CIS II: Project No. 2
Synthetic Aperture Ultrasound Imaging with Robotic Tracking Technique

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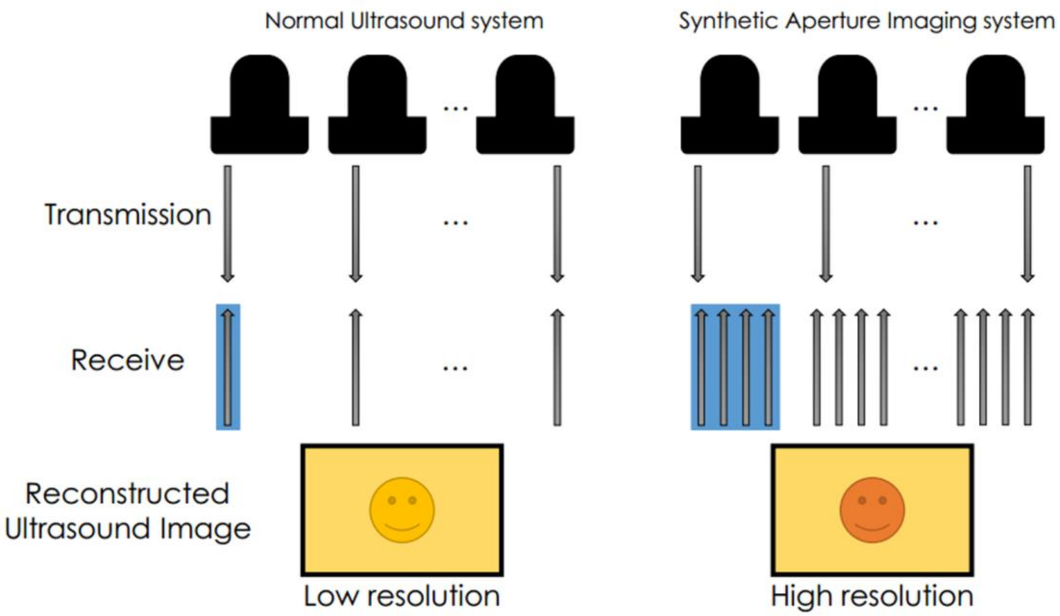
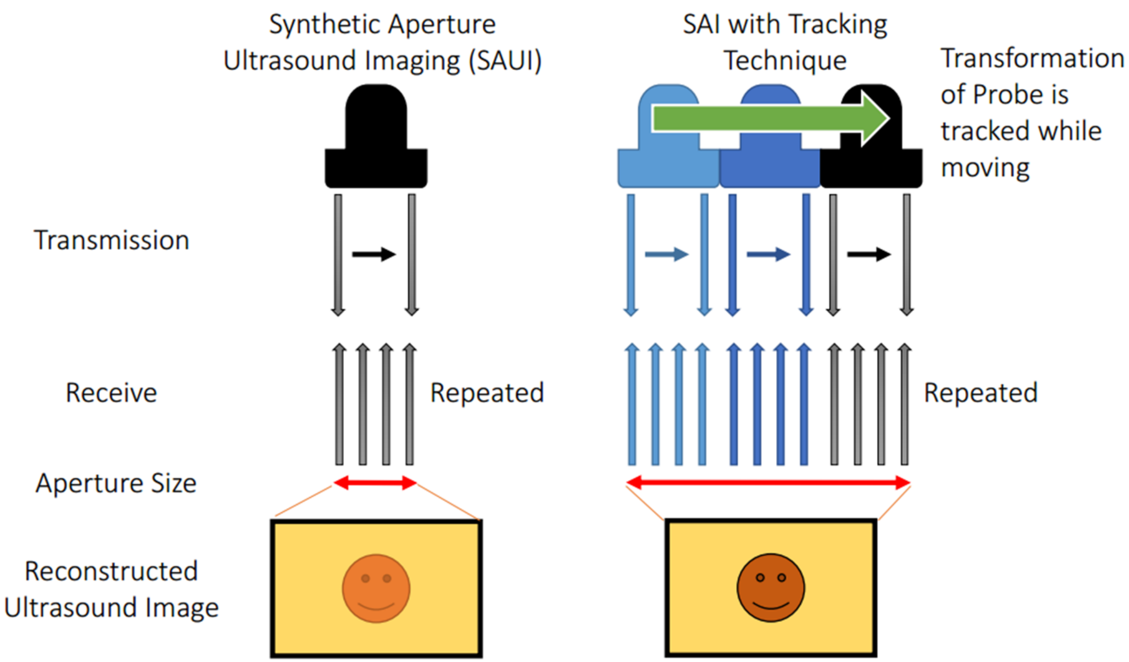
Checkpoint Presentation II

