Real-time needle tip tracking using Fiber Brag Grating sensors for MRI-guided prostate interventions: Design considerations

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Purpose: Needle tip tracking is a key element for precise targeting during prostate percutaneous interventions. Ideally, needle tracking should be performed under real-time MRI. However, limitations such as susceptibility artifacts, low image resolution, image acquisition time and image processing time have made this task challenging. We propose using optical strain gauge sensors for real-time needle shape/tip tracking.

Method: In our design, three channels will be cut into the inner stylet (0.6 mm) of a 20 G needle. Optical fibers with sensors will be placed at certain locations and imbedded into three needle channels. In order to find the optimal number of sensors and sensor locations along the optical fibers (see Fig.1), the estimated needle tip location was compared to the exact position of the tip attained from small deflection beam-column theory. This optimization was done for all possible force configurations by computer simulations in MATLAB, with the maximum tolerable error of 0.5 mm. Maximum deflection and insertion depth were 10 mm and 100 mm, respectively (max deflection <10% of needle length). In contrast to a previous study [1], we used a thinner "bevel" tip needle, which poses significant challenges in integrating the method in tele-operated bevel-tip needle steering for MRI-guided prostate interventions. We chose a 20G beveled needle, which is flexible enough for steering, yet has enough structural integrity and wall thickness for manufacturing. The tracking method is designed to be adaptive for varying insertion depths and two inflection points along the needle.

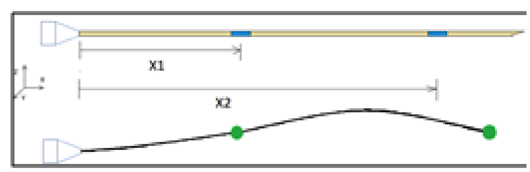

Fig. 1 – Illustration of sensor arrangement and two inflection point needle

Results: Simulation results with two sensors (Fig. 2) indicate the following. We expect an error of 0.67 mm when placed at optimal locations 45 and 67 mm for deep insertions, an error of 1.4 mm for low depth insertions (i.e. when only one sensor is active), and a maximum needle tip deflection of 3.3 mm at 33 mm insertion depths before any sensor can be activated.

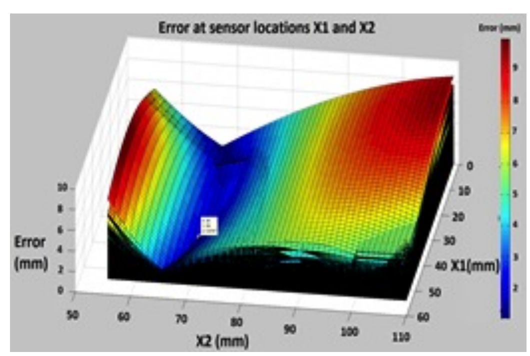

Fig. 2– "X" represents (x1, x2) optimal (45, 67) mm for maximum error of 0.61 mm

Conclusions: In order to achieve a position error threshold lower than 0.5 mm for both varying depth and force configuration, more than two are necessary. Further optimization for sensor location needs to be carried out. The needle and sensors will be fabricated and calibrated accordingly.

References: [1] Y.-L. Park *et al.*, "Real-Time Estimation of Three-Dimensional Needle Shape and Deflection for MRI-Guided Interventions," IEEE /ASME Trans. Mechatronics 15(6), (2010)