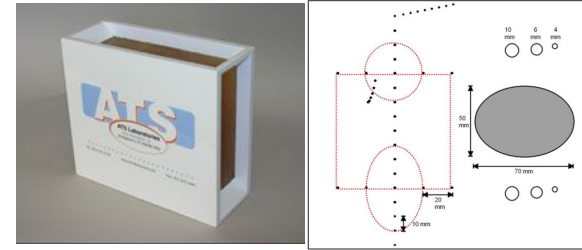
Points in 3D space formed using stylus or cross wire



- + Superior Accuracy
- + Provides Positional information
- Longer data acquisition times
- Difficult to automate

## Structural

Pre-determined structures



**3D Ultrasound Calibration Phantom ATS 560H**

- + Full pose information
- + More flexible
- + Easier to automate
- Less accurate

# Theory - Ultrasound Calibration

Solve for rigid-body transformation  $X$  via  $BXp = XB$  or  $AX = XB$  where  $A, X, B \in SE(3)$ , and  $p \in R^3$

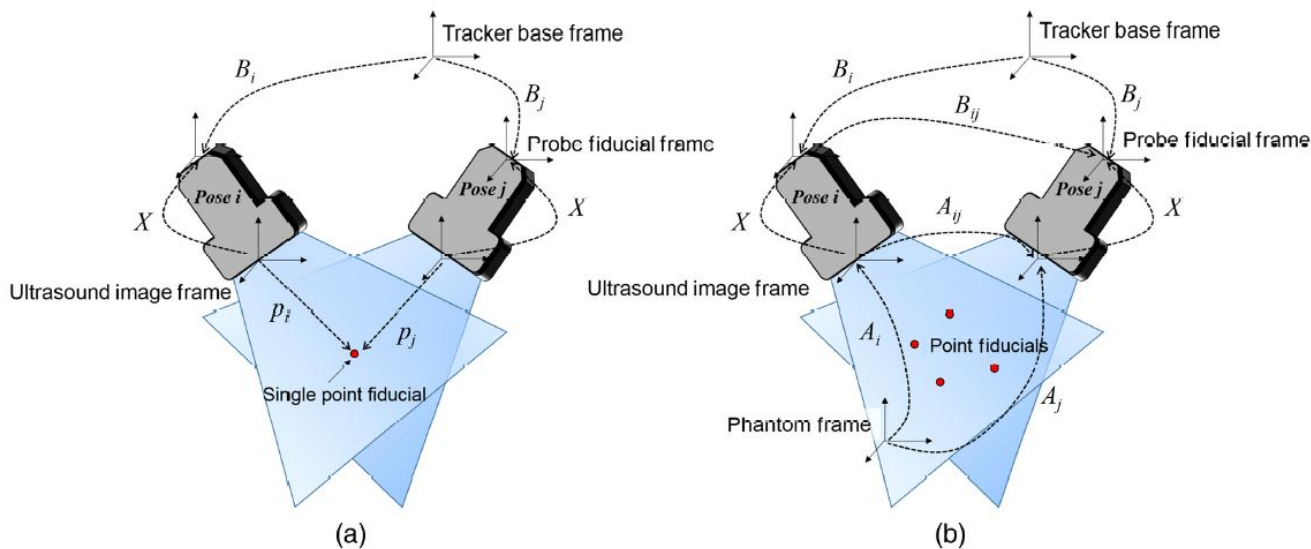
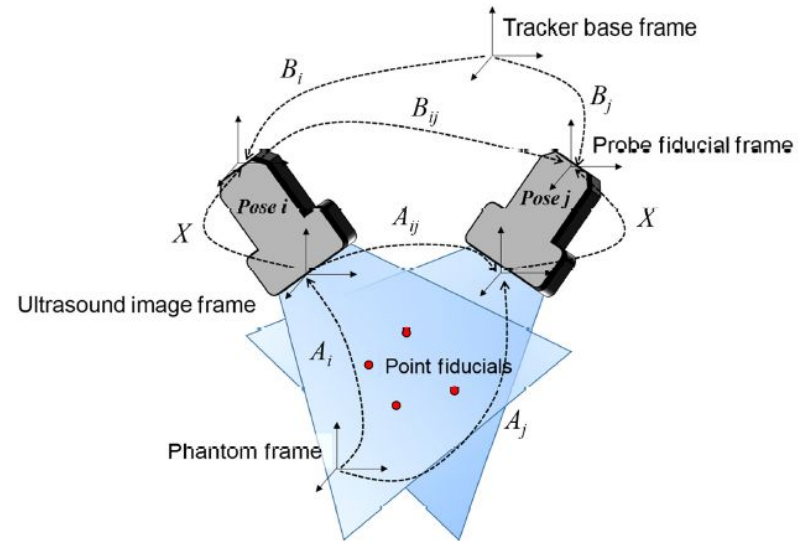


Fig. 1 Illustration of coordinate systems on ultrasound calibration. (a) A single point target phantom, in which  $BXp$  formulation is used. (b) The proposed MAP phantom, in which  $AX = XB$  formulation is used.

