SEMINAR PAPER PRESENTATION

Echospine: Developing an Ultrasound Assisted Lumbar Puncture Device

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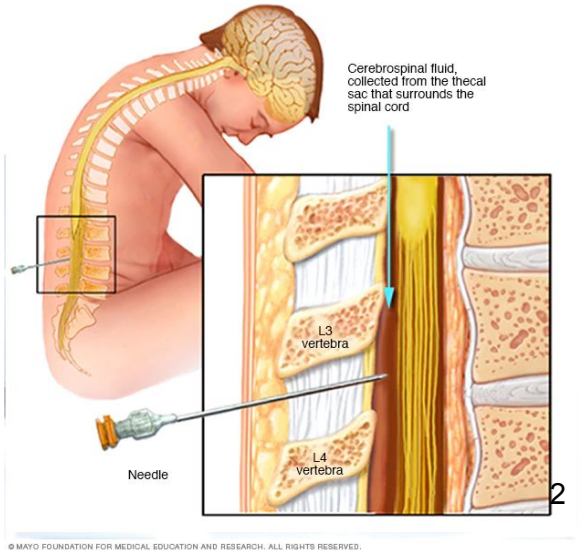
Review of Project Goals

- It is very important to verify needle position in lumbar puncture (spinal tap).
- Placement of a needle in the spinal column of obese patients without damaging anatomical structures is a challenging procedure, and **inaccurate needle placement can lead to complications that require the doctor to restart**.

We want to develop a low-cost medical device that can guide lumbar puncture using **real-time** ultrasound imaging to assist doctors in locating puncture points and **visualizing a needle** as it goes in for the most difficult cases.



Paper Selection

1. Haichong K. Zhang, Alexis Cheng, Nick Bottenus, Xiaoyu Guo, Gregg E. Trahey, and Emad M. Boctor"**Synthetic tracked aperture ultrasound imaging: design, simulation, and experimental evaluation,**" Journal of Medical Imaging 3(2), 027001 (8 April 2016). https://doi.org/10.1117/1.JMI.3.2.027001 ●

2. Zhang, Haichong K., et al. "**Toward dynamic lumbar puncture guidance using needle-based single-element ultrasound imaging.**" Journal of Medical Imaging 5(2), 021224 (Apr–Jun 2018) ●●

3. Zhang, H. K., et al. "**Single-element needle-based ultrasound imaging of the spine: An in vivo feasibility study.**" Simulation, Image Processing, and Ultrasound Systems for Assisted Diagnosis and Navigation - International Workshops, POCUS 2018, BIVPCS 2018, CuRIOUS 2018, and CPM 2018, Held in Conjunction with MICCAI 2018, Proceedings (pp. 82-89).●

4. Cheng, Alexis, et al. "**Fusing acoustic and optical sensing for needle tracking with ultrasound.**" Medical Imaging 2018: Image-Guided Procedures, Robotic Interventions, and Modeling. Vol. 10576. International Society for Optics and Photonics, 2018.●

● *Beamforming technique*

● *single-element ultrasound guided lumbar puncture*

● *photoacoustic needle tracking*

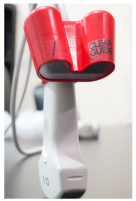
Commercial solutions

Rivanna Accuro

- Handheld device that automates image interpretation into a single phone-sized device
- Used pre-procedurally to find optimal location of trajectory

eZono eZGuide

- Uses magnetized needle & sensors to calculate needle trajectory
- Magnetizer may compromise sterility
- Optimal depth is less than 4 cm

