CIS II Background Reading

"Automatic Calibration of an FBG-based Force-Sensing Instrument for Intraocular Surgery"

Team 17

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1. A Sub-Millimetric 3-DOF Force Sensing Instrument with Integrated Fiber Bragg Grating for Retinal Microsurgery[1]

Approach: FBG-based force-sensing needle for retinal microsurgery

1.1 Selected paper background and goals

This paper focuses on the development and evaluation of an FBG-based force-sensing needle for retinal microsurgery. The authors aimed to demonstrate the feasibility of using FBGs to measure forces exerted by needles during eye surgery accurately. The paper also explores the calibration process, which is performed manually and influenced by the operator's skill and experience. Furthermore, the authors investigate the factors affecting the accuracy and reliability of FBG-based force-sensing needles in a surgical context.

1.2 Relevance

This paper is highly relevant to the project as it directly addresses the use of FBG-based force-sensing needles in intraocular surgery and the challenges associated with the calibration process. The limitations of the manual calibration process discussed in the paper highlight the need for an automatic calibration method. Additionally, the paper emphasizes the importance of addressing factors affecting the accuracy and reliability of FBG-based force-sensing needles.

1.3 Methods

The authors developed a force-sensing needle with a single FBG sensor to measure the force. They used a mechanical testing system to perform the calibration process and assessed the linearity, sensitivity, and repeatability of the force-sensing needle. The study also considered the influence of various factors, such as temperature, strain, and bending, on the sensor's performance. To evaluate the performance of the force-sensing needle, the authors conducted a series of experiments simulating retinal microsurgery conditions.

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[1] He X, Handa J, Gehlbach P, Taylor R, Iordachita I. A sub-millimetric 3-DOF force sensing instrument with integrated fiber Bragg grating for retinal microsurgery. IEEE Trans Biomed Eng. 2014 Feb;61(2):522-34. doi: 10.1109/TBME.2013.2283501. PMID: 24108455; PMCID: PMC3965652.