Project Background

- Aim: combine robotic tracking technique into synthetic aperture ultrasound imaging and to achieve higher resolution images
- Synthetic apertures improve the resolution of deep sight by utilizing expanded aperture size. The robotic tracking system can generate imaginary elements, which eventually expand the aperture size even more
- During the process, we also would work for inventing a new ultrasound calibration method with sub-millimeter error, which is necessary to reach our goal.



- While using synthetic aperture:
  - The performance is still restricted by physical limitation of the number of elements.
  - The approach of this project is to take away the limitation of aperture size by tracking the ultrasound transducer
- The performance of reconstructed synthetic aperture images is depending on the accuracy of the transformation between images and the probe.
- In order to move the probe for a designated position, unknown rigid-body transformation on the transducer from sensor to image needs to be calibrated. -> ultrasound calibration
- We aim to improve the tracking accuracy using robot and create a new ultrasound calibration method to utilize accurate transformation from probe to image.



Technical Summary of Approach

- Development of a new ultrasound calibration technique
  - Ultrasound calibration utilizing trajectory of moved phantom
  - Active echo ultrasound calibration
- Short-cut confirmation using active-echo
  - Simulation
  - Experiment
- Final combination:
  - Synthetic aperture using tracked transducer

Simulation

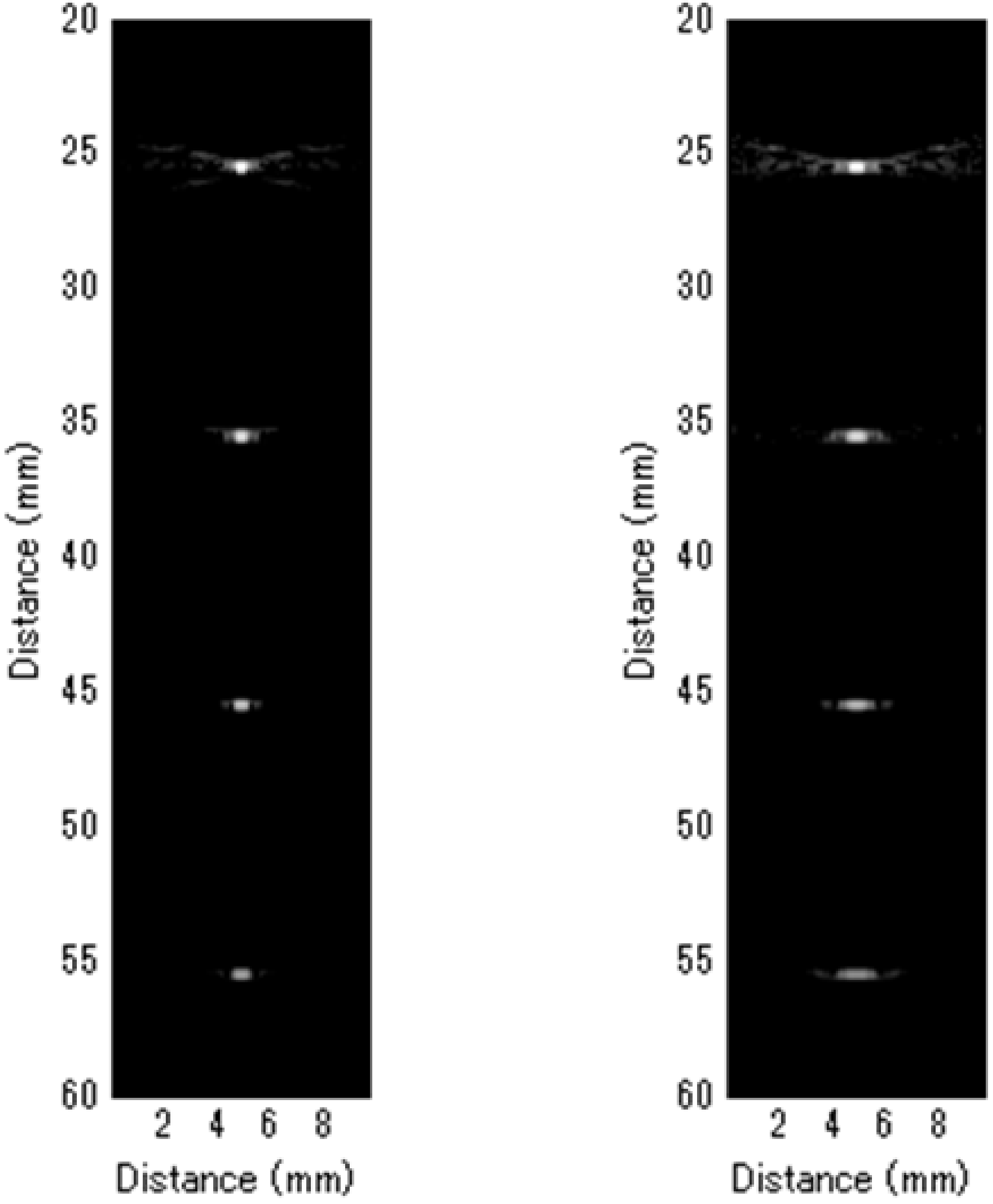
- Software:
  - Field II (used within Matlab)
- Designed point sources in different depths for imaging
- Designed a 64-element linear transducer array
  - 0.15 mm pitch size
  - Corresponds to 9.6 mm transducer (single pose)
  - Using 2 poses: 19.2 mm transducer
- The number of active elements used for both transmission and reception is set to one to simplify the analysis

