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Robotic Systems for Remote Surgery: Exploring Limitations

Chrispus Owunyesiga

Department of Electrical Engineering Kampala International University Uganda
Email: chrisounyesiga@gmail.com

ABSTRACT

Robotic systems in remote surgery have significantly transformed the landscape of modern medical procedures. These innovations have improved precision, reduced recovery time, and extended specialist access, especially in underserved regions. However, despite the advancements, several challenges persist. This paper critically evaluates the benefits and limitations of robotic systems in remote surgery. It highlights technological issues such as communication latency, system reliability, and lack of tactile feedback, as well as non-technical barriers such as cost, training, and global accessibility. Through case studies, the paper examines the current state of robotic systems in telesurgery and suggests future directions for overcoming existing hurdles.

Keywords: Robotic surgery, telesurgery, remote surgery, teleoperation, haptic feedback, surgical precision.

INTRODUCTION

Surgical procedures have undergone massive evolutions since their inception several centuries ago. Medical professionals have moved from open surgeries to laparoscopic and, more recently, robotic systems. The growing designs of robots for these systems have encouraged further research in this innovative direction. Early applications of these robots mostly paralleled human actions from the console and were, thus, termed "hands-free" surgery. As these robots began to take a more automated approach, a symbiotic form of surgery became increasingly tangible across surgeon groups in both medical and paramedical fields such as engineering. With the potential for remote surgery having become a reality, exploring what one could not do in robotic systems furthered the field by trying to correct these flaws. Additionally, creating a robotic surgery system without identifying its limitations would be "an injustice to the potential applications that have not yet been explored that really may require it" [1, 2]. The addition of human-like dexterity reduced the fear of errors in large complex human surgeries, also eliminating the risk of fatality. This provided further innovations in cases of mass disasters and the need for increased accessibility to specialists in developing countries. The benefits of the increased precision provided with dexterity could increase patient satisfaction with surgical outcomes. Surgery using minimally invasive techniques allows patients a faster recovery time, thereby reducing any additional costs the longer recovery normally entails. While the process of removing human error and injury due to a system by using feedback control was reaching high levels in most other fields, the belief was that it would also help the healthcare system in further reductions in insurance fees, medication, and various tests similar to other systems available for diagnostics and treatment. This paper aims to critically evaluate the advantages of surgical robotics, the criticisms, and, mainly, their effects. A few areas have been reached with their best performances, while others seem to continue explaining why utilities have barely scratched the surface [3, 4].

Overview of Robotic Systems in Remote Surgery

Robotic systems have revolutionized surgical procedures and have been adopted as a standard practice in operating rooms across the world. Such systems enable surgeons to perform procedures with high precision, less trauma, minimal blood loss, and shortened recovery times. The evolution of robotic systems is attributed to the development of minimally invasive surgical techniques, the field of telesurgery, space and military research, information exchange, and the development of enabling technologies such as haptic interfaces, position sensors, and high-speed networks [5, 6]. Robotics have further evolved in the last two decades, and various specialized systems have been developed, characterized by enabling features such as teleoperation, haptic feedback, advanced imaging, and other sensory features. Commonly employed robotic systems for remote surgery purposes can be categorized into four types: end effectors, mobile robots, master-slave robots, and wristed robotic arms. These systems are utilized to provide patients or subjects with minimally invasive therapy interventions, and they can be integrated into MRI scanners, CT scanners, and angiography suites. Additionally, these robotic systems enable the performance of surgery, tissue and pathology biopsies, muscle and joint treatments, explorative surgery, and cough tests [7, 8]. The integration and certification of robotic systems with the existing medical equipment comply with the relevant harmonized standards and regulatory agencies. In recent years, the market trend for robotic systems, including teleoperated remote systems, vibratory-based systems, and MRI-compatible robots, has shown an increasing interest in using robots for this type of intervention. Furthermore, teleoperated robotic systems that can interact with a surgeon using haptic feedback in real-time are also included in the market trend, providing a comprehensive overview that future robotic systems will consider regarding restrictions on market demand. As a result, concerning the utility function, medical robotic devices should not pose any potential danger, ensuring the safety of the devices [9, 10].