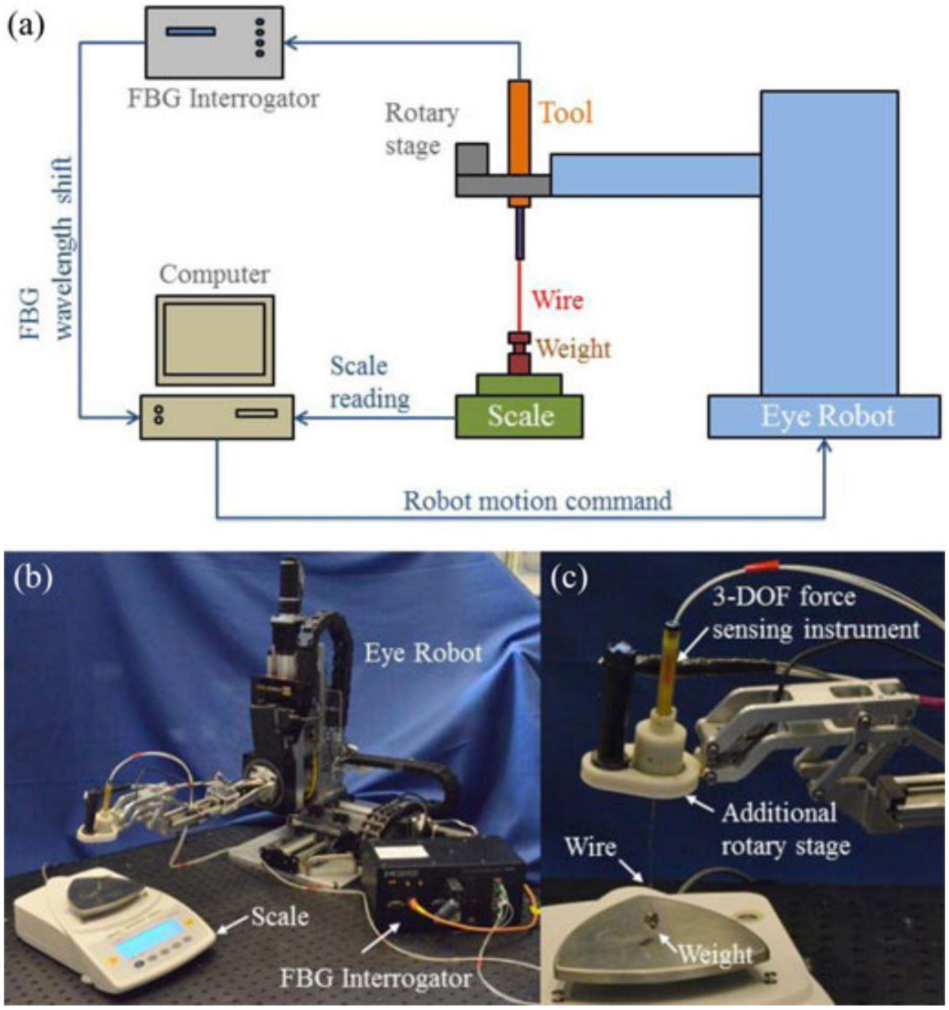

Fig. 5. (a) Diagram of the automated calibration system, (b) picture of the calibration setup with the robot, the scale, the tool, and the FBG interrogator, and (c) close-up of the additional rotary stage with the tool. Calibration chamber is not shown.

1.4 Results and conclusions

The results showed that the FBG-based force-sensing needle had good linearity, sensitivity, and repeatability. However, the calibration process was manual, time-consuming, and affected by the operator's skill and experience. The study also found that temperature, strain, and bending significantly influenced the sensor's performance, necessitating their consideration during the calibration process.

1.5 Critical assessment

Strengths:

- The paper demonstrates the feasibility of using FBG-based force-sensing needles in retinal microsurgery.
- The authors provide a detailed description of the calibration process and the factors affecting the sensor's performance.
- The experimental evaluation of the force-sensing needle under simulated retinal microsurgery conditions strengthens the study's findings.

Critique:

- The manual calibration process is time-consuming and relies on the operator's skill and experience, which can affect the accuracy and reliability of the measurements.
- The study uses a single FBG sensor, which may limit the potential to capture the full range of forces and effects during surgery.

1.6 Conclusion

This paper is a valuable reference for the proposed project as it directly addresses the calibration process of FBG-based force-sensing needles and the factors influencing their performance. The limitations of the manual calibration process highlight the need for an automatic calibration method, which is the main focus of the project. Furthermore, the paper emphasizes the importance of understanding and addressing the factors affecting the accuracy and reliability of FBG-based force-sensing needles in a surgical context. By building on the findings of this study, the proposed project aims to develop a more efficient and accurate calibration method that accounts for various factors influencing the sensor's performance, ultimately improving the outcomes of intraocular surgeries.

2. A Multi-Function Force Sensing Instrument for Variable Admittance Robot Control in Retinal Microsurgery [2]

Approach: Automatic calibration method based on a neural network

2.1 Selected paper background and goals

This paper proposes an automatic calibration method for FBG-based force-sensing needles based on a neural network. The authors aimed to overcome the limitations of the manual calibration process by developing an FBG-based force-sensing needle with multiple sensors and using a neural network to predict forces based on FBG signals. The paper explores the potential of machine learning techniques to streamline the calibration process and improve the accuracy of FBG-based force-sensing needles in intraocular surgery.

2.2 Relevance

The paper is highly relevant to the project as it directly addresses the development of an automatic calibration method for FBG-based force-sensing instruments. The proposed neural network-based approach offers insights into potential solutions for automating the calibration process and demonstrates the use of machine learning techniques to improve the accuracy and efficiency of FBG-based force-sensing needles.

2.3 Methods

The authors developed an FBG-based force-sensing needle with multiple FBG sensors and calibrated the needle using a training dataset containing different force levels and needle positions. A neural network was then used to predict forces based on the FBG signals. This approach aimed to reduce the dependence on manual calibration and minimize the influence of operator skill and experience on the calibration process.