Multiple poses

- The pre-beamformed data is split from the middle to simulate different signals taken from different poses of the robot arm, moving in the lateral direction perpendicular to ultrasound beam
- Point scatterers are designed so that each identical target is aligned in the axial direction and placed equidistantly in the axial direction (25 mm, 35 mm, 45 mm, and 55 mm) to observe the effect of imaging depth on the resolution
- To imitate possible uncertainty resulting from the robot movement, small displacements with a range of different magnitudes in axial and lateral directions are added to the right half of the pre-beamformed data before the resulting image with higher resolution is constructed

Result

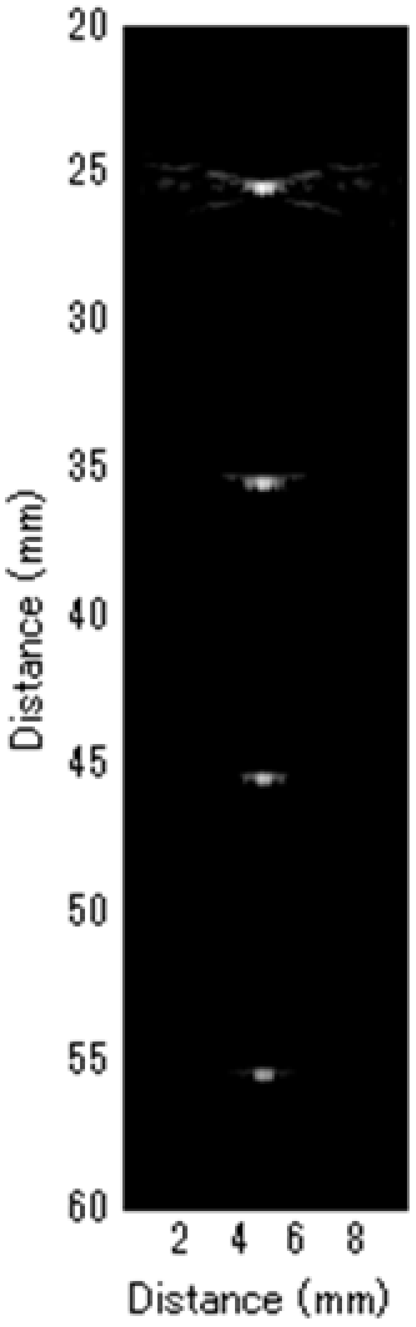
- The imaging quality of scatterers has improved distinguishably in the case of two-pose reconstruction without any uncertainty for all imaging depths

