Guest Editorial Special Section on Surgical Vision, Navigation, and Robotics

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.

The topic of this Special Section on "Surgical Vision, Navigation, and Robotics" is comprised under one of the six Journal Areas addressed in T-MRB, which is Surgical Robotics. In this Special Section, authors were invited to address these topics, and where appropriate emphasize applications of this theme with relevance to the COVID-19 pandemic.

The Guest Editors and the Authors of the papers included in this Special Section are heavily engaged in the Medical Image Computing (MICCAI) and the Computer-Assisted Interventions (IPCAI) communities, whose scope also encompasses the topics expressed in the Call for Papers, which sought articles relating to state-of-the-art research in Surgical Vision, Navigation, and Robotics. Recent advances are evident in real-time interventional imaging and visualization, surgical tracking, navigation, multi-spectral imaging and data fusion, and clinical robotics and haptics. Research related to the design, implementation, and evaluation of innovative solutions for endoscopic and robotic interventions and surgery has increased dramatically. More recently, the outbreak of COVID-19 has demanded new clinical approaches and medical robotic techniques to diagnose, treat, and provide healthcare solutions for COVID-19 patients and surgical approaches where technological solutions can prevent disease transmission.

All the papers have undergone full peer-review by 6 Guest Editors: Xiongbiao Luo, Xiamen University, China; Danail Stoyanov, University College London, U.K.; Nobuhiko Hata, Harvard University, USA; Alejandro Frangi, University of Leeds, U.K., and KU Leuven, Belgium; Russell H. Taylor, Johns Hopkins University, USA and Terry M. Peters, Western University, Canada.

II. Content

This Special Section on Surgical Vision, Navigation, and Robotics reports state-of-the-art research on key enabling technologies for surgical robots and robotic systems addressing challenges posed by the current COVID-19 pandemic.

Frisken *et al.* [A1] from Brigham and Women's Hospital, Isomics, and the Institute of Computing Technology of the Chinese Academy of Science explore the sources of uncertainty due to segmentation and brain shift that impact the planning of minimally invasive robotic neurosurgery. Their paper proposes a method for computing brain shift uncertainty, showing how to combine these uncertainties into a single risk volume, and providing clinical motivation by presenting their approach in a path planning system for robotic neurosurgery designed for treating mesial temporal lobe epilepsy. Such an approach will be extremely valuable for providing surgeons with an enhanced understanding of risks associated with resection margins close to eloquent brain tissue.

In [A2], Li *et al.* from Tsinghua University describe an environment that detects and segments key objects in the surgical scene, including the patient's head, head frame, and body, and then establishes a multi-view projection voting and super-voxel fusion pipeline that extracts further information from a 3D point cloud scene. The proposed solution allows stereotactic surgical robots to understand their surroundings better, provides semantic information useful for subsequent tasks such as surgical analytics, and lays a foundation for autonomous stereotactic surgical robots.

The contribution by Vagdargi *et al.* [A3] from Johns Hopkins University builds on the theme of robot-assisted neurosurgery dealing with tissue deformation, with a report on implementing a robot-assisted ventriculoscopy system. Their contribution describes an approach for 3D reconstruction, registration, and augmentation of the neuroendoscopic scene with intraoperative imaging, enabling navigation and guidance, even in the presence of tissue deformation, and providing visualization of structures beyond the endoscopic field-of-view of tissue surfaces.

Endoscopic surgery is also the topic of [A4], by Song *et al.* from Tianjin University, where they describe the development of a flexible endoscope joint with excellent motion range, outstanding constant curvature characteristics, minimal hysteresis, and high loading capacity, to support distal operation and observation for flexible endoscopic and natural orifice transluminal endoscopic surgery (NOTES) procedures. Obstacle

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avoidance and colorectal phantom experiments demonstrate its potential for endoscopic surgery and NOTES. Their results demonstrate that this approach can achieve high accuracy and low hysteresis while withstanding surgical forces and load of up to 5 N.

The following two publications deal with surgical skill assessment. The first paper in this theme by Zhou *et al.* [A5] from the Institute of Automation, Chinese Academy of Sciences, deals with the assessment of the high skill level and degree of dexterous manipulation necessary for interventional cardiologists to successfully implement percutaneous coronary interventions. Recognizing there are currently few objective, quantitative and effective methods currently available for PCI skill assessment, the authors propose a novel warping algorithm to match multiple manipulation data. The intra-similarity measure is computed to evaluate the level of consistency between the manipulations of each subject being evaluated. The inter-subject similarity is further analyzed to determine the differences in skill level among the different subjects. The results demonstrate the potential of the proposed technique to facilitate skill assessment in clinical practice and accelerate skill acquisition for surgical robotic training.

The second paper in this theme by Liu *et al.* [A6] from Shandong University, proposes a real-time deep learning approach to detect minimally invasive surgical tools in dynamic surgical video scenes. Their proposed network fully uses the complementary information of spatial and temporal features learned from the laparoscopic video frames. By processing the output information of the Minimally Invasive Surgery (MIS) tool detection algorithm, they extract information relating to surgical tool usage from the laparoscopic video in real-time.

In [A7], Bai *et al.*, from Imperial College London, propose an optimized anthropomorphic coordinated control strategy for single-port access robotic surgery. Their approach is based on a dual-step optimization approach: the configuration of the human arm inspires that during boxing maneuvers. The method's effectiveness is demonstrated in detailed simulation and in-vitro experiments to perform dexterous single-port surgeries requiring bimanual manipulation more effectively than existing methods. Their method encounters less instrument interference and is free from singularities, thereby improving the safety and efficiency of single-port surgery operations.

