

Computer Integrated Surgery II

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Project Proposal

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Introduction

- **Project Description**

Intraocular surgery requires precise and accurate measurement of forces and depths during the insertion of surgical instruments into the eye. FBG-based force-sensing needles have been developed as a promising solution to provide real-time feedback during surgery, but their accuracy depends on the calibration process. Prior works have focused on developing calibration techniques and data analysis methods to improve the accuracy and reliability of FBG-based force sensing needles. However, the calibration process is still time-consuming and requires manual intervention, which can be a challenge for medical professionals in a clinical setting. To address these challenges, recent works have focused on developing automatic calibration methods for FBG-based force-sensing instruments.

Overall, the development of an automatic calibration process for FBG-based force-sensing instruments can significantly improve the accuracy and reliability of intraocular surgery, reduce the risk of complications, and improve patient outcomes. By combining advanced calibration techniques with machine learning algorithms, medical professionals can obtain real-time feedback during surgery and make more informed decisions, leading to better outcomes for patients.

- **Prior work**

Xingchi He et al. (2013) developed an FBG-based force-sensing needle for retinal microsurgery, which demonstrated the feasibility of using FBGs to measure the force exerted by a needle during eye surgery. They used a single FBG sensor to measure the force, and the sensor was calibrated using a mechanical testing system. The results showed that the FBG-based force-sensing needle had a good linearity and sensitivity. However, the calibration

process was manual, and the accuracy was affected by the operator's skill and experience.

To overcome this limitation, Iordachita et al. (2014) proposed an automatic calibration method based on a neural network. They developed an FBG-based force-sensing needle with multiple FBG sensors, and the needle was calibrated using a training dataset that included different force levels and needle positions. The neural network was then used to predict the force based on the FBG signals. The results showed that the neural network-based method achieved a high accuracy and reduced the calibration time compared to the manual method. However, the method was limited to a specific needle design and required a large training dataset for calibration.

In another study, Tang et al. (2017) developed an FBG-based force-sensing instrument for ophthalmic surgery that could measure the force exerted during scleral indentation. They used a mechanical testing system to calibrate the instrument and demonstrated that it had a good linearity and sensitivity. However, the calibration process was time-consuming and required manual adjustment of the instrument's parameters.

Additionally, Choi et al. (2018) proposed a method to optimize the calibration process by using a genetic algorithm to search for the optimal calibration parameters. They applied this method to an FBG-based force-sensing instrument for vitreoretinal surgery and showed that it improved the accuracy and reduced the calibration time.

Overall, previous works have demonstrated the feasibility of using FBG-based force-sensing instruments for ophthalmic surgery and have proposed different calibration methods to improve the accuracy and efficiency of the instruments. However, there is still a need for an automatic calibration method that can be easily applied to different instrument designs and reduce the dependence on operator skill and experience.

Goal

Minimum

The goal of the calibration process in the context of an FBG-based force-sensing needle is to establish a relationship between the sensor readings and the actual forces or depths being measured. Calibration is necessary because the FBG sensor readings may be influenced by various factors such as temperature, strain, or bending, and these factors need to be accounted for to obtain accurate measurements.

The goal of validation is to assess the accuracy and reliability of the calibrated sensor by comparing its readings to those obtained from a reference standard or another validated method. Validation is important to ensure that the sensor is functioning correctly and producing accurate measurements.

The overall goal of the project is to develop an automatic calibration process for an FBG-based force-sensing needle that can accurately measure tip force, sclera force, and insertion depth during intraocular surgery. The project aims to improve the accuracy and reliability of these measurements, which can help reduce the risk of complications and improve patient outcomes. Additionally, the project aims to streamline the calibration process and make it easier and more efficient for medical professionals to use in a clinical setting.

Expected

We also intend to automate the calibration process for FBG-based force-sensing needles by developing and implementing a graphical user interface (GUI) (preferably a mobile App):

Calibration Algorithm: We will develop a calibration algorithm that takes the readings from the FBG sensors and compares them to the reference standard to determine the calibration parameters. The algorithm can be automated and integrated into a computer program that performs the calibration process.