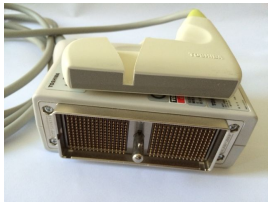


Clear Guide One

- Optical cameras attached to probe and computer vision to calculate needle trajectory
- Requires ≥ 4 cm length outside body
- Needle bending compromises accuracy

blind

registration error



Toshiba PLF-308P

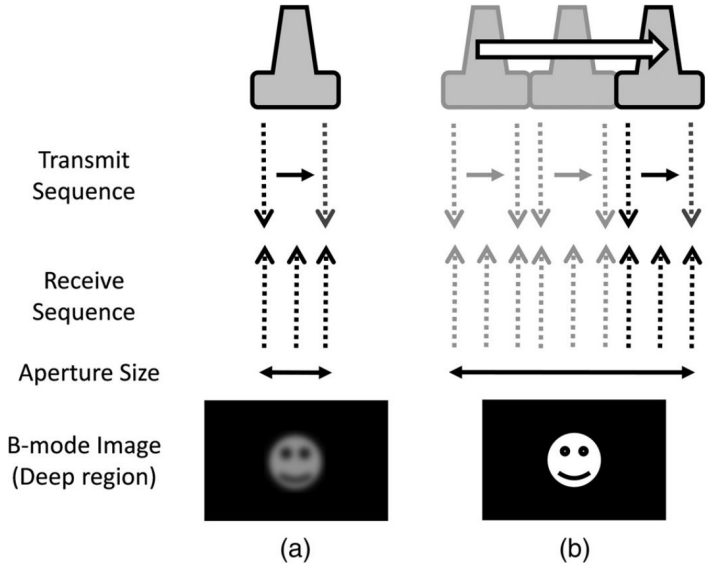
- Linear probe with a hole
- Geometrically limited
- Needs Toshiba machine

hard to see needle

Slide: Haichong (Kai) Zhang et al. Toward Dynamic Lumbar Punctures Guidance Based on Single Element Synthetic Tracked Aperture Ultrasound Imaging

Beamforming technique

Synthetic tracked aperture ultrasound imaging



- Deep tissue is hard to see
- Larger aperture size helps seeing deep tissue
- Synthetic aperture (transmit/receive using all elements simultaneously instead of one-by-one) helps but the aperture is still limited by physical probe size
- Move the ultrasound probe to simulate an aperture larger than physical probe

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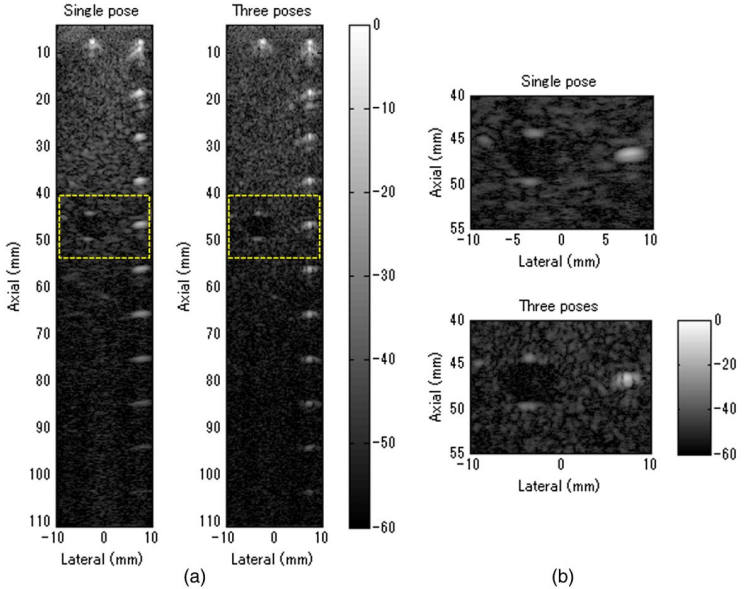
Results



Good

- **Improves deep tissue image quality with limited hardware**

Bad

- **No probe rotation**

Haichong K. Zhang, Alexis Cheng, Nick Bottenus, Xiaoyu Guo, Gregg E. Trahey, and Emad M. Boctor"Synthetic tracked aperture ultrasound imaging: design, simulation, and experimental evaluation," Journal of Medical Imaging 3(2), 027001 (8 April 2016). https://doi.org/10.1117/1.JMI.3.2.027001