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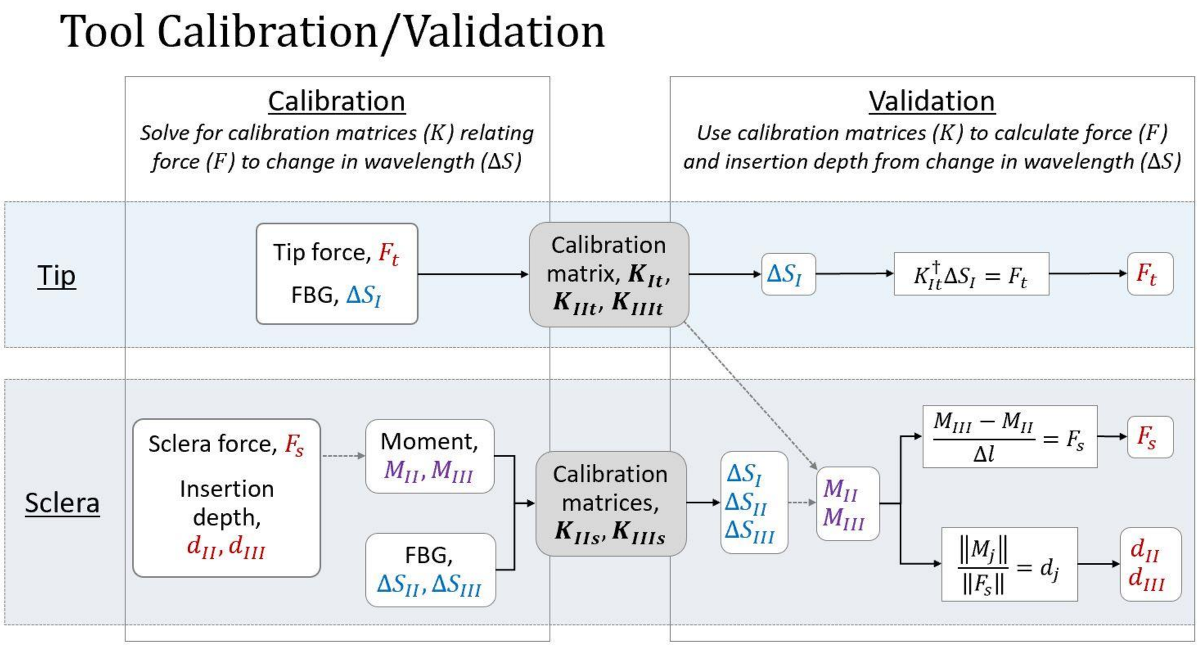
[2] He X, Balicki M, Gehlbach P, Handa J, Taylor R, Iordachita I. A Multi-Function Force Sensing Instrument for Variable Admittance Robot Control in Retinal Microsurgery. IEEE Int Conf Robot Autom. 2014 May;2014:1411-1418. doi: 10.1109/ICRA.2014.6907037. PMID: 25383234; PMCID: PMC4220308.



Proposed mathematical scheme of calibration and validation

2.4 Results and conclusions

The results showed that the neural network-based method achieved high accuracy and reduced 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. This demonstrates the potential of using machine learning techniques to improve the calibration process, but it also highlights the need for a more versatile calibration method that can be easily applied to different instrument designs.

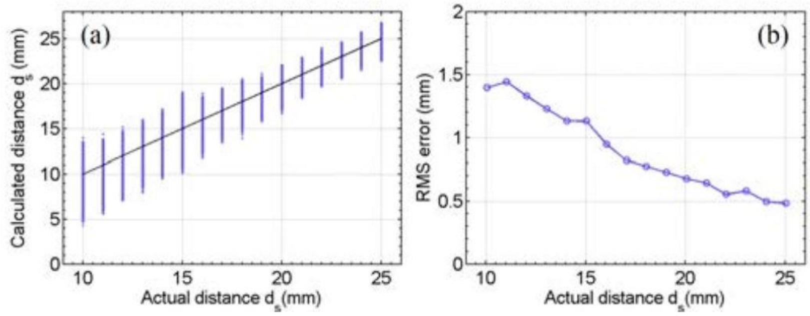


Fig. 8. Results of sclerotomy location calibration. The calculated distance from the tool tip to sclerotomy d_s versus the actual value (a), the RMS error at each calibrated location verus the actual distance (b). The further the scleratomy is located from the tool tip, i.e., the closer it is with respect to FBG-II and FBG-III, the smaller is the RMS error. Data points with forces smaller than 5 mN in magnitude is not included to reduce noise, as discussed in Section II-B.

