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Editorial for the special issue on design, sensing and control in medical robots

In the past decades, surgical robotics have been developed rapidly, promoting significant progress in the medical field. With the support of compact system design and advanced sensing technology, surgical robotics have successfully reduced doctors' training costs and surgical risks, and also shorten the patient recovery time. The continual progress advances in materials, microelectronics, medical vision, control theory and other related fields have played a pivotal role in facilitating unprecedented breakthroughs in surgical robotics. These advancements have resulted in improved biocompatibility and control accuracy of surgical robots, as well as enhanced intraoperative sensing capabilities. As a result, the prospects for medical applications of surgical robots are broad and promising.

This special issue "Design, Sensing and Control in Medical Robots" serves as a platform to present original research contributions and reviews on the latest technologies in this field. The issue comprises 6 research articles and 1 review, providing perspectives on the novel design, sensing capabilities, and control of surgical robots, shedding light on their potential medical applications.

The review paper by Lin et al. [1] provides an overview of the methods have been implemented to enable adjustable stiffness for flexible surgical robots. They categorized the methods based on their basic principles of varying the stiffness. Moreover, the paper summarized the anatomic constraints of common natural tracts of human body to provide a guidance for the design of variable stiffness flexible robots. In the end, two variable stiffness methods with great potential and the moving strategy of variable stiffness flexible robots are discussed.

Wan et al. [2] present an algorithm for defect detection and repair in structures generated by topology optimization. A 3D hierarchical fully convolutional network (FCN) is used to identify defects and suggest repairs. The approach integrates machine learning techniques with traditional optimization methods, enhancing the structural integrity and performance of the optimized designs. The method is validated through various examples, demonstrating its effectiveness and potential for practical applications in engineering.

The paper by Kou et al. [3] introduces a preoperative virtual reduction method for pelvic fractures utilizing statistical shape models and partial surface data. The method aims to enhance the efficiency and accuracy of pelvic fracture reductions in clinical applications. The proposed approach was validated through simulated fracture and clinical case experiments. The simulated experiments showed an average error of 1.57 ± 0.39 mm and a maximum error of 12.82 ± 3.54 mm, with the virtual reduction process taking approximately 40 s. Clinical case experiments demonstrated that the method achieves accuracy comparable to manual reduction by surgeons. This method offers the advantages of shorter reduction times and satisfactory accuracy and is planned to be integrated into preoperative planning systems to improve patient outcomes.

The paper by Jia et al. [4] presents a visual servoing-based pneumatic hair transplantation mechanism for robotic FUE surgery. The objective is to automate both hair implantation and extraction using a pneumatic system equipped with a camera. This method eliminates the complex needle structure and allows temporary storage of follicles inside the needle, facilitating the automation of follicle transfer. A visual feedback system is also proposed to accurately position the follicles during transplantation. Experimental results demonstrate the system's feasibility, showing an average distance deviation of 0.6128 mm between actual and target positions and an average hair implantation depth deviation of 1.7176 mm.

The paper by Zhang et al. [5] presents a positioning system design for a closed-loop magnetically driven laser steering manipulator intended for endoscopic microsurgery. The system features a multimagnetic field strength sensor circuit embedded in a 16-mm diameter analog laser steering manipulator. An integral model is used to accurately represent the magnetic field distribution of a cylindrical permanent magnet in three-dimensional space, addressing the errors from the magnetic dipole model. The integral is decomposed using Gauss–Legendre quadrature to enhance computational efficiency. Five global search optimization methods are compared, and a hybrid optimization algorithm combining the tree-seed algorithm and the Levenberg–Marquardt algorithm is developed for superior computational rate and accuracy. Static and dynamic experiments validate that this system achieves satisfactory computational errors while maintaining high computational speed.

In order to improve the repositioning accuracy of a fracture reduction robot (FRR), An et al. [6] proposed a Levy-sparrow search algorithm (Levy-SSA) to adjust the robot controller parameters. First, inverse dynamics controller for the FRR was designed using the computed torque control method. Then, Levy-SSA is added into the control framework to select appropriate PID parameters which effectively reduces error between the actual and desired positions. Both simulation and physical experiments show that Levy-SSA had an average error reduction of 98.74% comparing with the traditional unoptimized controller.

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Surgeon's field of view is easy to be hampered because the surgical instruments occupy most of the area in working space. The paper by Xie et al. [7] devoted to use image restoration and interframe information filling to remove the occlusions in endoscopic images. The algorithm proposed in this paper automatically fills the occluded region by utilizing information from the surrounding areas in the current frame and data from previous frames. Clinical endoscopic images are used to validate the feasibility, and the results indicate that it enhances the visual quality of endoscopic images by eliminating surgical-instrument occlusions.

The Guest Editors thank all authors and reviewers who made great contributions to this Special Issue. All of the papers underwent a two-round rigorous review process to ensure the high quality of the publications. A special thanks to the journal Editors for their support and effort in the organization and publication of this Special Issue. We hope the papers in this collection are helpful for researchers to develop advanced surgical robotics for the benefit of our society.

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