Backpropagation-based STAF

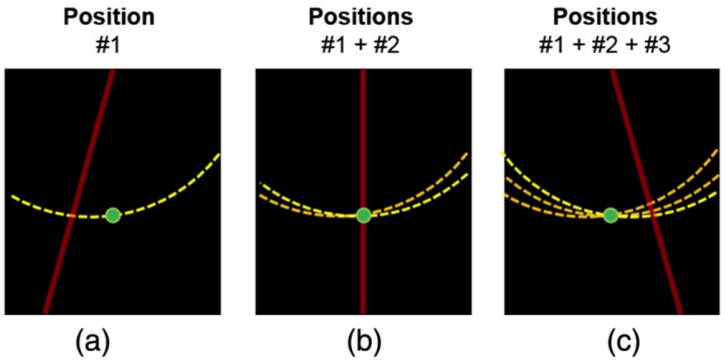


Fig. 3 The backpropagation reconstruction process corresponding poses #1, #2, and #3. (a) A-line data, highlighted in red, from position #1 was backpropagated. (b) Position #2 was backpropagated and summed on the left image. (c) Positions from #1, #2, and #3 were backpropagated and summed. The yellow line represents the back-propagation geometrical loci of a point target (green dot).

Good

- **Real-time B-mode image update mitigates frame rate issue**

Bad

- **Only works with uniformly-spaced A-lines**

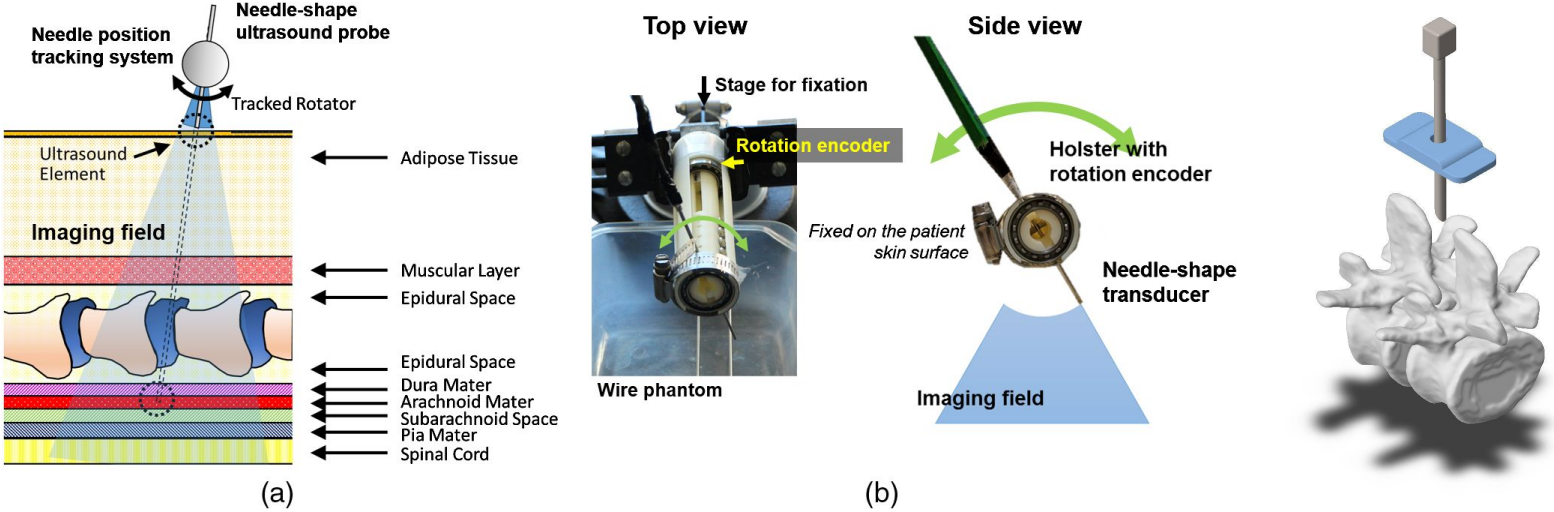
For our project

- **We need faster parallel implementation**
- **We need to account for non-uniform A-line spacings**
- **We work with transmit and receive element in different locations**