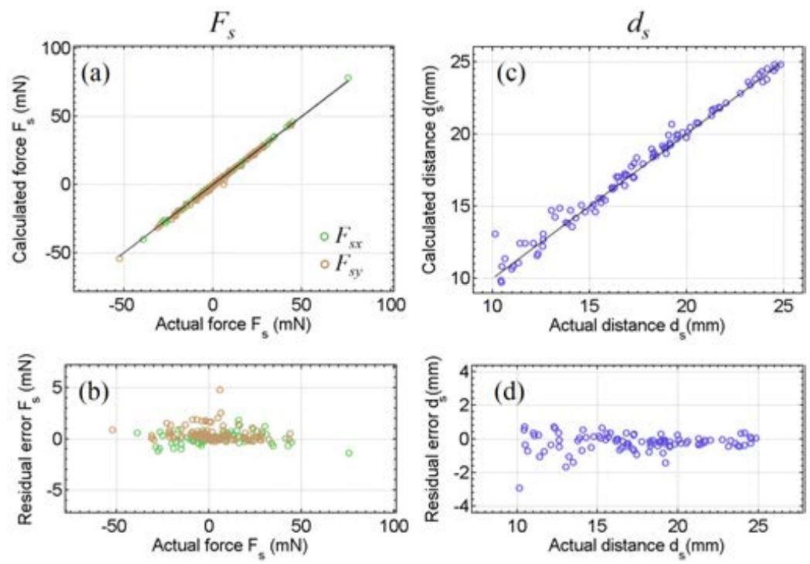


Fig. 10. Results of validation experiment for sclera contact force. The calculated sclera force versus the actual value (a), the residual error of force calculation (b). The calculated distance from the tool tip to sclerotomy d_s versus the actual value (c), and its residual error (d).

2.5 Critical Assessment

Strengths:

- The paper presents a novel approach to automating the calibration process using a neural network, which can potentially improve the accuracy and efficiency of FBG-based force-sensing needles.
- The neural network-based method shows promising results in terms of accuracy and calibration time, demonstrating the potential of machine learning techniques to enhance the performance of FBG-based force-sensing instruments.

Critique:

- The method is limited to a specific needle design, which may not be suitable for all surgical instruments. This highlights the need for a more versatile calibration method that can be easily applied to different instrument designs.
- The requirement of a large training dataset for calibration may not be practical in some clinical settings, as it can be time-consuming and resource-intensive to collect the necessary data. This suggests the need for a more efficient calibration method that can achieve high accuracy with a smaller dataset.

2.6 Conclusion

This paper provides valuable insights into the development of an automatic calibration method for FBG-based force-sensing needles using a neural network. The study demonstrates the potential of machine learning techniques to streamline the calibration process and improve the accuracy of FBG-based force-sensing instruments in intraocular surgery. However, the limitations of the proposed method, such as its dependence on a specific needle design and the need for a large training dataset, suggest the need for further research to develop a more versatile and efficient calibration method. This work serves as a valuable reference for the proposed project, as it highlights the potential benefits of automating the calibration process while also pointing out the challenges that need to be addressed.

Overall Progress and Importance of the Project

The two papers discussed above have made significant contributions to the development of FBG-based force-sensing needles for intraocular surgery and the calibration process. Xingchi He et al. (2013) demonstrated the feasibility of using FBG sensors for force measurements in retinal microsurgery, but their manual calibration process was time-consuming and dependent on the operator's skill. Iordachita et al. (2014) proposed an automatic calibration method based on a neural network, achieving high accuracy and reduced calibration time, but their method was limited to a specific needle design and required a large training dataset.

Moreover, none of these studies provided a specific, detailed procedure or framework for the calibration process, making it difficult for anyone without prior experience to perform the calibration effectively. This further highlights the need for a standardized and automated calibration method.

The importance of the current project lies in addressing the limitations of the prior works by developing an automatic calibration process that is applicable to a wider range of FBG-based force-sensing needles and is less dependent on operator skill and experience. By providing a clear and standardized procedure for the calibration process, the project will make it easier for medical professionals with varying levels of experience to perform accurate calibration. This improvement in the calibration process will lead to more accurate and reliable intraocular surgery measurements, significantly reducing the risk of complications and improving patient outcomes. Furthermore, streamlining the calibration process will make it more efficient and accessible for medical professionals in clinical settings.

Next Steps for Calibration:

Develop a clear and standardized procedure or framework for the calibration process that can be easily followed by medical professionals with different levels of experience.

Develop a calibration method that can adapt to different FBG-based force-sensing needle designs, making it more versatile and widely applicable.

Investigate machine learning algorithms and optimization techniques that can improve the accuracy of the calibration process while reducing the need for extensive training data.

Develop a robust temperature compensation technique to minimize the influence of temperature fluctuations on the FBG sensor readings during calibration.

Conduct experimental validation of the proposed automatic calibration method using a reference standard or a validated method to assess its accuracy and reliability.

Design user-friendly software that can streamline the calibration process and provide an intuitive interface for medical professionals to perform calibration in a clinical setting.

By addressing these next steps, the project will advance the state of the art in FBG-based force-sensing needles for intraocular surgery and contribute to safer and more accurate surgical procedures, ultimately improving patient outcomes.