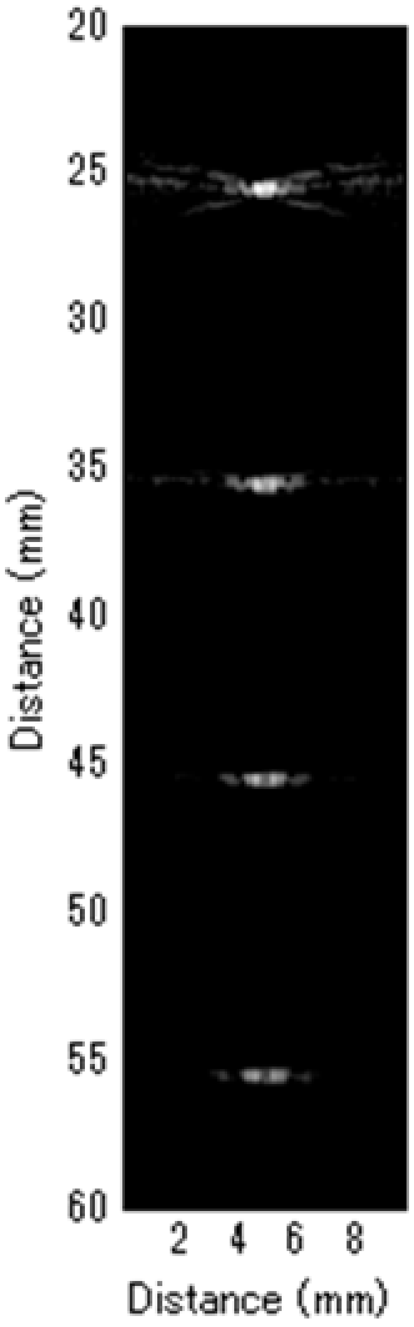


Figures:
(left) R-SAF with no uncertainty
(right) SAF with no uncertainly

Result

- Introducing different amounts of uncertainty to the reconstruction of the two-pose data did not have a significant effect on the resolution





Figures:
(left) R-SAF with 0.15 mm displacement on lateral direction
(right) R-SAF with 0.15 mm displacement on axial direction

- The extent of blurring of the target is expressed as the number of pixels counted over -16 decibel, which is based on the assumption that the more the target is blurred, the more pixels show up on the image at certain threshold
- The condition without any uncertainty is set to a grand truth, so that the size under different uncertainty is expressed in percentile compared to the grand truth
- The result tells us that the uncertainly can be accepted to some extent, and it can be seen that the proposed method is much patient to the uncertainty on lateral direction compared to axial direction