Benefits of Robotic Systems in Remote Surgery

Remote robotic systems provide an efficient means of improving precision and dexterity in the context of remote surgery. Robotic systems help turn the surgeon's hand movements into those with improved precision, providing superior control and tactile sensitivity. This added level of fine motor control and precision potentially translates to improved patient outcomes. Through the use of haptic feedback, robotic telemedicine allows surgeons to "feel" in a very limited fashion the forces encountered during surgery. Broadly speaking, operational ranges for remote and robotic systems are user-programmable. These features could potentially make for an easy transition to increasingly common, albeit in many cases uninitiated, robot-assisted surgical procedures of increased technical complexity such as partial nephrectomies or reconstructive surgery. Robotic remote surgical systems offer a platform for less invasive surgeries, which in turn might benefit the patient in terms of reduced scarring and/or improved recovery time in comparison to more radical open surgeries [11, 12]. The use of robotic systems also has the potential to improve the overall healthcare environment. The advent of minimally invasive surgery demonstrates extensive economic advantages, reduced pain and recovery times for the patient, and reduced displacement and fatigue for otherwise standing assistant staff in the crowded, unergonomic, radiation-laden environments of most major surgical subspecialties. Expanded use of ambidextrous telesurgical systems could serve as an excellent means of mathematically defining the non-verbal and partially directed intricacies of a given surgical robotic system. This definition could foreseeably be employed as part of the training process. Insomuch as remote surgical robotic systems might offer points of entry for direct multiple remote operator control, the resultant points of operation of the robot are assumed to be very similar, if not identical. The robotic extension of minimally invasive laparoscopic surgeries therefore will not differ from side to side with minor exceptions. Given the preponderance of dual-console surgically oriented robots in laparoscopy, a practicing laparoscopic surgeon would in theory not have to take the "off" console whenever passing back and forth on a remote or robotic surgical case. In current practice, the off console is indeed vacated during a switchover. The number of surgeon-staff available to be off-console is often limited; however, necessitating some form of automatic robotic transition on the "off" console [13, 14].

Challenges and Limitations of Robotic Systems in Remote Surgery

Robotic systems have become an attractive option for the execution of remote surgeries. Despite this, the technology also presents researchers with numerous challenges, both of a technical and a non-technical nature. At the end of the day, the most desirable properties of a robotic system for surgical intervention are that it can reliably reproduce what a surgeon wishes to do. The majority of technological limitations of these systems are related to the digitization of the human operator and patient, and the transmission of commands over a network. First, there exists the problem of time delay in the communication line between the human and the robotic system, and the reflected delay arising from the control system present within a robotic system. The latency and low data throughput of the available technologies will also determine the burden of the data compression strategy potentially implemented to reduce the impact [15, 16]. The cost of purchasing, as well as the maintenance of such remote surgical robotic systems, is also a downside of present implementations. Although most developed countries can afford such expenses and incorporate the use of such systems in their medical facilities, there exist many developing countries that would struggle to do this. Most of the robotic systems proposed are composed of state-of-the-art technologies and thus are very expensive to produce. Apart from the expenses, other factors that should be taken into account for implementation in a hospital are the respective training programs needed for the surgeons to get used to the technologies and prior experience with telecommunication software and human control. It should be noted that the surgical robot is traditionally looked upon as the surgeon's arms. Mastering the controls that the robot offers may be the most difficult hurdle that surgeons may have to encounter. The feeling of deoculus manibus that the surgeon may have would be comforting [17, 18]. Based on the distance present and the time delay, or to be more specific, the consequences of an insurmountable and unmanageable time delay, it is generally accepted that there are four types of teleoperations. Although any teleoperator could be a form of remote surgery, we shall focus on the details of communications performance. Teleoperation systems are subjected to the constraints of asymmetry (even though surgeons and patients are performing in the same physical environment, the surgeon is subject to much more feedback). There is also little or no tactile feedback available in control systems, and psychophysical transparency, and abilities to manipulate remote objects, are limited. In addition to the note at the beginning of this paper, there should be emphasis on some of the preliminary discussions about teleoperations, humans at a remote location, robotics, etc., including those on safety and reliability. These are currently live discussions in the robotics community. Furthermore, while these issues are significant in other teleoperation arenas, they are, for the most part, less mature and have significant challenges that must be addressed. Hyper research is therefore dedicated to these topics [19, 20].

Case Studies and Examples

To concretely examine the problems associated with developing a robot for remote manipulation and telesurgery, we have developed a small series of prototype systems. These systems are: 1) a small five-degree-of-freedom robotic arm for basic research; 2) a pair of nine-degree-of-freedom arm/hand robotic systems designed for control and study of the issues involved in preparing the operation fields of remote surgery; 3) a master-slave force-controlling robotic system that is cable-operated; and 4) an optically tracked master-slave force-reflecting robotic system capable of providing base isolation. These systems exhibit the basic technologies involved: integrated robot design, base isolation, and advanced human/machine interfaces all implemented using a small number of degrees of freedom in each arm in keeping with a measure of controller simplicity, possibly easing the burden that LEDs and head-mounted optics impose on the surgeon [21, 22]. For each unique interface and researching its potential, we have executed a series of simple manipulation experiments and occasionally generated models of forces and torques caused by blunt or sharp tools. For example, we have determined some force properties of forced probing where a feedback loop is governed by passive manipulation of the robotic systems by the operator. As a result, we are accumulating the requisite practical knowledge with a few robotic system degrees of freedom currently available in readily deployable, cost-effective systems [23, 24].

