Project Title: Accuo - Real Time Needle Integrated Ultrasound Imaging
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Goal:

The system we will be improving consists of a single disc shaped PZT element mounted to the tip of a 14G lumbar puncture introducer needle. The system creates a B-mode image by pulsing the element while sweeping it through tissue and tracking its angular position. The goal of this project is to improve three elements of the real time ultrasound imaging system. By the end of the semester, I hope to integrate the beamforming algorithm and scan conversion for real time imaging, improve the speed of the system by basing the whole system on C++, and adding depth tracking to the device.

Importance:

The lumbar puncture (LP) is a clinical diagnostic technique involving the collection of cerebrospinal fluid (CSF) from the subarachnoid space in a patient. In order to successfully collect CSF, clinicians have to blindly yet accurately navigate a needle through the L3-L5 intervertebral space, epidural space, dura mater, and arachnoid mater whilst avoiding nerves, blood vessels, and bone. More than 400,000 LP's are performed annually but nearly 23.3% end in failure due to the myriad of challenges. These failures lead to misdiagnoses, treatment delays, and subsequent unnecessary and dangerous follow-up procedures. Patients with abnormal spinal anatomy and excess adipose tissue between skin and target structure, namely scoliotic and obese patients, suffer a significantly increased probability of LP failure.

Technical Approach:

As this is an improvement on a device rather than the creation of one, the technical approach is dependent on what can be integrated into the current instrumentation. In addition, this project largely software based and as such will consist mostly of algorithm creation, language translation, and cross correlation for depth tracking. The algorithm will be used to link the beamforming and scan conversion parts of the software. Mechanical or optical solutions to the depth tracking problem will also be explored in the event that cross correlation is not well suited for this application.

Deliverables:

1. A C++ translated script which can perform faster than the current Matlab one. (Minimum)
2. A real time beam formed, scan converted image from the system. (Expected)
3. Ability to track depth and overlay position of needle onto initial B-mode image. (Maximum)

Estimated Dates of Task Completion:

1. C++ integration (In parallel with below code)
2. Beamforming and Scan Conversion
    a. Understand the Code (3/1/17)
        i. Beamforming (2/27/17)
        ii. Scan Conversion (3/1/17)
    b. Able to implement Existing algorithm (3/6/17)
    c. Study Literature (3/13/17)
    d. Add real time scan conversion visualization in matlab (3/17/17)
    e. Backprojection reconstruction (3/24/17)
3. Depth Tracking
    a. Take images of wire phantom (3/31/17)
    b. Attempt to use cross correlation to discern depth (4/6/17)
    c. Fabricate needle with side shooting element (4/13/17)
        i. Or mechanical tracking (4/20/17)
        ii. Or optical tracking (4/20/17)
    d. Integrate side shooting signal into algorithm (4/30/17)

Dependencies and Resolution Plans:

The largest unknown in this project is if depth tracking can be accomplished through cross correlation of the current A-line with the previous B-mode image. If this isn't possible with the spinal anatomy, then we will explore other methods of depth tracking. These options will be considered in more detail later on in the semester but include integrating a side shooting element into the device to better cross correlate with the B-mode image or at least give feedback on the

proximity of bone when in the interspinous space. Other possibilities include tracking depth mechanically with a linear encoder or optically tracking the needle.

Management Plan:

Weekly meetings with Kai and/or Younsu, weekly meetings with the rest of the undergraduate team (Saturday, 3hrs).

Reading List:

[1] Armon C., Evans R. W., "Addendum to assessment: prevention of post-lumbar puncture headaches," Neurology 65, 510-512 (2005).
[2] American Society for Healthcare Risk Management, "Risk Management Handbook for Health Care Organizations", Jossey-Bass, 5 (2009).
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[4] Shah K. H., Richard K. M., et al., "Incidence of traumatic lumbar puncture," Academic Emergency Medicine 10(2), 151-4 (2003).
[5] Ahmed S. V., Jayawarna C., and Jude E., "Post lumbar puncture headache: Diagnosis and management," Postgraduate Medical Journal 82(273), 713-716 (2006).
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[8] Engedal T. S., Ørding H., Vilholm O. J., "Changing the needle for lumbar punctures," Clinical Neurology and Neurosurgery 130, 74-79 (2015).
[9] Tamas U., Abolmaesumi P., Jalal R., Welch M., Ayukawa I., Nagpal S., Lasso A., Jaeger M., Borschneck D., Fichtinger G., and Mousavi P., "Spinal Needle Navigation by Tracked Ultrasound Snapshots," IEEE Transactions on Biomedical Engineering 59(10), 2766-72 (2012).
[10]Moore J., Clarke C., Bainbridge D., Wedlake C., Wiles A., Pace D., and Peters T., "Image Guidance for Spinal Facet Injections Using Tracked Ultrasound," Medical Image Computing and Computer-Assisted Intervention, (2009).
[11]Chen E. C. S., Mousavi P., Gill S., Fichtinger G., Abolmaesumi P., "Ultrasound guided spine needle insertion," Proc. SPIE 7625, 762538 (2010).
[12]Najafi M., Abolmaesumi P., Rohling R., "Single-Camera Closed-Form Real-Time Needle Tracking for UltrasoundGuided Needle Insertion," Ultrasound in Medicine and Biology, 41(10), 2663-2676 (2015).
[13]Wang X. L., Stolka P. J., Boctor E., Hager G., Choti M., "The Kinect as an interventional tracking system," Proc. SPIE 8316, 83160U (2012).
[14]Nagpal S., Abolmaesumi P., Rasoulian A., et al., "A multi-vertebrae CT to US registration of the lumbar spine in clinical data," Int. J. CARS 10(9), 1371-81 (2015).
[15]Jensen J. A., Nikolov S. I., Gammelmark K. L., Pedersen M. H., "Synthetic aperture ultrasound imaging," Ultrasonics 44(22), e5-e15 (2006).

[16]Zhang H. K., Cheng A., Bottenus N., Guo X., Trahey G. E., Boctor E. M., “Synthetic Tracked Aperture Ultrasound (STRATUS) Imaging: Design, Simulation, and Experimental Evaluation,” Journal of Medical Imaging 3(2), 027001 (2016).
[17]Bottenus N., Long W., Zhang H. K., Jakovljevic M., Bradway D. P., Boctor E. M., Trahey G. E., “Feasibility of Swept Synthetic Aperture Ultrasound Imaging,” IEEE Transactions on Medical Imaging 35(7), 1676-1685 (2016).