Zhang, Haichong K., et al. “Toward dynamic lumbar puncture guidance using needle-based single-element ultrasound imaging.” Journal of Medical Imaging 5(2), 021224 (Apr–Jun 2018)

single-element ultrasound guided lumbar puncture

MUSiiC previous work: put “eyes” on the needle



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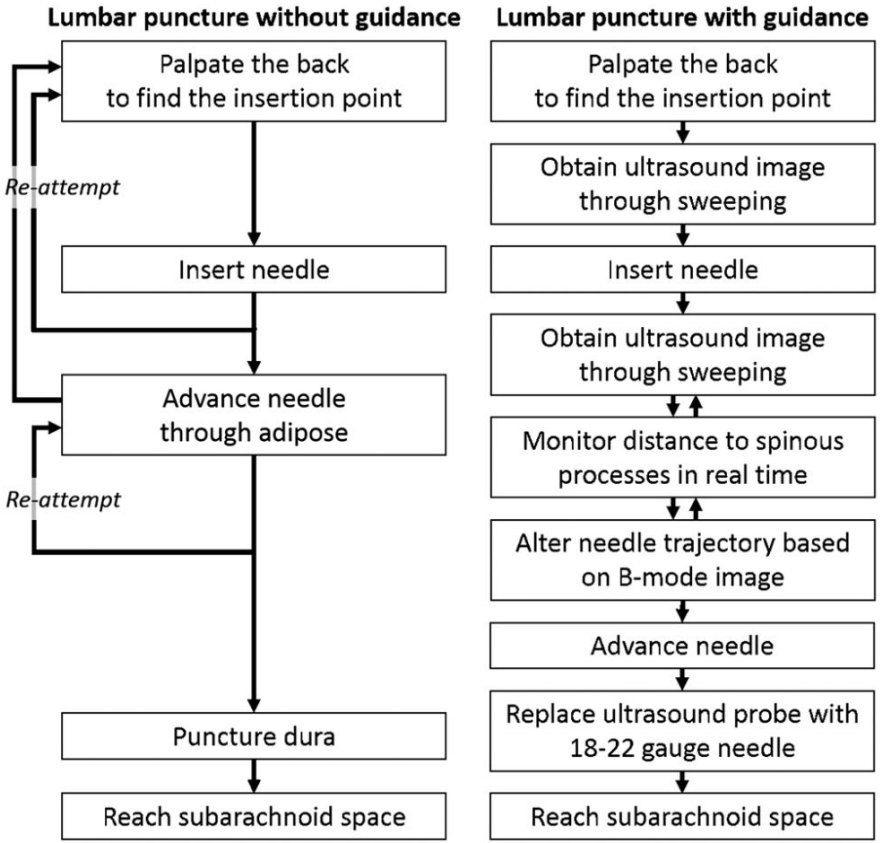
Clinical workflow



