Robot-assisted FBG-sensorized Needle Calibration

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Introduction

Fiber Bragg Grating (FBG) sensors can be implemented inside flexible hollow needles to reflect their curvatures in real time. Such needles often have multiple FBG fiber channels distributed uniformly against the inner wall of the needle, and each fiber has its specific active areas (AA) where data is collected (Figure 1).

Project objective: to build a robotic system to perform automatic needle calibration of FBG-sensorized flexible needles on an individual basis.

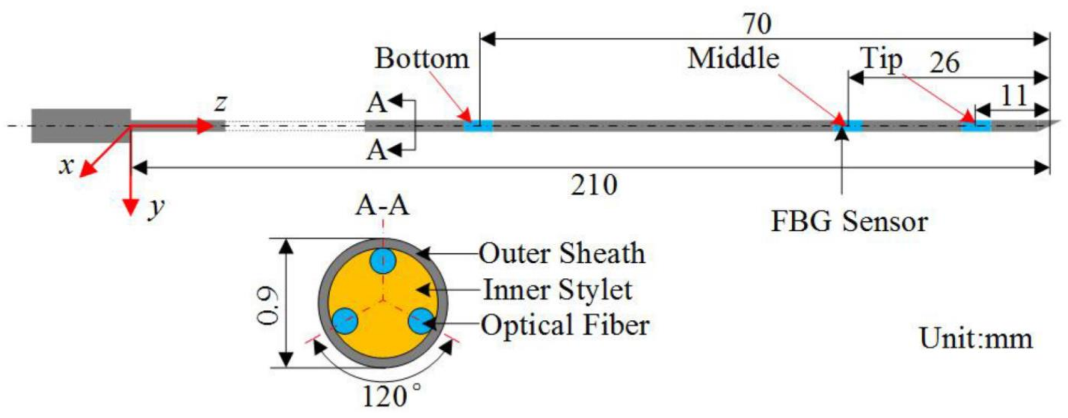

Figure 1. A 3-channel 3-active area FBG needle.

Current Problem

Clinical motivation: Current prostate biopsy and brachytherapy procedures

- Stiff needle with ultrasound guidance
- Subject to deformation and displacement error[1]

Updated approach uses FBG-sensorized flexible needle along with MRI guidance

- Preplan insertion path
- Update insertion path in real-time

Multiple researches done on this topic, including mathematical models for needle trajectory[2] and algorithms for the needle insertion[3].

Problem: each needle needs to be calibrated individually, which is time consuming and prone to human error

Solution

- Robot-assisted FBG-sensorized Needle Calibration System
  - **Calibration platform:** Contains both characterization and calibration stations
  - **Algorithm:** Semi-automatically perform both tests, collect raw data and analyze the result.