The contribution from Gervasoni *et al.* [A8] of the University of Zurich and ETH Zurich describes a robotically assisted endoscopic procedure based on magnetically steerable catheters to perform a minimally invasive treatment for spina bifida. While current fetal operative procedures require laparotomy of the abdomen and hysterotomy of the uterus, their proposed minimally invasive approach avoids such trauma and associated complications.

A timely paper due to the impending time of the current pandemic comes from Neidhardt *et al.* [A9] of the Institute of Medical Technology and Intelligent Systems at the Hamburg University of Technology. To minimize the risk of infection when acquiring biopsy samples from diseased cadavers, the authors propose a minimally invasive biopsy strategy with robot assistance under CT guidance to minimize the risk of disease transmission during tissue sampling and improve the risk of disease transmission the accuracy of targeting the biopsy site. They employ a flexible robotic system applied to the cadavers inside protective body bags, where an automatic planning and decision system estimates optimal insertion points. Heat maps projected onto the segmented skin visualize the distance and angle of insertions and estimate the minimum cost of a puncture while avoiding bone collisions. They evaluate their system on 20 corpses and 10 tissue targets, 5 of which were infected with SARS-CoV-2 and demonstrate a mean planning time including robot path planning of ~ 5.7 s and a mean needle placement accuracy of ~ 7.2 mm.

A second paper following the Covid-related theme is from Lv *et al.* [A10] of Zhejiang University, the University of Sydney, and ABB Corporate Research. The authors, driven by the demand to largely mitigate nosocomial infection problems when dealing with COVID-19 patients, demonstrate a novel teleoperation platform that employs a synchronization method enabled by the hybrid mapping of hand gesture and upper-limb motion (GuLiM). This approach allows the joint kinematic design of the human motion tracking and robot motion plan to be simplified such an operational complexity can be reduced and pre-training steps optimized. They demonstrate that the proposed GuLiM method outperforms the traditional direct mapping approach for robotic grasping tasks, and a field investigation of GuLiM illustrates its potential for the teleoperation of a medical assistive robot in the isolation ward to avoid exposure of healthcare workers to COVID-19.

III. Conclusion

This Special Section confirms the important progress made in the areas of Surgical Vision, Navigation, and Robotics, emphasizing the role of these domains in a variety of applications from context-awareness for surgical planning and guidance, surgical skill assessment, minimizing trauma during surgical procedures, and the special role that surgical robotics can play during the current pandemic.

We hope that this Special Section will help stimulate greater interest in this field to address unmet needs in various clinical domains and inspire a new generation of researchers to respond to these challenges.

Appendix: Related Articles

[A1] S. Frisken *et al.*, "Incorporating uncertainty into path planning for minimally invasive robotic neurosurgery," *IEEE Trans. Med. Robot. Bionics*, vol. 4, no. 1, pp. 5–16, Feb. 2022, doi: 10.1109/TMRB.2021.3122357.

[A2] L. Li, P. Feng, H. Ding, and G. Wang, "A preliminary exploration to make stereotactic surgery robots aware of the semantic 2D/3D working scene," *IEEE Trans. Med. Robot. Bionics*, vol. 4, no. 1, pp. 17–27, Feb. 2022, doi: 10.1109/TMRB.2021.3124160.

[A3] P. Vagdargi *et al.*, "Pre-clinical development of robot-assisted ventriculoscopy for 3-D image reconstruction and guidance of deep brain neurosurgery," *IEEE Trans. Med. Robot. Bionics*, vol. 4, no. 1, pp. 28–37, Feb. 2022, doi: 10.1109/TMRB.2021.3125322.

[A4] Y. Song, S. Wang, X. Luo, and C. Shi, "Design and optimization of a 3D printed distal flexible joint for endoscopic surgery," *IEEE Trans. Med. Robot. Bionics*, vol. 4, no. 1, pp. 38–49, Feb. 2022, doi: 10.1109/TMRB.2022.3142516.

[A5] X.-H. Zhou *et al.*, "Surgical skill assessment based on dynamic warping manipulations," *IEEE Trans. Med. Robot. Bionics*, vol. 4, no. 1, pp. 50–61, Feb. 2022, doi: 10.1109/TMRB.2022.3141313.

[A6] Y. Liu, Z. Zhao, P. Shi, and F. Li, "Towards surgical tools detection and operative skill assessment based on deep learning," *IEEE Trans. Med. Robot. Bionics*, vol. 4, no. 1, pp. 62–71, Feb. 2022, doi: 10.1109/TMRB.2022.3145672.

[A7] W. Bai *et al.*, "Anthropomorphic dual-arm coordinated control for a single-port surgical robot based on dual-step optimization," *IEEE Trans. Med. Robot. Bionics*, vol. 4, no. 1, pp. 72–84, Feb. 2022, doi: 10.1109/TMRB.2022.3145673.

[A8] S. Gervasoni *et al.*, "Magnetically assisted robotic fetal surgery for the treatment of spina bifida," *IEEE Trans. Med. Robot. Bionics*, vol. 4, no. 1, pp. 85–93, Feb. 2022, doi: 10.1109/TMRB.2022.3146351.

[A9] M. Neidhardt *et al.*, "Robotic tissue sampling for safe post-mortem biopsy in infectious corpses," *IEEE Trans. Med. Robot. Bionics*, vol. 4, no. 1, pp. 94–105, Feb. 2022, doi: 10.1109/TMRB.2022.3146440.

[A10] H. Lv *et al.*, "GuLiM: A hybrid motion mapping technique for teleoperation of medical assistive robot in combating the COVID-19 pandemic," *IEEE Trans. Med. Robot. Bionics*, vol. 4, no. 1, pp. 106–117, Feb. 2022, doi: 10.1109/TMRB.2022.3146621.

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