Error analysis

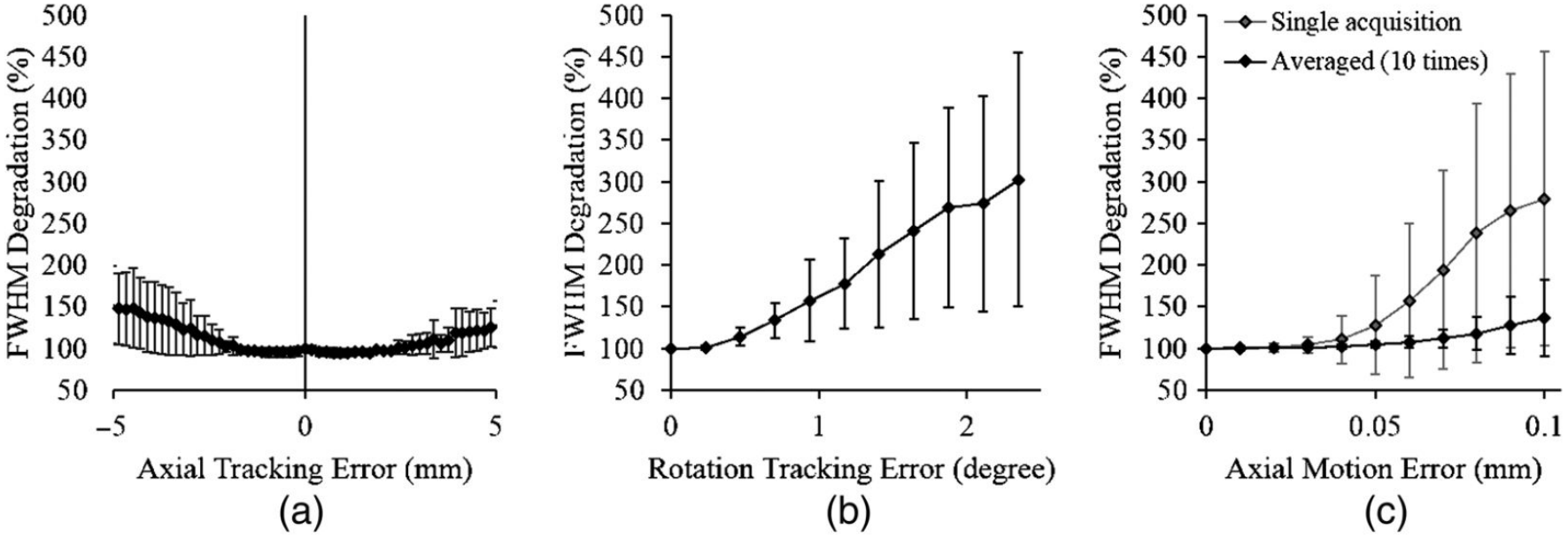
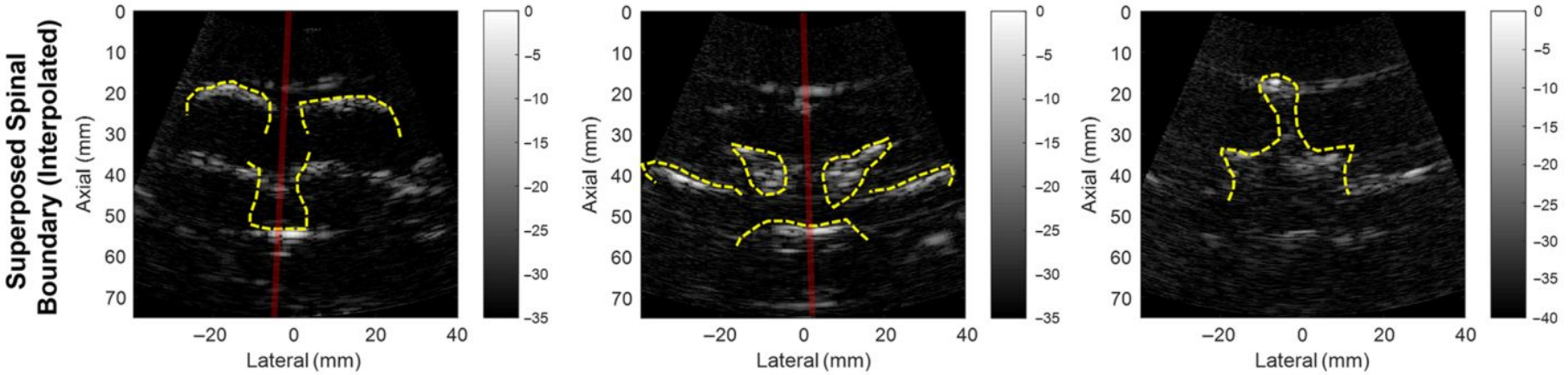


Fig. 7 The full-width at the half maximum (FWHM) of the point targets for different error sources. (a) The resolution in the presence of error in axial direction for entire channel data, (b) the resolution in the presence of error in rotational angle tracking, and (c) the resolution in the presence of error in axial direction for each receive line.