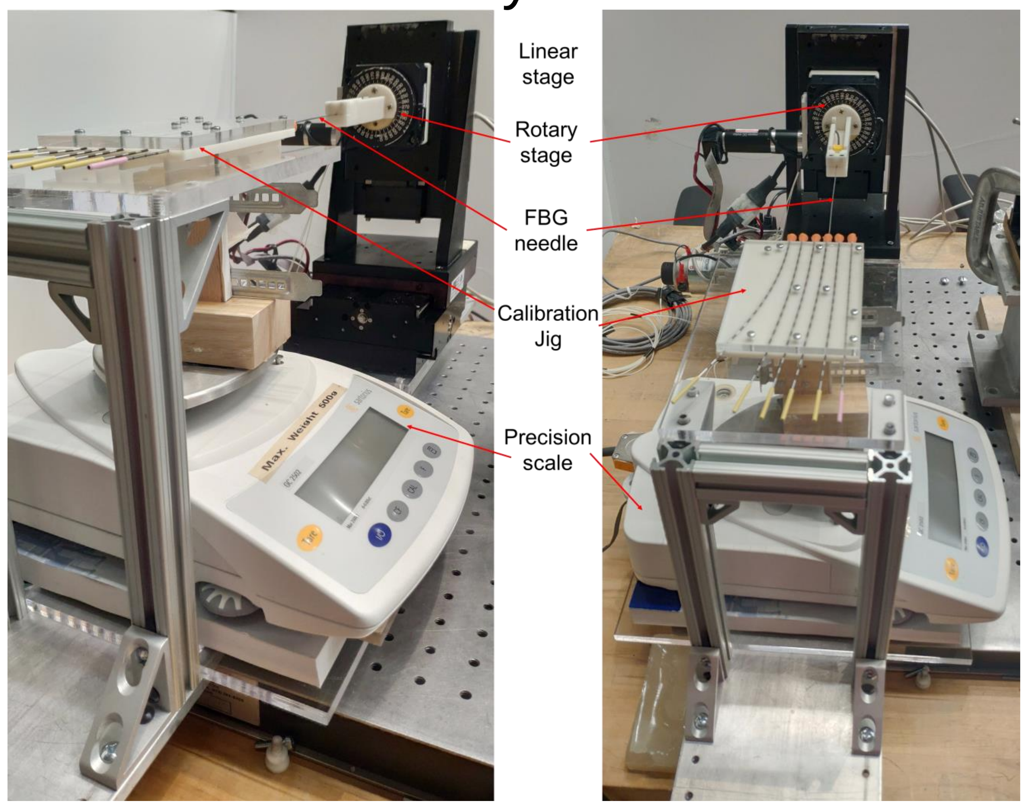

Figure 2. Side view (left) and top view (right) of the calibration platform.