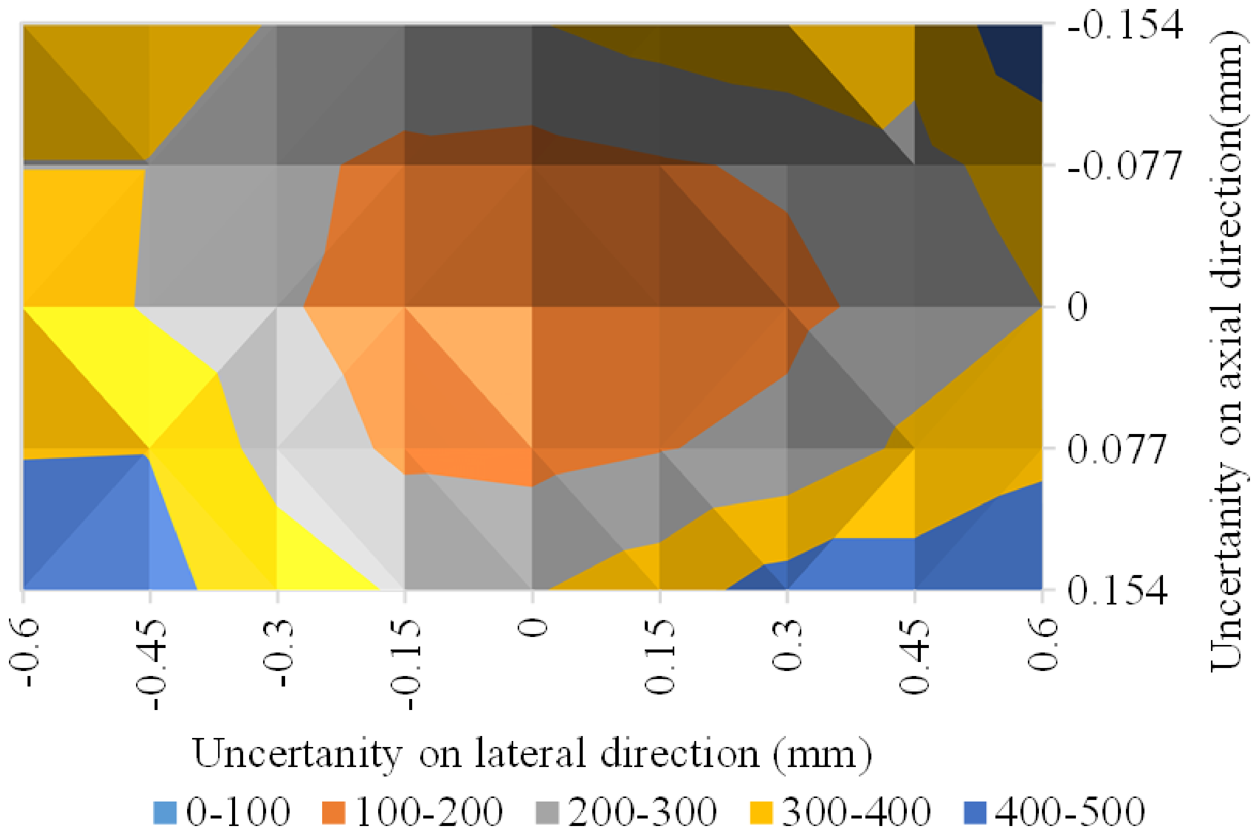


Figure:
The effect of uncertainty to the size of reconstructed target. The magnitude represents the percentage compared to the size without uncertainty

Experiment

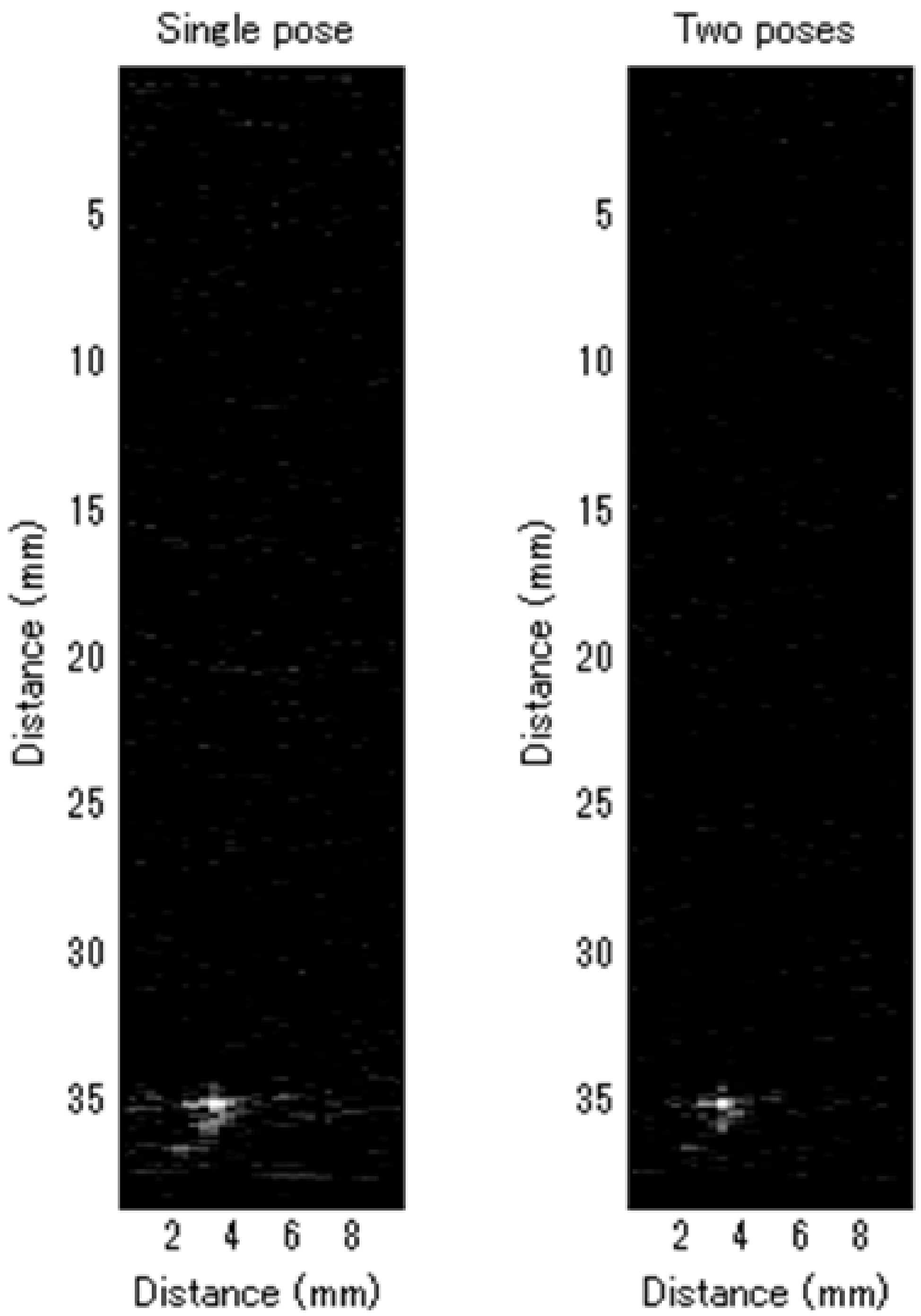
- Universal robot (UR5, Universal Robot) was used to move the transducer
- Pre-beamformed RF signals were collected from clinical ultrasound machine (Sonix Touch, Ultrasonix Inc.) using DAQ device
- A point target is placed in a water tank at 3.5 mm depth
- A 38.4 mm L14-5W transducer with 128 elements is prepared and the center 32 elements (9.6 mm) are used to easier the comparison toward our proposed method