Results



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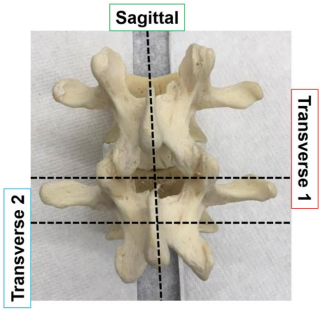
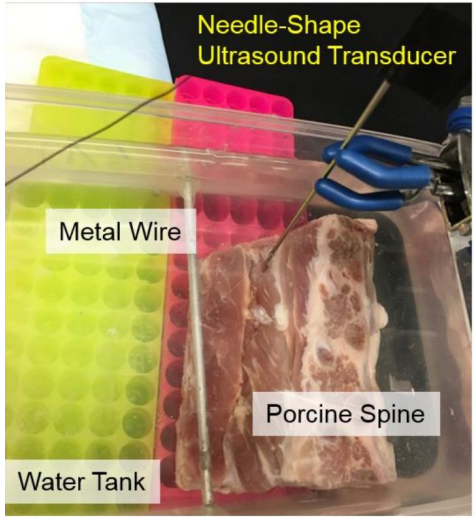


ex vivo + in vivo study



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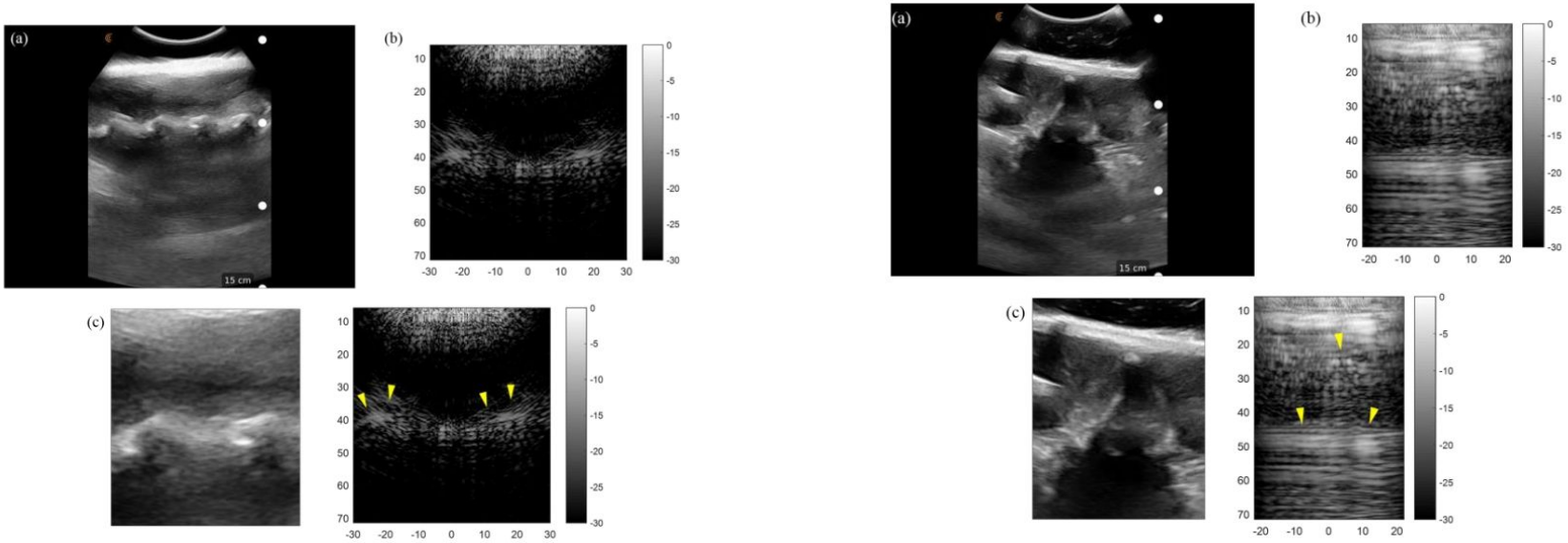

