Guest Editorial Sensors for Physical Interaction and Perception in Minimally Invasive Robotic Surgery

I. Introduction

THE IEEE Transactions on Medical Robotics and Bionics (T-MRB) is an initiative shared by the two IEEE Societies of Robotics and Automation – RAS – and Engineering in Medicine and Biology – EMBS.

T-MRB is a multi-disciplinary journal aimed at publishing peer-reviewed papers and focused on innovative research ideas and medical application results, reporting significant theoretical findings and application case studies in the areas of medical robotics and bionics.

In particular, one of the six Journal Areas addressed in T-MRB is Surgical Robotics.

Robotic surgery is a research field in continuous evolution and many aspects are still to be optimised to develop more complex clinical operations [1]. One big problem that still remains unsolved is the sensorization of surgical tools [2], [3], [4]: designs still rely on classical configurations, fabrication is very challenging, and sterilization of electronics prevents embedding sensors in the instruments [5].

This Special Section aims at presenting contributions on sensors for monitoring and rendering physical interaction to increase perception in surgical robotics, such as, for example, force/torque, contact, proximity, virtual sensors, and their corresponding feedback devices.

In this Special Section some relevant recent advances in force/torque sensors for minimally invasive surgery robotic tools, compliant mechanisms, palpation forces, and flexible medical instruments are included.

The editorial choice to open this issue of T-MRB is to promote a new research direction in sensors for physical interaction and perception in minimally invasive robotic surgery.

Guest Editors of this Special Section have a complementary experience in robotic surgery, autonomous systems, and computer science, from one side and robotics, compliant mechanisms, and machine sciences from the other side. These complementary knowledges allow to include different points of view in the Special Section and permitted to collect the expression of interest from authors underlining contribution in both computer science and machine sciences research fields with application to robotic surgery.

All the papers have undergone full peer review.

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II. Special Section Content

This Special Section includes four manuscripts that give an overview on research problems, solutions, and open questions in surgical robotics: mechanics and mechanisms in surgical tools, force and sensor feedback, force/torque sensor design in minimally robotic surgery tools, force palpation, etc.

The paper by Sun and Lueth [A1] addresses the issue of safe manipulation of soft tissues proposing a soft mechanism to achieve a stable force regulation of robotic-assisted minimally invasive surgery forceps [6]. The proposed constant force mechanism consists of a pair of symmetrical compliant slider-crank mechanisms and the whole system is positioned between the motor and the forceps. A grasping test of artificial artery was also performed and presented in the paper. This test is used to demonstrate and to validate the first hypotheses of working conditions.

The paper by Lu et al. [A2] addresses a generic graph-based framework for 3-D shape reconstruction of flexible medical instruments [7]. In the proposed system, the fiber Bragg grating sensors are used. In the paper, dynamic filtering approach is introduced for iterative curvature and twist estimation. Experiments are processed to validate the proposed methods. This solution is useful in the new open challenges of robotic surgery tools related to flexible instruments.

The paper by Muscolo and Fiorini [A3] presents an overview on force-torque sensors used in different domains, including robotic surgery [8]. The absence of force feedback to surgeons during robotic surgery clinical interventions, the need of sterilization of clinical instruments, and the technological limits open new challenges to design the force/torque sensors for a new era of minimally invasive robotic surgery. This paper analyzed a total of 1520 papers and gives to the reader an overview of the research directions in the design of the surgery robotic tools of the next future.

The paper by Lee et al. [A4] proposes an indirect force-sensing method that combines monocular images with Inertial Measurement Units (IMU) sensors attached externally to the instrument shaft [9]. The article presents a deep-learning model that predicts palpation forces performed with the surgical tool by using visual and inertial data.

III. Conclusion

This Special Section confirms the important progress made in the area of Robotic Surgery emphasizing the importance of force feedback to the surgeon, but also the technological limitations to obtain the sensitive instruments.

