Robot-Assisted FBG-based Sensorized Needle Calibration

Team 6: Kefan Song

Mentors: Iulian Iordachita, Dimitri Lezcano, Jin Seob Kim

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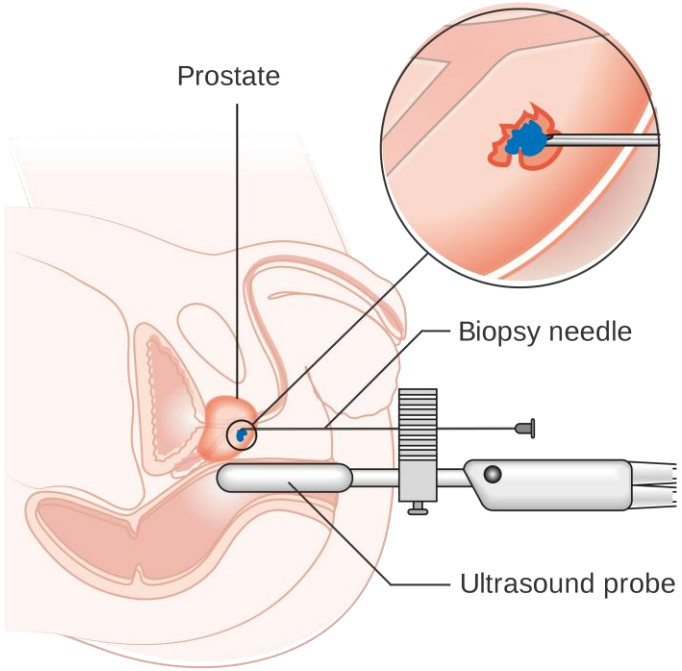
Team member

- Team 6: Kefan Song

- **Prof. Iulian Iordachita**: principal investigator
- **Dimitri Lezcano**: primary mentor
- **Dr. Jin Seob Kim**: mentor on algorithms
- **Ge Sun**: mentor on robot control and needle calibration

Motivation

- **Problem setting:** Prostate biopsy & brachytherapy
- **Current approach:** Ultrasound guided manual needle insertion with stiff needle
- **Problems:** target displacement, poor repeatability
- **Updated approach:** MRI guided robot needle insertion with flexible needle

