# Echospine

**Members and Mentor:**
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Mentor: Emad Boctor

**Project Goal:**

The objective of this project is to develop a registration-free needle insertion assistance device for the lumbar puncture that displays the real-time pre- and intra-operative in-plane image and visualizes the position of the needle. The device targets point-of-care application and require clinical workflow compatibility and cost-effectiveness.

**Background & Impact:**

Lumbar puncture (spinal tap) is the process by which physicians insert an epidural needle between the bone structures of the vertebra in order to collect cerebrospinal fluid. A lumbar puncture can help diagnose serious infections, such as meningitis; other disorders of the central nervous system, such as Guillain-Barre syndrome and multiple sclerosis; or cancers of the brain or spinal cord. However, physicians must avoid blood vessels, nerves, and bone without visibility. The physician palpates to locate the interspace between L2-L3, L3-L4, or L4-L5, then inserts the needle slightly cephalad into the interspace. The physician slowly advances the needle until they sees the fluid return. The position and angle to insert the needle are especially difficult to determine on obese patients. Error in the position and angle of the needle results in reattempt and sometimes complications. Conventional ultrasound guidance requires the practitioner to search for the gaps between vertebrae using an ultrasound transducer, mark insertion point, then insert blindly.

Commercial solutions include Rivanna Accuro, eZono eZGuide, and Clear Guide One. Rivanna Accuro integrates the ultrasound probe with a skin marking tip. The physician uses the ultrasound imaging to locate the insertion point, then uses the marking tip to mark the insertion point on the patient skin. The physician then inserts the needle with the same blind procedure as the palpation-based method. eZono eZGuide has a magnetic sensor fixed to the ultrasound probe that tracks the position of a magnetized needle. Clear Guide One is an attachment for an ultrasound probe that tracks the needle with cameras. Both eZono EZGuide and Clear Guide One are sensitive to registration error between the needle tracker and the ultrasound probe, which can be exacerbated by needle bending. Both of these systems require the physician to hold and actively position the ultrasound probe before and during needle insertion, which distracts the physician from needle insertion.

Zhang et. al. presented a single-element approach to needle guidance in the lumbar puncture. They attached a single PZT element at the tip of the needle. By tracking the position of the needle with a rotary encoder and synthetic aperture beamforming A-scans with position data, their needle mimics a curvilinear array that is capable of obtaining a pre-operative image of the spine. The single element approach eliminated the registration problem by using the same ultrasound modality for both visualization and localization. By reducing the number of elements, the cost of the system can be greatly reduced, which promotes accessibility in point-of-care applications. However, their proposed system is unable to image intra-operatively, which is critical for the visibility of the procedure.

## Technical Approach

In our work, we will extend upon the single element ultrasound needle guidance system proposed by Zhang et. al. To maintain image update during needle insertion, we move the imaging element out of the needle onto two parallel rails that are parallel to the image plane. We will continue to use the backpropagation-based synthetic tracked aperture focusing, which mitigates the low frame-rate problem by updating the image as soon as each new A-line is acquired. To address the low visibility of the needle in B-mode image, we will keep an ultrasound source (PZT/PA) on the tip of the needle to enable triangulation with the ultrasound elements on the rails. Each of the rails contains one large (5mm dia) and sensitive ultrasound element with 5 MHz center frequency or a low-element-count (~8) array facing the skin of the patient. The rails are parallel to the spine and centered on the midline of the patient. The element or array can move in 1 degree of freedom.

**Deliverables:**

Below is the timeline for our minimum, expected, and maximum deliverables

- Minimum: (Expected by 4/12/2019)
    1. Documentation: Image Collection and Position Sensing Software
    2. Documentation: Schematics of Rail and Moving Parts
    3. Documentation: Selection of ideal Ultrasound configuration
    4. Image of Spine Phantom
- Expected: (Expected by 4/26/2019 )
    1. Documentation: Video & Pictures of Needle Insertion
    2. Demo of insertion into spine phantom
- Maximum: (Expected by 5/15/2019)
    1. Documentation: Design of FPGA-based ultrasound transmit/receive interface
    2. Documentation: Needle Tracking Software
    3. Tool tracking of needle tip insertion
    4. Animal Demo

**Key Dates/Milestones:**

Milestones

To produce the above deliverables, these milestones I'd like to reach by certain dates.

- Initial Design Sketch (3/1/2019)
- Documentation of Specifications and Conceptual Design (3/6/2019)
- Choice of compatible ultrasound system (3/8/2019)
- Rail Construction (3/25/2019)
- Output ultrasound image pattern (4/12/2019)
- Working prototype that meets specified specifications (4/26/2019)
- Documentation of working prototype (5/1/2019)
- Documentation of Data (5/5/2019)
- Final Report and Presentation (5/15/2019)

**Dependencies:**

| Level of Deliverable Affected | Dependency | Proposed Solution | Important Dates | Alternatives | Status |
|---|---|---|---|---|---|
| Minimum | Financial Resources | Provision by MUSiiC lab | Need by 2/21/2019 | Personal funds | Resolved as of 3/8/2019 |
| Minimum | Mentorship | Weekly meetings if possible, availability upon need | Need by 2/21/2019 | Rely on papers and online literature | Have met with all mentors by 2/28/2019 |
| Minimum | Spine Phantom | CIRS spine phantom | Need by 3/29/2019 | Create the phantom ourselves | Resolved |
| Minimum | Rail machinery and equipment | Construct with components from vendors | Need by 3/29/2019 | Adapt existing tools from the lab space | Not yet resolved |
| Minimum | Ultrasound Transducers and compatible algorithms | Provision by MUSiiC lab | Need by 2/21/2019 | Purchase through external company | Partially resolved as of 3/7/2019 |
| Minimum | Imaging Software and Interface | Provision by MUSiiC lab | Need by 2/21/2019 | Develop internally | Not yet resolved |

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| Expected / Maximum | Needle and tip element | Purchase components | Need by 2/21/2019 | Use probe tool for insertion | Not yet resolved |
| Maximum | Needle position tracking using ultrasound methods | Purchase components | Need by 4/25/2019 | Develop photoacoustic method | Not yet resolved |
| Maximum | Animal Protocol Approval | | Need by 4/25/2019 | Continue work with phantom | Not yet resolved |

**Management Plan:**

Meeting with Emad: ad-hoc + weekly lab meeting
Weekly meeting: Tuesdays 2:45-4:45pm
Communication: text and email
Code storage: LCSR Git

**Reading List:**


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.