Multiple Poses

- For single pose case, the target is located at the center toward the transducer, while 19.2 mm aperture was generated by sweeping the probe for left -4.8 mm to right +4.8 mm relative to the center position of single pose
- One directional lateral translation
  - Two rotations were aligned using active-echo element
  - Active-echo element system tells the mid-plain of ultrasound transducer as well as the depth of the element, so two relative rotations of the probe to the robot end effector is manually aligned to fit to the robot-based coordinate

Result

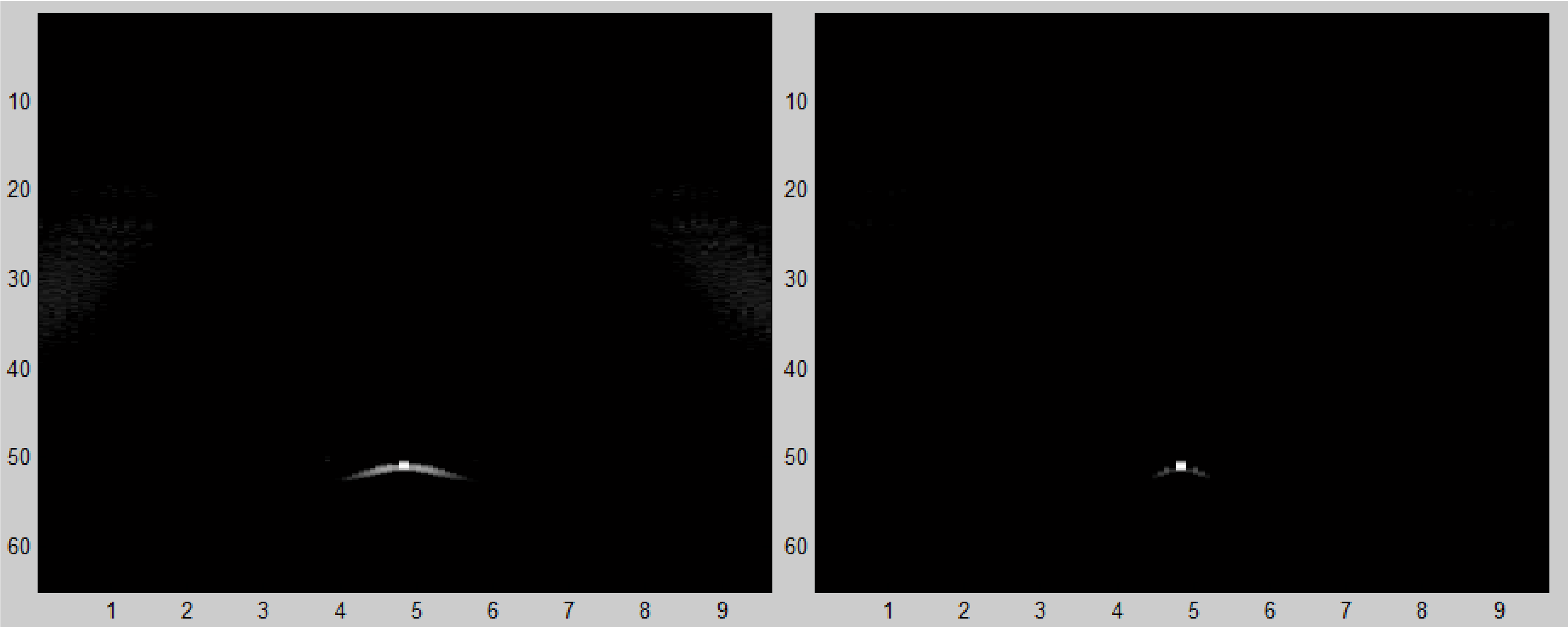
- The lateral resolution of R-SAF is observed to be better than SAF by comparing the width of target at 3.5 mm depth