Future Directions

Recently, the advent of robotic systems for remote surgery suggested potential support for performance improvement due to cognitive overload. In this paper, we discussed the motivations for pursuing robotic surgical systems and existing robotic-assisted systems for semi-automated and teleoperated procedures. Although progress suggests that such systems have clinical potential, there are still limitations, such as variations in cognitive load monitoring, the assessment of surgical skills, and the ethical impact of performing general surgery without clinical training, which must be addressed. Future work must carefully consider these limitations and aim to expand on areas of promise for validated progress. The possible distribution of high-quality surgical care and knowledge on a global scale has been established as a future direction for medical innovation by robotics companies. The demand for surgery is expected to evolve in alignment with the growing prevalence of non-communicable diseases in developing countries. It will be crucial that future developments of robotic surgical technology focus on addressing the limitations of remote systems previously discussed and plan more broadly to generate innovative solutions for the healthcare demands of tomorrow. The development of such surgical technological systems will require collaboration between a wide interdisciplinary range of stakeholders: technologists and engineers must work with medical professionals to develop clinically relevant, evidence-based systems that can be trusted through the regulatory process. Given these large-scale collaborative systems development projects, the true potential of robotic surgery could still lie in the future. Building upon the present discussions in remote technology, recent advances in robotic applications in telesurgery are also prominent. There is ongoing research in telesurgery systems, and this project is a progenitor of telesurgical robotics [25, 26, 27].

CONCLUSION

While robotic systems for remote surgery have shown considerable promise, several significant limitations hinder their widespread adoption and effectiveness. Key challenges include communication delays, lack of tactile feedback, and the high cost of implementation, particularly in developing countries. These factors restrict the potential for large-scale deployment and comprehensive use. Nevertheless, advancements in robotics, teleoperation, and interdisciplinary collaboration between engineers and medical professionals continue to push the boundaries of what is possible. Future research should focus on improving system reliability, reducing costs, and enhancing the training processes for surgeons, while also addressing the ethical concerns around performing surgeries remotely. The future of remote surgery lies in overcoming these challenges, fostering innovation, and ensuring that the benefits of this technology are accessible worldwide.

REFERENCES

1. Zhang T, Mo H. Reinforcement learning for robot research: A comprehensive review and open issues. International Journal of Advanced Robotic Systems. 2021 May 28;18(3):17298814211007305. sagepub.com
2. Choi H, Crump C, Duriez C, Elmquist A, Hager G, Han D, Hearl F, Hodgins J, Jain A, Leve F, Li C. On the use of simulation in robotics: Opportunities, challenges, and suggestions for moving forward. Proceedings of the National Academy of Sciences. 2021 Jan 5;118(1):e1907856118. pnas.org
3. Patuzzo S, Balistreri M, Marinelli T, Giacopuzzi S. Is a robot surgeon with AI the ideal surgeon? A philosophical analysis. AI and Ethics. 2023 Nov 6:1-1.
4. Cepolina F, Razzoli RP. An introductory review of robotically assisted surgical systems. The International Journal of Medical Robotics and Computer Assisted Surgery. 2022 Aug;18(4):e2409. wiley.com
5. Chen IH, Ghazi A, Sridhar A, Stoyanov D, Slack M, Kelly JD, Collins JW. Evolving robotic surgery training and improving patient safety, with the integration of novel technologies. World journal of urology. 2021 Aug;39:2883-93. springer.com
6. Haidegger T, Speidel S, Stoyanov D, Satava RM. Robot-assisted minimally invasive surgery—Surgical robotics in the data age. Proceedings of the IEEE. 2022 Jun 23;110(7):835-46. ieee.org
7. Moniruzzaman MD, Rassau A, Chai D, Islam SM. Teleoperation methods and enhancement techniques for mobile robots: A comprehensive survey. Robotics and Autonomous Systems. 2022 Apr 1;150:103973. [HTML]
8. Ghith ES, Tolba FA. Design and optimization of PID controller using various algorithms for micro-robotics system. Journal of Robotics and Control (JRC). 2022 May 1;3(3):244-56.
9. Iizuka M, Ikeda Y. Regulation and innovation under the 4th industrial revolution: The case of a healthcare robot, HAL by Cyberdyne. Technovation. 2021 Dec 1;108:102335.
10. Calleja C, Drukarch H, Fosch-Villaronga E. Harnessing robot experimentation to optimize the regulatory framing of emerging robot technologies. Data & policy. 2022 Jan;4:e20.
11. Zhu J, Lyu L, Xu Y, Liang H, Zhang X, Ding H, Wu Z. Intelligent soft surgical robots for next-generation minimally invasive surgery. Advanced Intelligent Systems. 2021 May;3(5):2100011. wiley.com
12. Reddy K, Gharde P, Tayade H, Patil M, Reddy LS, Surya D. Advancements in robotic surgery: a comprehensive overview of current utilizations and upcoming frontiers. Cureus. 2023 Dec;15(12). nih.gov
13. Emmen AM, Görgec B, Zwart MJ, Daams F, Erdmann J, Festen S, Gouma DJ, van Gulik TM, van Hilst J, Kazemier G, Lof S. Impact of shifting from laparoscopic to robotic surgery during