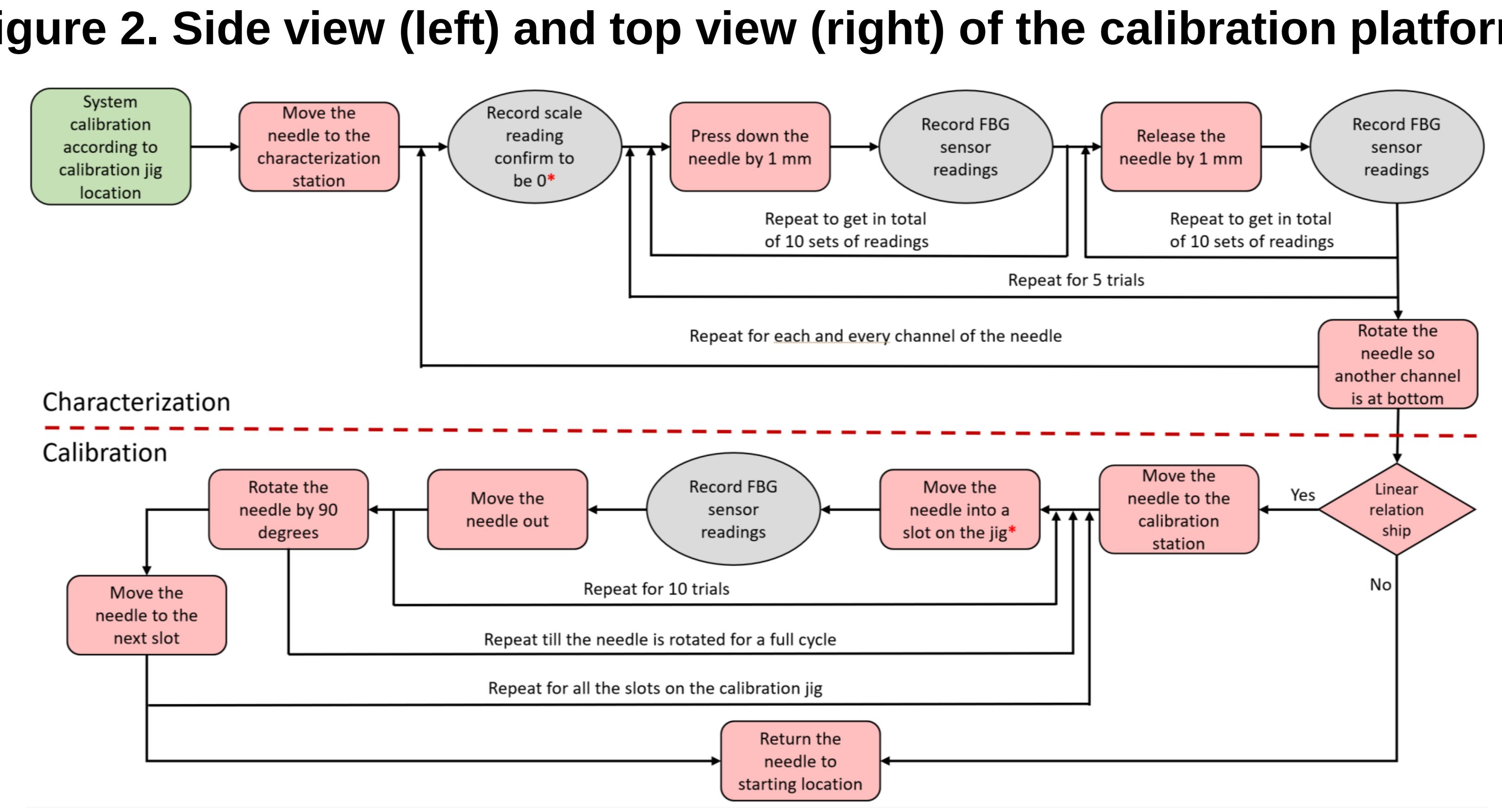

Figure 3. Workflow of the current algorithm.

Outcomes and Results

- Able to perform both characterization and calibration and calculate calibration matrices for the needle.
- Not fully automatic. Same overall time span, but only requires short attentions periodically
  - 30s per every 10min for characterization
  - 1min per every 20min for calibration
- The first calibration matrix has larger error. The other two matrices are similar.
- Error in calibration matrices is likely due to the inaccurate calibration jig.

