Flexible Needle Shape Reconstruction based on FBG Sensors

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Percutaneous soft tissue needle interventions are standard for prostate cancer diagnosis and therapy. Clinicians must insert surgical needles into the suspected cancer region for biopsy, tissue sampling for cancer diagnosis, and for brachytherapy, radioactive seed placement for cancer therapy. Flexible bevel-tipped needles can be used to avoid obstacles between the insertion point and the target such as blood vessels, nerves, and bones. A bevel-tip needle will tend to bend in a direction opposite the bevel angle as it is inserted into tissue, and the orientation of the bevel can be modified with an axial rotation to adjust the trajectory of the needle as needed (Figure 1).

In order to accurately place a needle in tissue, it is desirable to track the needle during insertion. Recently, studies have shown the potential for Fiber Bragg Grating (FBG) sensors to estimate needle shape [1][2]. An FBG sensor is a strain gauge consisting of an optic fiber with a series of grated mirrors that reflect and collect a certain wavelength of visible light. When exposed to mechanical or thermal stresses, the distance between these mirrors changes, resulting in a shift in the wavelength of light that is collected. This shift in wavelength is proportional to the strain the fiber experiences [1]. Three fibers, each etched with multiple active areas with FBGs, are arranged along the length of our "Smart Needle" to measure bending strain at each of the FBG locations. The bending strain can then be used to estimate curvature at each of the three locations. Interpolation of the curvatures generated by the FBG sensors and double integration generates a 2D position profile of the needle for shape estimation. The FBGs work in real-time and are MRI compatible.

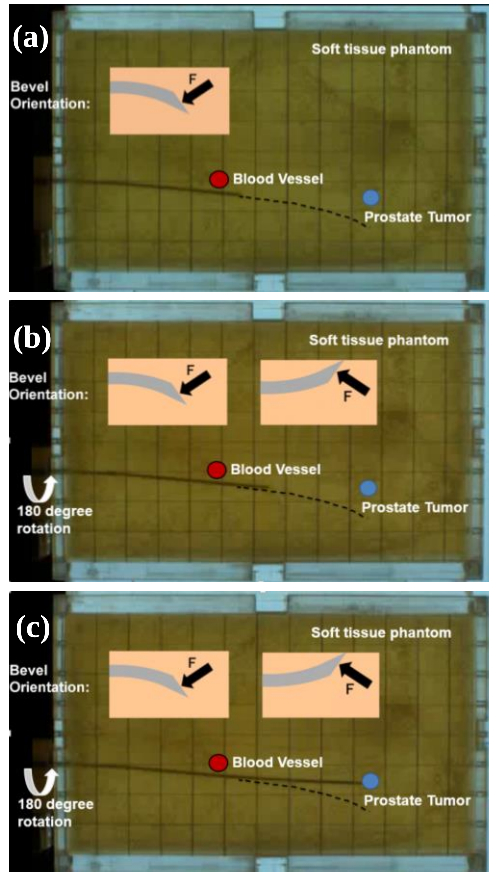

Figure 1: (a) An insertion with the bevel-tip oriented upward and a misaligned needle trajectory. (b) 180 degree axial rotation reverses the bevel angle. (c) The needle is fully inserted to the target.

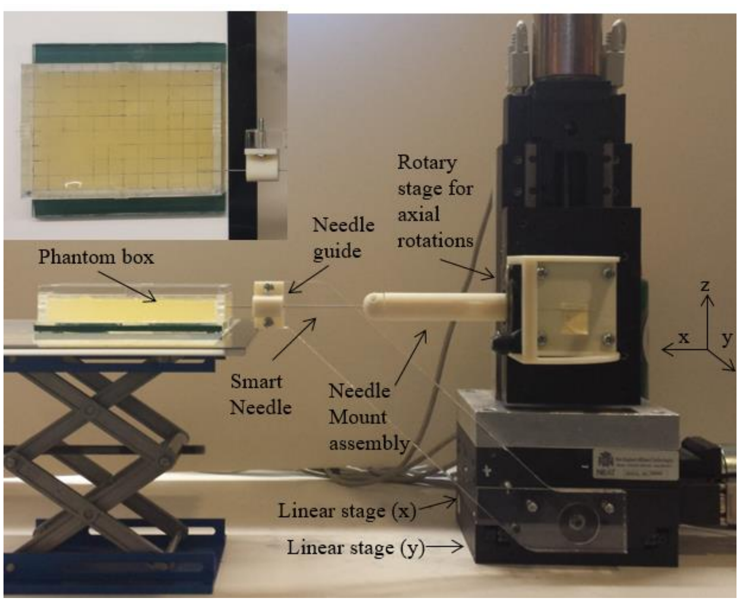

Figure 2: Soft phantom insertion setup

In this preliminary study, we showed that FBG-based needle shape reconstruction is viable for phantom gel insertions with up to one axial rotation. A second order polynomial fit curvature interpolation method was shown to estimate needle tip position for insertions with and without axial rotation with a mean error under 0.8 mm, for clinically relevant insertion depths from 20 to 90 mm. Maximum tip estimation error for all insertion depths was 1.2 mm for this reconstruction method. Future work to do be done includes needle steering experiments and the addition of the Smart Needle to an MRI-compatible robotic needle driver for automated target alignment, insertion and axial rotation.

[1] R. Seifabadi, E. E. Gomez, F. Aalamifar, G. Fichtinger, and I. Iordachita, "Real time tracking of a bevel tip needle with varying insertion depth toward teleoperated MRI guided needle steering," in Proc. IEEE/RSJ Int. Conf. Intell. Robots Syst., 2013, pp. 469–479.

[2] Roesthuis, R. J., Kemp, M., van den Dobbelsteen, J. J., and Misra, S., 2014, "Three-Dimensional Needle Shape Reconstruction Using an Array of Fiber Bragg Grating Sensors," IEEE/ASME Trans. Mechatron., 19(4), pp. 1115–1126.