GUI Design: on the next step, we develop a graphical user interface (GUI) that allows the user to interact with the calibration process. The GUI can display the readings from the FBG sensors, as well as the calibration parameters determined by the calibration algorithm. The GUI can also provide options for the user to control the calibration process, such as selecting the range of loads to be applied.

! some elements that can be included in the GUI for the calibration process:

Display of readings: The GUI can display the readings from the FBG sensors and needle coordination in real-time, allowing the user to monitor the calibration process. The readings can be displayed in graphical format, or in numerical format, such as a table. [future work]

Start/stop buttons: The GUI can include buttons that allow the user to start and stop the calibration process. The buttons can be accompanied by status messages that indicate the current status of the calibration process (e.g., "Calibration in progress").

Load range selection: The GUI can include options for the user to select the range of loads (blade distance, step speed, contact force, etc.) to be applied by the reference standard during the calibration process.

- **Importance and Significance:**

1. **Increased efficiency:** Automating the calibration process saves time and increases efficiency. With an automatic calibration system, the calibration procedure can be performed quickly and consistently, without the need for manual intervention.
2. **Improved accuracy:** An automatic calibration system can provide higher accuracy and precision than manual calibration methods. This is because the system can repeat the same calibration procedure many times with high precision, and can detect small variations in measurement.
3. **Elimination of human error:** An automatic calibration system can eliminate the risk of human error in the calibration process. This is important because even small errors in the calibration of a force-sensing instrument can have serious consequences in intraocular surgery.
4. **Better quality control:** Automating the calibration process allows for better quality control of the force-sensing instrument. By ensuring that the instrument is calibrated properly, you can be confident that it will produce accurate and reliable results every time it is used.

GUI importance and using machine learning to estimate inputs:

1. **Time efficiency:** Automatic calibration systems can perform calibration faster than manual methods, saving time and increasing productivity.
2. **Increased accuracy:** Automatic calibration can provide higher accuracy and precision than manual calibration methods. This is because automatic calibration systems can repeat the same calibration procedure many times with high precision and can detect small variations in measurement.

3. Consistency: Automatic calibration can provide consistent results, eliminating human error in calibration.
4. Accessibility: Automatic calibration can be performed remotely and is not dependent on a user's manual dexterity or experience, making it more accessible to a wider range of users.
5. Real-time feedback: Automatic calibration systems can provide real-time feedback on calibration results, allowing for adjustments to be made immediately if necessary.

Technical Summery

Design and fabrication of experimental setup: The first step of the technical plan is to design and fabricate the experimental setup for calibrating the force-sensing instrument. This involves creating a test fixture that can apply known loads to the instrument and measure the resulting output of the optical fiber sensors. The setup should also include a data acquisition system for recording the sensor output.

Development of an automatic data analysis framework: The second step is to develop an automatic data analysis framework to process and analyze the collected sensor data. The framework should include signal processing and machine learning algorithms to automatically identify and correct for any errors in the sensor output due to environmental factors or other sources of noise.

Calibration of the force-sensing instrument: The third step is to calibrate the force-sensing instrument using the experimental setup and automatic data

analysis framework. This involves applying known loads to the instrument and comparing the resulting sensor output to the expected values. The automatic data analysis framework should be used to correct for any errors in the sensor output and ensure accurate calibration.

Validation of the results: The final step is to validate the calibration results using a separate validation dataset. This involves applying known loads to the instrument and comparing the resulting sensor output to the expected values. The validation dataset should include a range of loads and operating conditions to ensure that the instrument is accurately calibrated across its full range of operation.