Synthetic Aperture: Multi-Element Receive

- Point phantom in simulation
- Single pose

Figures:
(left) Single SA reconstruction
(right) Multi SA reconstruction



Summary

- From the result of simulation, we can see that uncertainty of the lateral resolution is not really problematic compared to the axial resolution because axial resolution is sensitive to the center frequency of transmission
- To overcome the uncertainly, image based correction is possible. If there is an overlap between displaced position data, the overlapping area should contain identical signals. Therefore, finding maximum normalized cross-correlation can be a way to predict possible fluctuation. If the uncertainty is predictable, it is possible to compensate for the displacement during the reconstruction process.

Deliverables

- **Minimum**: Expected by March 14 → Achieved March 19
  - Experimentally confirm the new calibration method is superior to segmentation based calibration
    - Achieved through active-echo calibration
  - Construct the design for SAUI w/ robotic tracking using active-echo system
- **Expected:** Expected by April 1 → Achieved April 7
  - Confirm SAUI w/ robotic tracking using active-echo system
  - Field II simulation of SAUI w/ robotic tracking
- **Maximum:** Expected by May 2
  - Implement SAUI w/ robotic tracking using calibrated transducer
  - Confirm the resolution improvement through phantom experiment
  - Finalized ultrasound calibration utilizing trajectory of moved phantom

Milestones (Complete)

- Confirm the performance of new US calibration utilizing moved phantom trajectory.
  - Planned Date: Feb 28, Finished Date: Feb 28
- Learn how to use active echo element
  - Planned Date: Feb 28, Finished Date: Feb 28
- Confirm the accuracy error of the new calibration method is better than segmentation based method.
  - Planned Date: March 7, Finished Date: March 1
- Understand synthetic aperture algorithm
  - Planned Date: Feb 28, Finished Date: March 11
- Initial Test of SAUI using active element
  - Planned Date: March 14, Finished Date: March 19
- Construct a simulation to test synthetic aperture imaging
  - Planned Date: April 1, Finished Date: April 7
- Build a connector to connect phased array probe and ultrasound machine
  - Planned Date: April 5, Finished Date: April 15
- Make an attachment for hold the probe with robot
  - Planned Date: April 5, Finished Date: April 15
- Connect probe to ultrasound machine
  - Planned Date: April 5, Finished Date: April 15
- Confirm resolution improvement by SAUI using active element
  - Planned Date: April 5, Finished Date: April 15

Milestones (Incomplete)

- Try generate SAUI using calibrated probe
  - Planned Date: April 11, Expected Date: May 2
- Confirm resolution improvement by SAUI using calibrated probe
  - Planned Date: April 18, Expected Date: May 2
- Achieve the accuracy error of the new calibration method in sub-millimeter.
  - Planned Date: April 18, Expected Date: May 2