600 minimally invasive pancreatic and liver resections. Surgical endoscopy. 2023 Apr;37(4):2659-72. springer.com
14. Lunardi N, Abou-Zamzam A, Florecki KL, Chidambaram S, Shih IF, Kent AJ, Joseph B, Byrne JP, Sakran JV. Robotic technology in emergency general surgery cases in the era of minimally invasive surgery. JAMA surgery. 2024 May 1;159(5):493-9. [HTML]
15. Wrzosek M. Challenges of contemporary command and future military operations. Scientific Journal of the Military University of Land Forces. 2022;54(1 (203):35-51. bibliotekanauki.pl
16. Lang V. Digitalization and digital transformation. InDigital Fluency: Understanding the Basics of Artificial Intelligence, Blockchain Technology, Quantum Computing, and Their Applications for Digital Transformation 2021 Apr 9 (pp. 1-50). Berkeley, CA: Apress. [HTML]
17. Hughes T, Rai B, Madaan S, Chedgy E, Somani B. The availability, cost, limitations, learning curve and future of robotic systems in urology and prostate cancer surgery. Journal of Clinical Medicine. 2023 Mar 15;12(6):2268. mdpi.com
18. Mehta A, Ng JC, Awuah WA, Huang H, Kalmanovich J, Agrawal A, Abdul-Rahman T, Hasan MM, Sikora V, Isik A. Embracing robotic surgery in low-and middle-income countries: Potential benefits, challenges, and scope in the future. Annals of Medicine and Surgery. 2022 Dec 1;84:104803. sciencedirect.com
19. Zhao Y, Liu PX, Wang H, Bao J. Funnel-bounded synchronization control for bilateral teleoperation with asymmetric communication delays. Nonlinear Dynamics. 2022 Mar;107(4):3641-54.
20. Kucukdemiral I, Yazici H, Gormus B, Bevan GP. Data-driven H∞ control of constrained systems: An application to bilateral teleoperation system. ISA transactions. 2023 Jun 1;137:23-34.
21. Zhang W, Li H, Cui L, Li H, Zhang X, Fang S, Zhang Q. Research progress and development trend of surgical robot and surgical instrument arm. The International Journal of Medical Robotics and Computer Assisted Surgery. 2021 Oct;17(5):e2309. [HTML]
22. Kikuchi K, Suda K, Shibasaki S, Tanaka T, Uyama I. Challenges in improving the minimal invasiveness of the surgical treatment for gastric cancer using robotic technology. Annals of Gastroenterological Surgery. 2021 Sep;5(5):604-13. wiley.com
23. Pisetskiy S, Kermani MR. Design and development of the transmission for a fully actuated 5-degrees-of-freedom compliant robot manipulator with a single motor. Journal of Mechanisms and Robotics. 2024 Feb 1;16(2):021003. researchgate.net
24. Jiang J, Newman ST, Zhong RY. A review of multiple degrees of freedom for additive manufacturing machines. International Journal of Computer Integrated Manufacturing. 2021 Feb 1;34(2):195-211. bath.ac.uk
25. Habuza T, Navaz AN, Hashim F, Alnajjar F, Zaki N, Serhani MA, Statsenko Y. AI applications in robotics, diagnostic image analysis and precision medicine: Current limitations, future trends, guidelines on CAD systems for medicine. Informatics in Medicine Unlocked. 2021 Jan 1;24:100596. sciencedirect.com
26. Iordachita II, De Smet MD, Naus G, Mitsuishi M, Riviere CN. Robotic assistance for intraocular microsurgery: Challenges and perspectives. Proceedings of the IEEE. 2022 May 9;110(7):893-908. nih.gov
27. Mohan A, Wara UU, Shaikh MT, Rahman RM, Zaidi ZA. Telesurgery and robotics: an improved and efficient era. Cureus. 2021 Mar;13(3). nih.gov

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