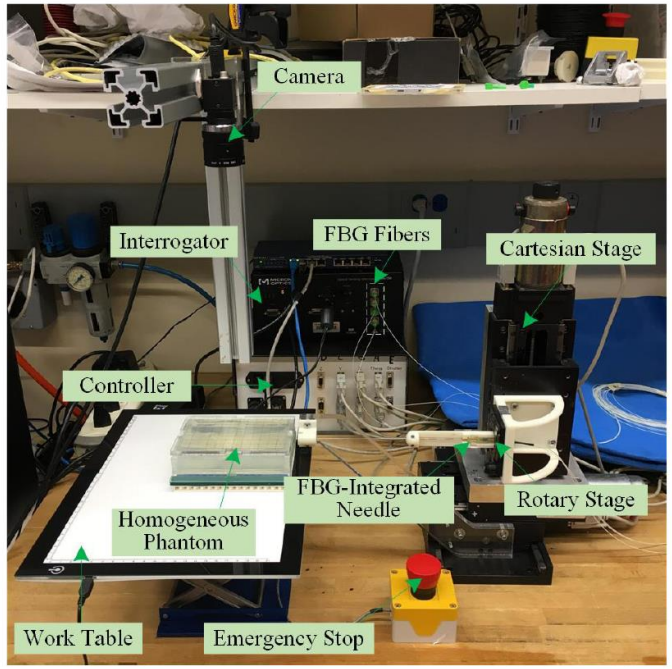


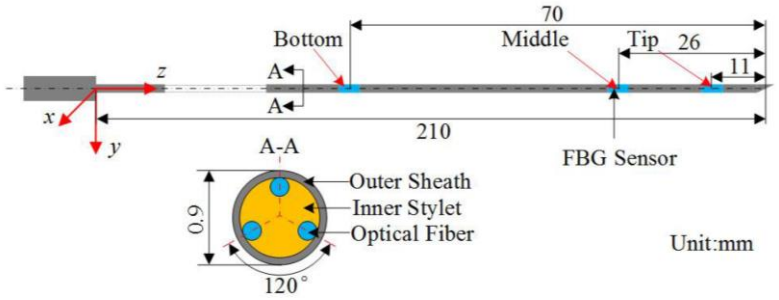
Picture credit: Cancer Research UK

Prior work

- Flexible bevel tip needles are chosen with FBG sensors to monitor curvature
- Mathematical models are calculated to determine the shape of the needle
- Calibrations are performed for precise and consistent measurement

- Current problem: calibration is done by hand
  - Time consuming
  - Prone to human error





Picture credit: Kim, J.S. et al., 2017

Goal/Project statement

- **This project aims to build a robotic system for (semi)automatic calibration of flexible needles with FBG-based shape-sensing capabilities.** FBG-embedded needles require precise and consistent calibration which can take several hours and is prone to human errors. Robot-assisted needle calibration would optimize needle construction and improve shape-sensing accuracy.

Approach

- 1. Design calibration platform
- 2. Design algorithm for the movement of the robot arm
- 3. Process calibration data and calculate calibration matrix

Approach: Design calibration platform

- Two types of calibration needed:
  1. Ensure that the needle is working properly:

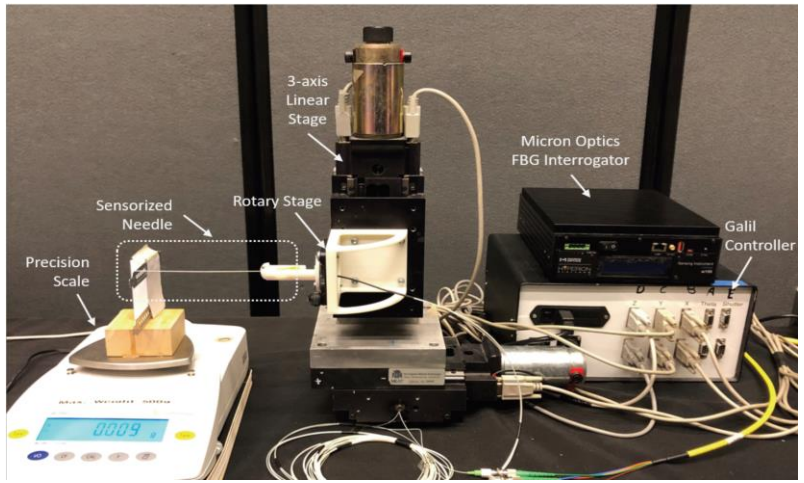
     check if the curvature and sensor reading has linear relationship

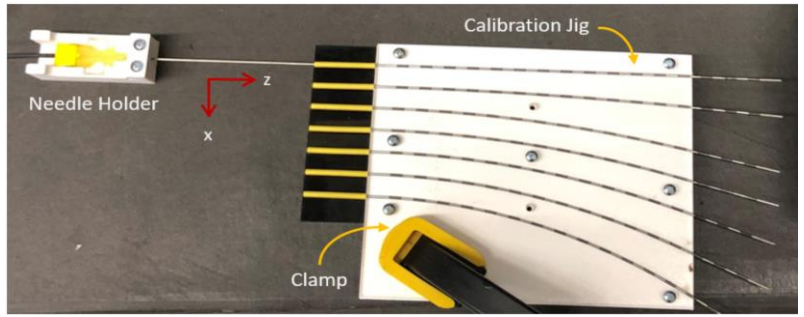
     Potential improvement: find substitute for the scale

  2. Perform 2D needle calibration

     Insert needle into slots with constant curvatures

     Potential improvement: compatible with multiple types of calibration jigs





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Approach: Design algorithm for robotic arm

- Semi-automatic calibration process
- Requirements:
  - Move between calibration jigs and between each curvature slot
  - Ability to stop if the first part of the calibration shows faulty needle
  - Enable rotation of the needle for calibration across different planes
  - Control movement velocity to reduce error in data due to sensitive sensor
  - Complete the entire calibration cycles within minutes