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Assessment

Good

- Innovative approach to track needle registration-free
- Proved the feasibility of using a single element ultrasound to pre-op image the spine

Bad

- No intra-op imaging
- Image quality sensitive to needle position/angle measurement error
- Needle position measurement error sensitive to needle bending

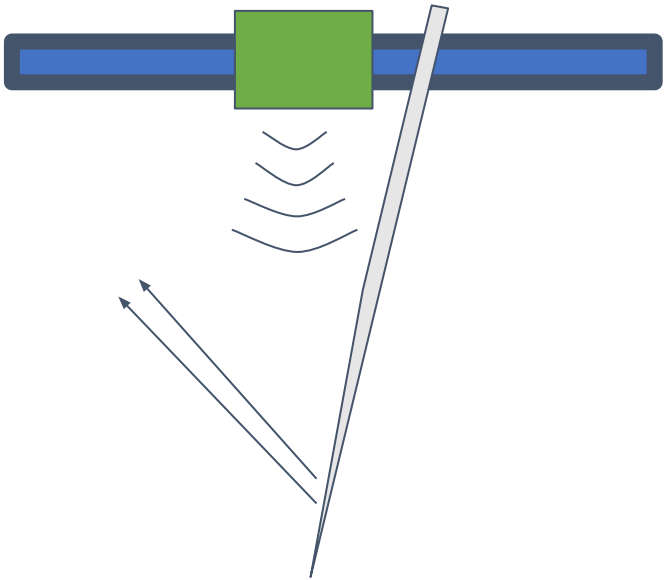
For our project

- We move the imaging element out of the needle to provide intra-op imaging
- We move the element linearly to circumvent angle measurement
- We keep the acoustic source in the needle for registration-free tracking

photoacoustic needle tracking

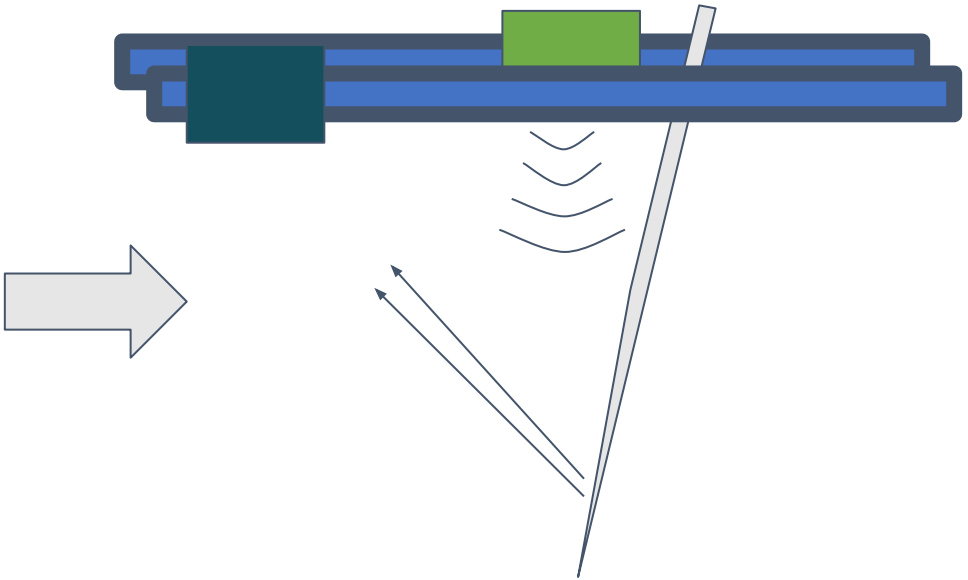
Needle Tracking

Ultrasound Probe - SIDE VIEW



(SPINE REGION)

Ultrasound with second rail- SIDE VIEW



(SPINE REGION)

Photoacoustic Effect

- It refers to the generation of acoustic waves by the absorption of electromagnetic energy, such as the light from a pulsed laser beam

- Active point sources are generally straight-forward to segment from ultrasound images because they either have higher intensity than the background or the ultrasound system can be configured such that there is no acoustic transmission and hence no background.