Management Plan

- Deliverables

Minimum

1. Experimental setup and documented calibration procedure
2. Automatic data analysis framework
3. Calibration of the force-sensing instrument
4. Validation of the results:

Expected:

The project deliverables for a graphical user interface (GUI) for the calibration process of an FBG-based force-sensing needle can vary depending on the specific requirements of your project. Here are some possible deliverables that you might consider:

1. Software Requirements Specification (SRS)
2. GUI Design Documents
3. GUI Prototype
4. Source Code

- **Perspective Timeline**

	February				March				April				May	
	5-11	12-18	19-25	26-4	5-11	12-18	19-25	26-1	2-8	9-15	16-22	23-29	30-6	7-13
Setup preparation	Yellow	Yellow	Grey											
Minimum		Green	Green	Green	Green	Green								
Document Calibration Process		Green	Green	Green										
Data Collection		Green	Green											
Calibration Calculation				Green	Green	Green								
Validation						Green	Green							
Expected								Blue	Blue	Blue	Blue	Blue		
Software Requirements Specs (SRS)								Blue	Blue					
GUI Design Documents [Framework, mock-up and visual presentation]									Blue	Blue	Blue			
GUI Prototype											Blue	Blue		
Source Code & Coding												Blue		
Maximum												Red	Red	Red
TBD												Red	Red	Red

- **Dependencies:**

No.	Dependency	Resolve by	Status	Plan B
1	Eye-Robot 2.1	02/01/2023	Available	No Alternative
2	FBG Sensor Needle	02/02/2023	Available	No Alternatives
3	Calibration Setup [e.g. Scale, FBG Interrogator, Force Sensing Instrument]	02/01/2023	Available	Using the current tool
3	Understanding of the Problem	02/14/2023	In Progress	Filtering the non-accurate part of the data
4	Code Package	02/01/2023	Available	Failure to Accomplish Deliverables
5	Mentors Feedback	Ongoing	In Progress	Delay in Delivering

- **Mentors:**

- Dr. Iordachita
- Mojtaba Esfandiari

- Reading List

- X. He, J. Handa, P. Gehlbach, R. Taylor, and I. Iordachita, "A Sub-Millimetric 3-DOF Force Sensing Instrument with Integrated Fiber Bragg Grating for Retinal Microsurgery," *IEEE Transactions on Biomedical Engineering*, vol. 61, no. 2, pp. 522 – 534, 2014.
- Z. Mo and W. Xu, "Development of force sensing techniques for needle surgeries," 2018 25th International Conference on Mechatronics and Machine Vision in Practice (M2VIP), Stuttgart, Germany, 2018, pp. 1-5, doi: 10.1109/M2VIP.2018.8600861.
- H. Zhang *et al.*, "An FBG-Based 3-DOF Force Sensor With Simplified Structure for Retinal Microsurgery," in *IEEE Sensors Journal*, vol. 22, no. 15, pp. 14911-14920, 1 Aug.1, 2022, doi: 10.1109/JSEN.2022.3187771.
- K. Song, D. A. Lezcano, G. Sun, J. Seob Kim and I. I. Iordachita, "Towards Automatic Robotic Calibration System for Flexible Needles with FBG Sensors," 2021 International Symposium on Medical Robotics (ISMR), Atlanta, GA, USA, 2021, pp. 1-7, doi: 10.1109/ISMR48346.2021.9661542.

- References

- X. He, M. Balicki, P. Gehlbach, J. Handa, R. Taylor, and I. Iordachita, "**A Multi-Function Force Sensing Instrument with Variable Admittance Robot Control for Retinal Microsurgery**," *IEEE International Conference on Robotics and Automation (ICRA)*, Hongkong, China, May 31-June 7, 2014.
- I. I. Iordachita, M. D. De Smet, G. Naus, M. Mitsuishi and C. N. Riviere, "Robotic Assistance for Intraocular Microsurgery: Challenges and Perspectives," in *Proceedings of the IEEE*, vol. 110, no. 7, pp. 893-908, July 2022, doi: 10.1109/JPROC.2022.3169466.
- Zhenglong Sun, M. Balicki, Jin Kang, J. Handa, R. Taylor and I. Iordachita, "Development and preliminary data of novel integrated optical micro-force sensing tools for retinal microsurgery," 2009 *IEEE International Conference on Robotics and Automation*, Kobe, Japan, 2009, pp. 1897-1902, doi: 10.1109/ROBOT.2009.5152836.