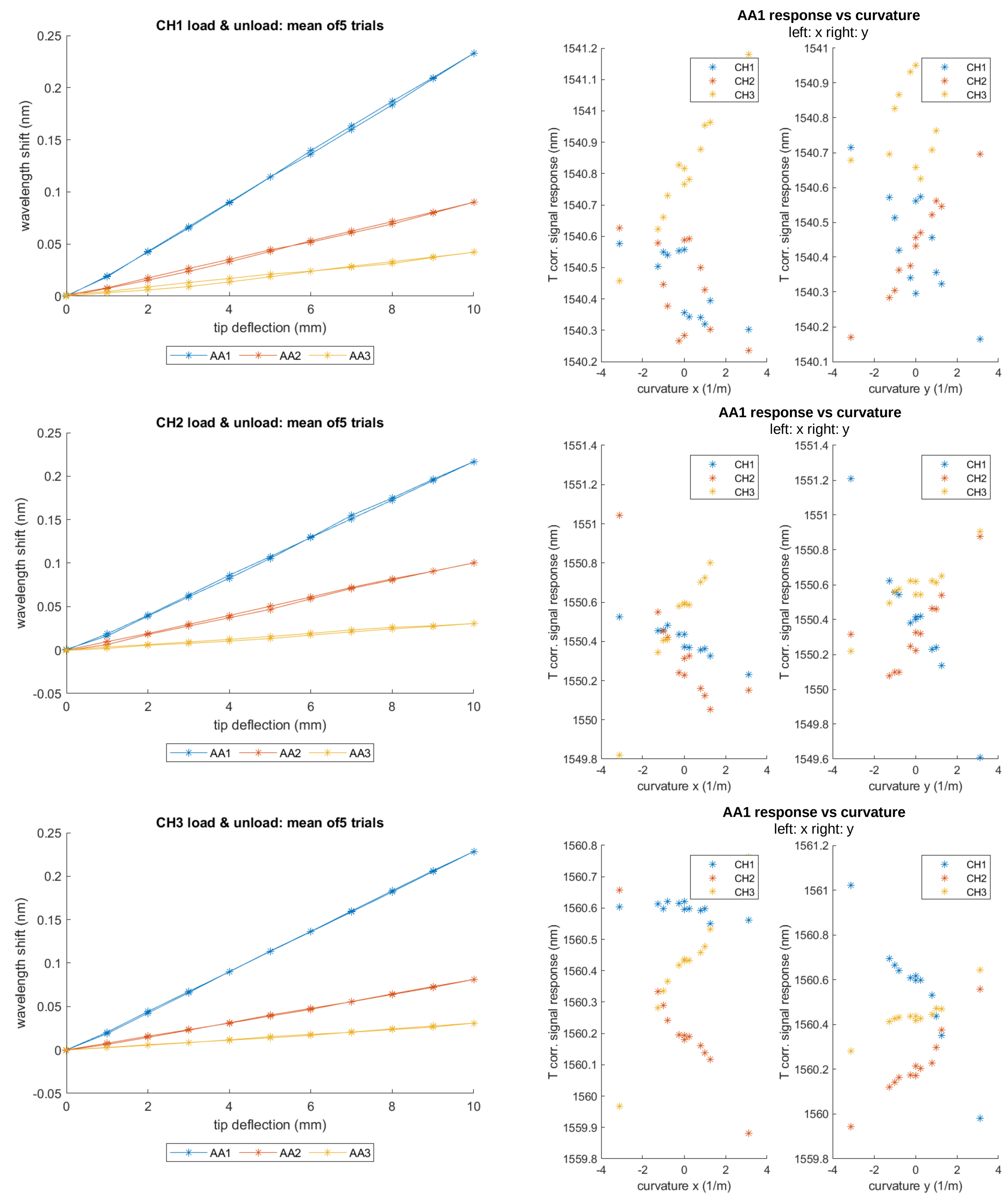

Figure 4. Characterization (left) and calibration (right) results of a sample needle.

$$C1_{rob} = \begin{bmatrix} -1.5283 & -3.7178 \\ -2.5518 & 3.6508 \\ 4.0791 & 0.0670 \end{bmatrix} \quad C1_{man} = \begin{bmatrix} -0.0173 & -2.3648 \\ -2.2199 & 1.4113 \\ 2.2368 & 0.9533 \end{bmatrix}$$

$$C2_{rob} = \begin{bmatrix} -0.3211 & -2.7145 \\ -2.1057 & 1.8308 \\ 2.4265 & 0.8837 \end{bmatrix} \quad C2_{man} = \begin{bmatrix} -0.2493 & -2.6264 \\ -2.3826 & 1.5096 \\ 2.6316 & 1.1167 \end{bmatrix}$$

$$C3_{rob} = \begin{bmatrix} -0.8032 & -4.0764 \\ -3.6630 & 2.2644 \\ 4.4657 & 1.8127 \end{bmatrix} \quad C3_{man} = \begin{bmatrix} -0.5065 & -3.9892 \\ -3.7144 & 1.9389 \\ 4.2205 & 2.0510 \end{bmatrix}$$

Figure 5. Calibration matrices for each active area obtained through robotic (left) and manual (right) calibration of the same needle.

Future Work

- Validate the calibration results
- Explore possible sources of errors through repetitive experiments
- Improve the system to be fully automatic

Publications

The work of this research will be submitted to the 2021 International Symposium on Medical Robotics (ISMR)

References

[1] Seifabadi, R., Iordachita, I., & Fichtinger, G. (2012, June). Design of a teleoperated needle steering system for MRI-guided prostate interventions. In *2012 4th IEEE Ras & Embs International Conference on Biomedical Robotics And Biomechatronics (Biorob)* (pp. 793-798). IEEE.

[2] Lezcano, D. A., Iordachita, I. I., & Kim, J. S. (2020, October). Trajectory Generation of FBG-Sensorized Needles for Insertions into Multi-Layer Tissue. In *2020 IEEE Sensors* (pp. 1-4). IEEE.

[3] Kim, J. S., Guo, J., Chatrasingh, M., Kim, S., & Iordachita, I. (2017, September). Shape determination during needle insertion with curvature measurements. In *2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)* (pp. 201-208). IEEE.