1. Cheng, Alexis, et al. "Fusing acoustic and optical sensing for needle tracking with ultrasound." *Medical Imaging 2018: Image-Guided Procedures, Robotic Interventions, and Modeling*. Vol. 10576. International Society for Optics and Photonics, 2018.

Results

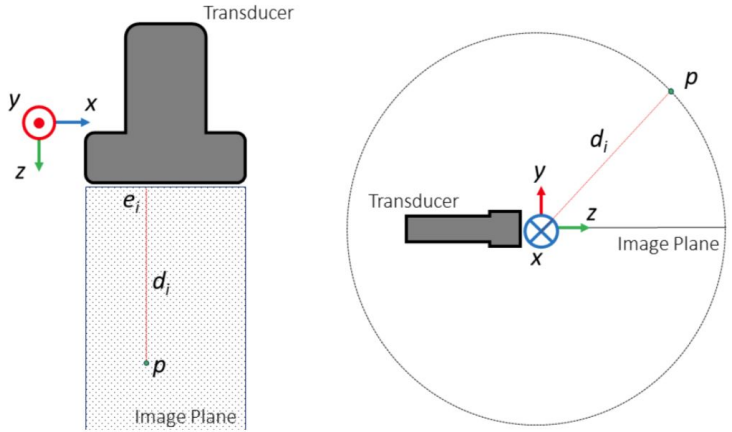


Figure 1. Out-of-plane estimation. Given the lateral coordinate and the distance between the point and the transducer element closest to it, the point must exist on a circle within the axial-elevational plane. [7]

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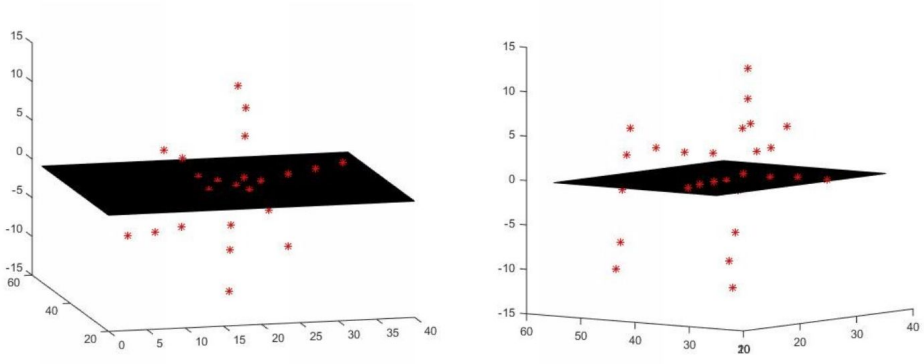

Figure 4. Subsets of detected PZT positions with respect to the ultrasound image plane (black plane).

Good

- Submillimeter Errors
- The relative accuracy measure had a minimum, maximum, mean, and standard deviation of 0.02mm, 2.15mm, 0.61mm, and 0.61mm respectively.

Bad

- Used a tool, not a needle

For our project

- Need to account for bending
- We need to manufacture the needle

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Photoacoustic Tracking

- It is possible to insert a fiber optic cable or attach an LED to the needle tip.
- Pairing a piezoelectric sensor at the tip with an ultrasound transducer it would be possible to build a system that can both see and hear the needle tip .
- By spatially combining the geometrical loci from the two sensors using an ultrasound calibration process, one can uniquely determine the location of the piezoelectric sensor.

Because they are on rails, only two transducers are required to **triangulate** the needle position

Questions?