# Proposed - Multiple Active Point (MAP) Phantom

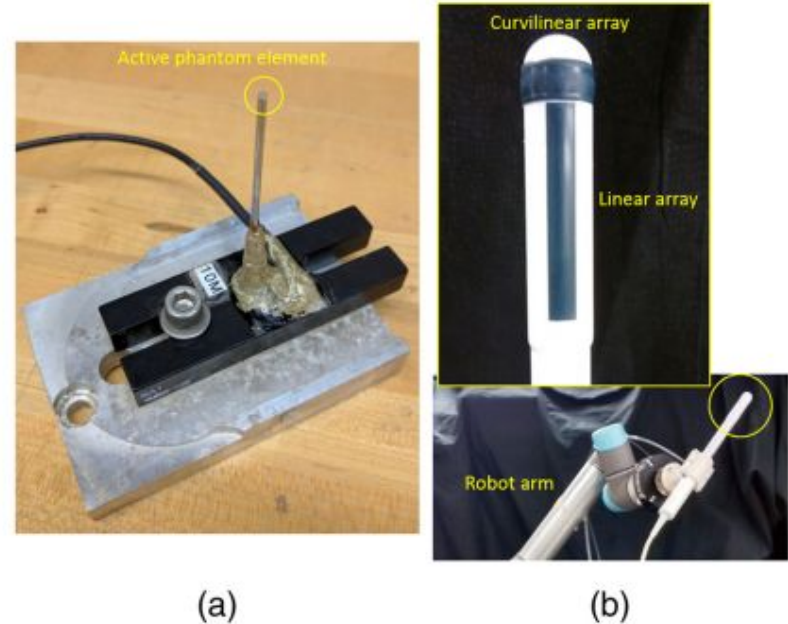
Active Points actively interact with US receiver by transmitting acoustic waves

- + Provides background free signals
- + Minimizes artifacts
- + **Allows for  $AX=XB$  formulation without requiring feature segmentation**



# Materials

- Mechanical Tracker: UR5
- Active element: disc-shaped 1-mm diameter piezoelectric element
- Probe: BPL9-5/55 Transrectal Bi-plane, Ultrasonix
- Data recording device: SonixDAQ, Ultrasonix



**Fig. 5** Pictures of the experimental setup. (a) Active-point phantom and (b) transrectal probe mounted on the robot arm.

# Methods

- 12 phantom designs shown on the right were tested
- 125 probe poses were used for each design
  - 60 poses were randomly chosen for calibration
  - 60 of the remaining poses were chosen for evaluation
- Only 1 active element was used. The robot arm was moved translationally in each pose to simulate multiple elements

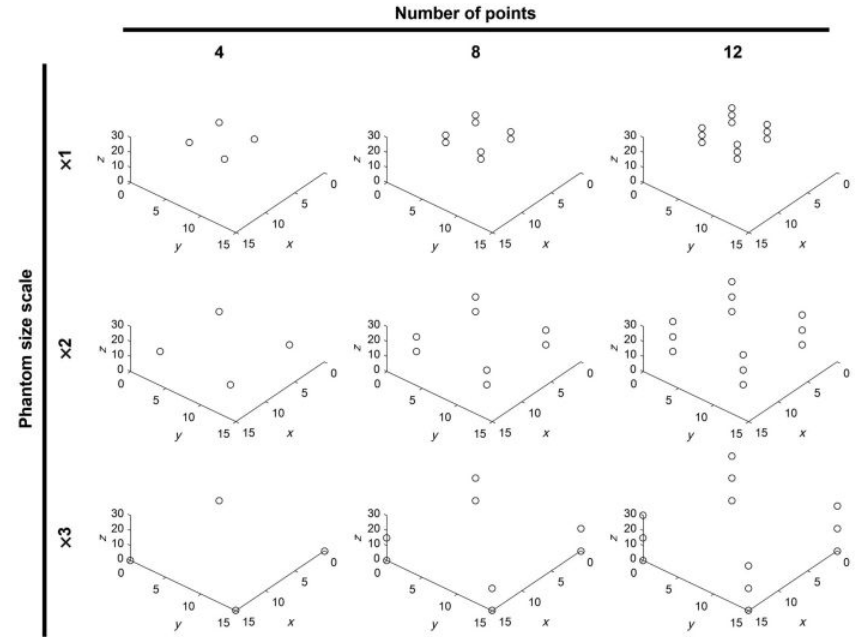


Fig. 4 Simulated phantom design. Four points separated by 5-mm distance was regarded as the base, the size scale of phantom (1, 2, 3 times), and the number of points (4, 8, 12) were varied. The unit was mm.