In particular, we hope that this Special Section will contribute to clarify the field, help defining the promising technologies and their applications, and list the progress in using interaction data to simplify surgery tasks.

Interaction among sensors and new haptic devices for increasing perception in surgeons are others interesting aspects included in the topics of the Special Section but are also an open challenge for the research in the next future.

Appendix: Related Articles

[A1] Y. Sun and T. C. Lueth, "Safe manipulation in robotic surgery using compliant constant-force mechanism," *IEEE Trans. Med. Robot. Bionics*, vol. 5, no. 3, pp. 486–495, Aug. 2023, doi: 10.1109/TMRB.2023.3237924.

[A2] Y. Lu et al., "A robust graph-based framework for 3-D shape reconstruction of flexible medical instruments using multi-core FBGs," *IEEE Trans. Med. Robot. Bionics*, vol. 5, no. 3, pp. 472–485, Aug. 2023, doi: 10.1109/TMRB.2023.3239685.

[A3] G. G. Muscolo and P. Fiorini, "Force–torque sensors for minimally invasive surgery robotic tools: An overview," *IEEE Trans. Med. Robot. Bionics*, vol. 5, no. 3, pp. 458–471, Aug. 2023, doi: 10.1109/TMRB.2023.3261102.

[A4] Y.-E. Lee, H. M. Husin, M.-P. Forte, S.-W. Lee, and K. J. Kuchenbecker, "Learning to estimate palpation forces in robotic surgery from visual-inertial data," *IEEE Trans. Med. Robot. Bionics*, vol. 5, no. 3, pp. 496–506, Aug. 2023, doi: 10.1109/TMRB.2023.3295008.

Acknowledgment

In closing, we would like to extend our appreciation to all reviewers who played a crucial role in the peer-review process for the manuscripts submitted to this issue for their timely and professional comments.

Most importantly, thanks to all the authors who submitted their manuscripts for consideration of publication.

Many thanks to our Editors colleagues, the T-MRB Editorial Office, and the T-MRB Editor in Chief for their support during the special section proposal submission and revision process, and for their assistance in all phases of the papers' submission and revision.

References

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[3] P. E. Dupont et al., "A decade retrospective of medical robotics research from 2010 to 2020," *Sci. Robot.*, vol. 6, no. 60, p. eabi8017, 2021.

[4] G. G. Muscolo and P. Fiorini, "A new cable-driven model for under-actuated force–torque sensitive mechanisms," *Machines*, vol. 11, p. 617, Jun. 2023. [Online]. Available: https://doi.org/10.3390/machines11060617

[5] T. L. Thomas, V. Kalpathy Venkiteswaran, G. Ananthasuresh, and S. Misra, "Surgical applications of compliant mechanisms: A review," *J. Mech. Robot.*, vol. 13, no. 2, 2021, Art. no. 20801.

[6] Y. Sun and T. C. Lueth, "Safe manipulation in robotic surgery using compliant constant-force mechanism," *IEEE Trans. Med. Robot. Bionics*, early access, Jan. 18, 2023, doi: 10.1109/TMRB.2023.3237924.

[7] Y. Lu et al., "A robust graph-based framework for 3-D shape reconstruction of flexible medical instruments using multi-core FBGs," *IEEE Trans. Med. Robot. Bionics*, early access, Jan. 25, 2023, doi: 10.1109/TMRB.2023.3239685.

[8] G. G. Muscolo and P. Fiorini, "Force–torque sensors for minimally invasive surgery robotic tools: An overview," *IEEE Trans. Med. Robot. Bionics*, early access, Mar. 29, 2023, doi: 10.1109/TMRB.2023.3261102.

[9] Y.-E. Lee, H. M. Husin, M.-P. Forte, S.-W. Lee, and K. J. Kuchenbecker, "Learning to estimate palpation forces in robotic surgery from visual-inertial data," *IEEE Trans. Med. Robot. Bionics*, early access, Jul. 13, 2023, doi: 10.1109/TMRB.2023.3295008.

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