Moving Needle Segmentation Using Freehand Doppler Ultrasound

# Motivation

Previous work by Berkeley and Sarthak’s group has demonstrated ultrasound feedback for continuous control of steerable needles using robotic control of a 2D ultrasound transducer. In addition, Troy has shown feedback for incremental control of steerable needles using a 3D Doppler ultrasound transducer that is mechanically fixed over the needle. This work extends both these papers to ultrasound feedback for continuous control of steerable needles using 2D freehand Doppler ultrasound. This is arguably the most clinically relevant form of ultrasound feedback.

Sarthak and Berkeley’s implementations require a robot to control the ultrasound transducer which has been demonstrated for flat gelatin phantoms/chicken breast only. In a clinical environment, an ultrasound robot will be more difficult. The ultrasound robot will need to follow the curvature of the patient’s body, while also maneuvering to get an acoustic window in awkward ways. In addition, the ultrasound segmentation itself relies on the needle showing up as the brightest reflector in the B-mode image. Troy’s current version uses incremental insertions between ultrasound scans.

Both of these techniques run up against the problem that they are “shining a 2D flashlight on a 3D object”. The part of the needle we care about for closed loop control is the tip. However, there is no guarantee that the ultrasound image will contain the needle tip. Sarthak and Berkeley’s answer to this is to shine the light as best as possible on the tip. This is hard for a human to do, so they use a robot. Troy’s answer is to scan the flashlight across the entire needle each measurement so that he can determine where the tip is. The problem is that this slows the feedback rate down, which means that he uses incremental insertions.

This new technique allows continuous feedback of the needle tip with a 2D ultrasound transducer. It does not require that the needle tip is in the ultrasound frame. The key insight is that even if the ultrasound transducer is not over the needle tip, the measurement still provides information about the needle tip. If the ultrasound frame is past the end of the needle tip, this helps localize the needle axially since we know that the needle is further back than the ultrasound transducer. If the ultrasound frame is before the needle tip, it helps localize it axially because we know the needle tip is past the end of the transducer. Furthermore, we can project hypothesis needle tip position backward in time using the kinematic model to the point of the ultrasound measurement, thereby allowing us to use the measurement to judge which tip positions are more or less likely. This technique makes this rigorous using a Bayesian estimation scheme for needle tip state estimation. It is implemented using a particle filter. Needle tip orientation, position and radius of curvature are estimated.