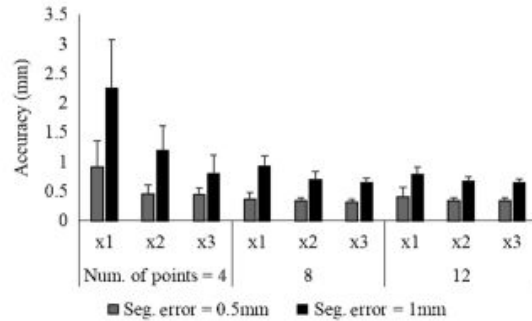
# Evaluation Method

- Calibrations were evaluated using accuracy and precision
- $c$  - ground truth point location

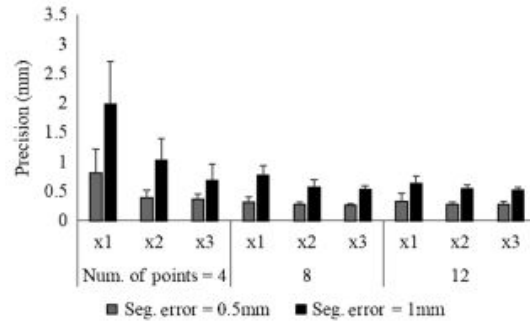
$$\sigma_{\text{Accu}} = \left\| \frac{1}{N} \sum_{i=1}^N (B_i X p_i - c) \right\|_2,$$

$$\sigma_{RP} = \left\| \sqrt{\frac{1}{N} \sum_{i=1}^N (B_i X p_i - \overline{BXp})^2} \right\|_2, .$$

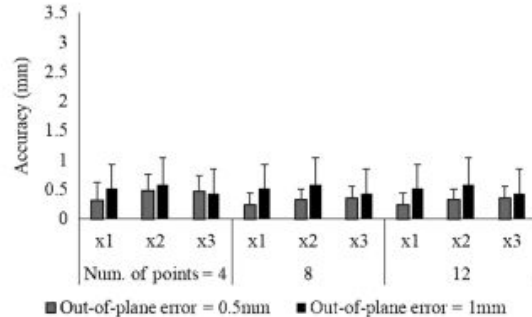
# Results



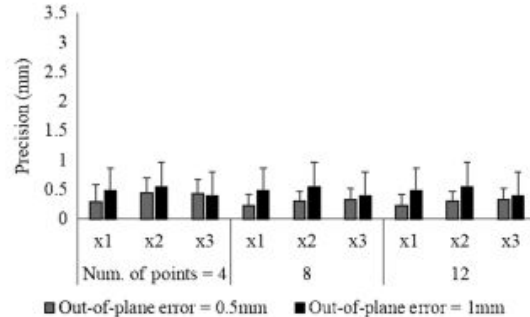
(a)



(b)



(c)



(d)

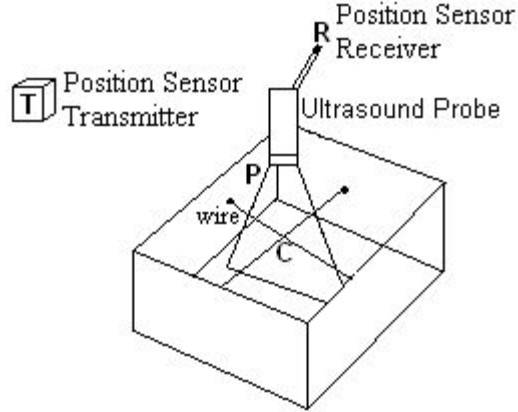
- Segmentation Error - error biases in image plane axes
- Out-of-Plane Error - error biases in the elevation axis

# Results

- Phantom size is very important for an accurate calibration especially when using fewer points.
- Number of points used has a minor, less crucial effect.

# Result: Comparison with Cross Wire Phantom

- Cross Wire Phantom:
  - Very easy to set up
  - Cheap
  - Good Calibration Performance



**Table 1** The experimental results.

Calibration		Internal precision $c$ (mm)	External precision $c$ (mm)
Dual array (biplane)	<i>BXp</i> Point #1	0.77	2.55
	<i>BXp</i> Point #2	0.68	1.56
	<i>BXp</i> Point #3	0.79	3.59
	<i>BXp</i> Point #4	0.66	2.60
	<i>AXXB</i>	0.60	0.67
Mono (1-D) array	<i>AXXB</i>	0.93	0.98
Control ( <i>BXp</i> ) <sup>14</sup>	<i>CW/AE</i>	1.72	—
	<i>AE/CW</i>	1.00	—

# Critical Review

## Strength:

- MAP phantom can improve calibration performance
- MAP phantom can decrease the data acquisition time by reducing the number of midplane detection processes necessary

## Weakness:

- The fabrication of a MAP phantom requires a special hardware setup
  - Multiple Active US elements with known geometric relationships

## Future work:

- MAP phantom can be simplified and integrated into a compact package

Theory	Materials/Methods	Results	Review
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# Takeaways

- MAP phantom provide a method to achieve high US calibration performance
- Evaluation method can be used to evaluate our US calibration performance
- Our project does not require high accuracy US calibration as we are using cameras to direct the movement of our robot
- MAP phantom calibration is probably outside of our scope, but we will keep in mind

Theory	Materials/Methods	Results	Review
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# References

- Zhang, H. K., Cheng, A., Kim, Y., Ma, Q., Chirikjian, G. S., & Boctor, E. M. (2018). Phantom with multiple active points for ultrasound calibration. *Journal of medical imaging (Bellingham, Wash.)*, 5(4), 045001.  
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