Approach: Process experiment data

- Data sources: FBG sensors, scale, curvature parameters of the jig
- Mathematic algorithm based on Kim, J.S. *et al.* 2017
- Output: calibration matrices for each FBG sensor

Deliverables

	Hardware	Algorithm	Experiment data
Minimum	Calibration platform	Semi-automatic (manual movement between calibration jigs + manual needle rotation)	Calibration matrices of one needle
Expected	Updated platform	Mostly automatic (manual needle rotation)	
Maximum		Fully automatic	Calibration results using other calibration jigs

Project timeline

	Feburary				March					April				May			
	1	2	3	4	1	2	3	4		1	2	3	4	1	2	3	4
Preliminary Research																	
Literature Review																	
Project Proposal																	
Platform																	
Design & build calibration platform																	
Calibrate position of components																	
Software																	
Understand current code for robot																	
Code for robotic arm movement																	
Integrate data acquisition & calculation																	
Integrate movement between jigs																	
Integrate rotation of needle																	
Final Report																	

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Dependencies

- Robot system & data acquisition unit (acquired)
- Needle for testing & actual experiments (acquired)
- Platform base for construction (acquire by 2/25)
- Curvature jig model (acquired)
- Lab access (acquired)
- Substitute force sensing mechanism for scale (acquire by 3/29)

Management plan

- Meetings:
  - Weekly meeting with Dimitri, Ge and Prof. Iordachita (Wednesdays)

- Communications:
  - Email
  - Personal interaction in lab

Reading list

- Zhang, L., Li, C., Zhang, X., Liu, G., Liu, Y., Zhao, J., ... & Fan, Y. (2019, December). A New Method For Fiber Bragg Grating Based Needle Shape Sensing Calibration. In 2019 IEEE International Conference on Robotics and Biomimetics (ROBIO) (pp. 1953-1958). IEEE.
- 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.
- Sankaran, N. K., Chembrammel, P., & Kesavadas, T. (2020). Force calibration for an endovascular robotic system with proximal force measurement. The International Journal of Medical Robotics and Computer Assisted Surgery, 16(2), e2045.
- Seifabadi, R., Gomez, E. E., Aalamifar, F., Fichtinger, G., & Iordachita, I. (2013, November). Real-time tracking of a bevel-tip needle with varying insertion depth: Toward teleoperated MRI-guided needle steering. In 2013 IEEE/RSJ International Conference on Intelligent Robots and Systems (pp. 469-476). IEEE.
- 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.
- 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.
- Kim, J. S., Chatrasingh, M., Kim, S., Suthakorn, J., & Iordachita, I. I. (2017, December). Fiber Bragg Grating based needle shape sensing for needle steering system: Evaluation in inhomogeneous tissue. In 2017 IEEE SENSORS (pp. 1-3). IEEE.
- Henken, K. R., Dankelman, J., van den Dobbelsteen, J. J., Cheng, L. K., & van der Heiden, M. S. (2013). Error analysis of FBG-based shape sensors for medical needle tracking. IEEE/ASME Transactions on mechatronics, 19(5), 1523-1531.
- Galloway, K. C., Chen, Y., Templeton, E., Rife, B., Godage, I. S., & Barth, E. J. (2019). Fiber optic shape sensing for soft robotics. Soft robotics, 6(5), 671-684.
- Chen, X., Yi, X., Qian, J., Zhang, Y., Shen, L., & Wei, Y. (2020). Updated shape sensing algorithm for space curves with FBG sensors. Optics and Lasers in Engineering, 129, 106057.

References

- Seifabadi, R., Gomez, E. E., Aalamifar, F., Fichtinger, G., & Iordachita, I. (2013, November). Real-time tracking of a bevel-tip needle with varying insertion depth: Toward teleoperated MRI-guided needle steering. In 2013 IEEE/RSJ International Conference on Intelligent Robots and Systems (pp. 469-476). IEEE.
- 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.
- 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.
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