MRI-compatible Haptics: Feasibility of using optical fiber Bragg grating strain-sensors to detect deflection of needles in an MRI environment

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Introduction

The manipulation of catheters, needles and other minimally invasive devices to reach tumors and other targets is the initial step of nearly all MRI-guided interventions. To date, most research on MRI targeting has focused on using MR to image the target, and to plan the trajectory of interventional devices. During the subsequent manipulation, however, it is useful to track any deviation from the planned trajectory to minimize positioning error and procedural complications. Previous techniques for tracking devices include rapid MRI, MR-tracking [1] and gradient-based tracking ("Endoscout®", Robin Medical Inc). These methods are all limited because they require use of the MRI system during manipulation, require the device to be within the homogeneous volume of the gradient fields used for imaging, and because susceptibility artifacts from MRI-compatible metallic devices may cause distortions that lead to poor signal and/or inaccurate position information. The latter two tracking methods also require integration of an electronic apparatus into the interventional devices, which further increases device complexity including adding the need for appropriate patient isolation electronics.

Recently, miniaturized fiber-optic-based force and deflection sensors based on fiber Bragg grating (FBG) technology have been developed and integrated into robotics for force feedback [2] and endoscope design for shape detection [3]. FBG sensors reflect light with a peak wavelength that shifts in proportion to the strain to which they are subjected. Given that fiber-optic devices are inherently MRI-compatible, do not interact with the MRI process, and do not cause significant imaging artifacts, we hypothesized that FBG sensors may provide an ideal method of sensing the configuration and forces upon interventional devices in the MRI environment. FBG strain sensors can resolve strains as small as 0.1 micro-strain and multiple FBG sensors can be located along a single fiber and addressed via optical multiplexing. As an initial demonstration of the feasibility of using FBG devices in the MRI scanner, we investigated the ability of FBG sensors to detect the deflection of an MRI compatible needle. If successful, this apparatus could have immediate applications to improve MRI-guided percutaneous needle biopsy and brachytherapy, in which MRI is used to plan needle placement, but is limited due to needle deflections that commonly occur.

Prototype Development

A prototype was developed using a single optical fiber and an MRI compatible biopsy needle (22ga x 15cm). The FBG sensor was located close to the base, where strain is concentrated in bending. Figure 1(A) shows wavelength changes in force loading and unloading tests. Based on the plot the needle tip deflection can be calculated from the sensor signal (wavelength change). A small amount of hysteresis, due to the cyanoacrylate bonding, is evident. This effect can be reduced with alternative bonding methods under investigation.

Experimental Result

The initial experiments involved two and three point bending cases in two dimensions. The prototype needle was placed in a water bath and bent as shown in Figure 1(B). Based on the wavelength change from the attached FBG, the deflection of the needle was calculated. The MR image of the needle taken shows no artifact from the optical fiber (Figure 1(C)). The actual deflection (*d*) of the needle tip in the experiment is 30 mm and the estimated deflection (d_e) from the sensor signal is 33mm. More accurate measurement during the calibration and experiment will reduce the error.

Conclusion

This study shows that FBG sensors can be used to estimate the tip deflection of biopsy needles during MR imaging. The optical fiber with an FBG sensor did not produce any artifact on the images, and the sensor signal was not affected by the magnetic field. Ongoing work is exploring the use of multiple FBG sensors through optical multiplexing and improved bonding methods of the optical fiber to the needle. The next prototype with multiple sensors will be able to detect more complicated bend shapes in 3D.

References

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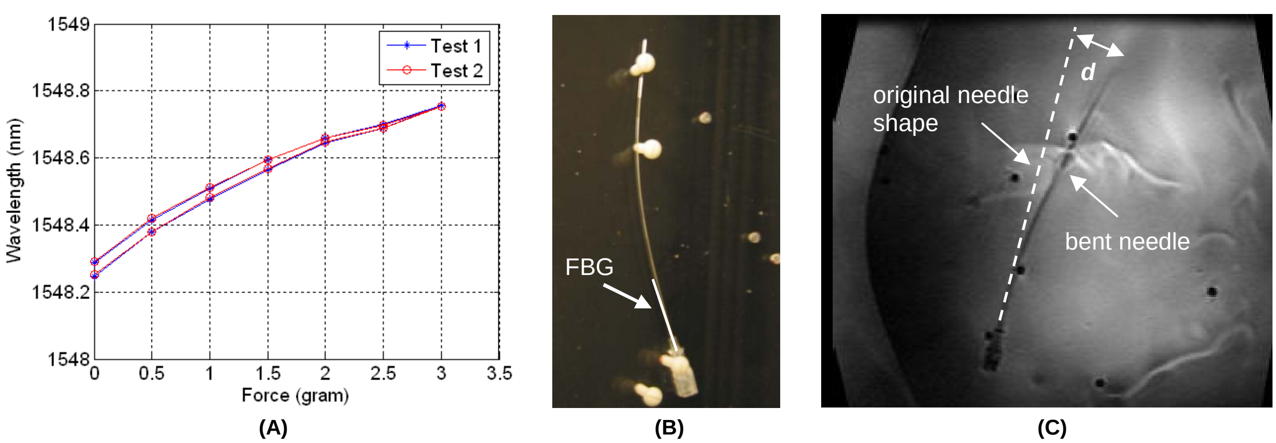

Figure 1. (A) Force loading and unloading test, (B) Bent needle with one FBG attached in a water bath, (C) MR image of bent needle showing no artifact from the attached optical fiber