International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 2, No. 4, October 2013

Review Article

MEDICAL ROBOTICS AND AUTOMATION

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The Society is interested in both applied and theoretical issues in robotics and automation. Robotics is here defined to include intelligent machines and systems used, for example, in space exploration, human services, or manufacturing; whereas automation includes the use of automated methods in various applications, for example, factory, office, home, laboratory automation, or transportation systems to improve performance and productivity. Robotics and Automation involves designing and implementing intelligent machines which can do work too dirty, too dangerous, too precise or too tedious for humans. It also pushes the boundary on the level of intelligence and capability for many forms of autonomous, semi-autonomous and teleported machines. Intelligent machines have applications in medicine, defense, space and underwater exploration, service industries, disaster relief, manufacturing and assembly and entertainment. This paper employs the rubric of medical robotics, reflecting common historical use of Medicine to differentiate non-invasive diagnosis and therapy from surgery.

Keywords: Automation, CARDI, Non-invasive diagnosis, Biomechatronics, Neurorobotics, Telesurgery

INTRODUCTION

This paper employs the rubric of medical robotics, reflecting common historical use of Medicine to differentiate non-invasive diagnosis and therapy from surgery (e.g., medical oncology that counteracts tumor growth with chemotherapy vs. surgical oncology that removes tumors; medical cardiology that reverses atherosclerosis with drugs, diet, and exercise vs. surgical cardiology that uses angioplasty to remove coronary plaque). Therapeutic and rehabilitative applications of robots (e.g., physical therapy, prosthetic machines to emulate limb function) arguably merit a fourth classification—perhaps presaging a fourth TEWS white paper. Indeed, current differences in specific applications support designation of four distinct categories of robots in health care delivery: surgical, medical, service, and rehabilitative. The distinctions are relevant because robots designed to perform tasks in

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any one of the four clinical areas would generally not be suitable for use in any one of the others. Vendors will be differentiated accordingly, that is, a market leader in one area will probably not offer products in the other three.

The expanding scope of robotic applications in health care is demonstrated by a sampling of keywords used to catalogue articles in a recent issue of the Proceedings of the Institute of Electrical and Electronics Engineers.

- Active constraint robotics.
- Anatomical models.
- Augmented reality.
- Biomechanics.
- Biomechatronics.
- Computational models.
- Computer-integrated surgery.
- Haptic interfaces.
- Virtual reality.
- Telesurgery.
- Human-machine Cooperative systems.
- Medical image analysis.
- Navigation.
- Neurorobotics.
- Robotic assistive systems.
- Surgical assistants.
- Telerobotics.

The diverse professional origins of these terms demonstrate how robotic applications in Health care are the product of multidisciplinary collaboration. Bioscientists, statisticians, psychologists, and many types of engineers (e.g., computer, mechanical, electrical, Optical) are contributing simultaneously to the creation of robotic applications in wide variety of domains. New applications in health care will evolve from today's robotic developments in aerospace, aviation, manufacturing, distribution, transportation, and other industrial sectors. Consequently, medical robotics has the potential to develop in some unexpected and promising directions.

KEY TECHNOLOGY

Key technologies for robotics in biological and medical applications include the following:

- MEMS technologies that can fabricate tools and devices suitable for micro sensing, micro actuation and micromanipulation of biosamples/solutions and bio-objects such as cells. These technologies use either IC-fabricating methods or use micromachining methods.
- Special robotic systems that can perform surgery precisely and at low cost. The challenge is to program motion of robots efficiently based on patient-specific modeling and analysis.
- Modeling and analysis algorithms that is precise and fast for individual patients.
- Reliable and efficient system integration of off-the-shelf components and devices for specific biological and medical operations.
- Engineering modeling of biological systems. The purpose is to develop mathematical models for explaining the behavior and structure of biological systems as engineers do for artificial physical

systems. This has been proved extremely challenging because of the complexity of biological systems.

- Solid understanding of life science. To develop an effective robotic or automation system for biological and medical applications, it is necessary for engineers to have a deep understanding of life science. Yuan Zheng, George Bekey, Arthur Sanderson 67 From the above, one can see that robotics for biological and medical applications covers a wide scope of technologies from conventional robots and sensors to micro sensors and actuators, from tools and devices to Algorithms. For molecular-level study of biological systems, nano-devices and actuation are key technologies as well.

THE FUTURE OF ROBOTIC SURGERY

Medical robotics (and the larger field of computer integrated interventional medicine) has great potential to revolutionize clinical practice by:

- Exploiting technology to transcend human limitations in treating patients .
- Improving the safety, consistency, and overall quality of interventions.
- Improving the efficiency and cost-effectiveness of patient care.
- Improving training through the use of simulators, quantitative data capture and skill assessment methods, and the capture and playback of clinical cases.
- Promoting more effective use of information at all levels, both in treating individual patients and in improving treatment processes From being the stuff of late-night comedy and science

Fiction 20 years ago, the field has reached a critical threshold, with clinically useful systems and commercial successes. The scope and number of research programs has grown exponentially in the past 5 years, and this chapter is by no means a comprehensive survey of the field. Interested readers are urged to refer to the further reading section for more complete treatments. In particular, the survey articles in listed at the end of this section collectively contain somewhat fuller bibliographies than space permits here. In the future, we can expect to see continued research in all aspects of technology and system development, with increasing emphasis on clinical applications. As this work proceeds, it is important that researchers remember several basic principles. The first, and arguably most important, principle is that medical robotics is fundamentally a team activity, involving academic researchers, clinicians, and industry. Each of these groups has unique expertise, and success comes from effective, highly interactive partnerships drawing upon this Expertise. Building these teams takes a long-term commitment, and the successes in recent years are largely the pay-off from investments in creating these teams second, it is important to work on problems with well-defined clinical and technical goals, in which the criteria for measuring success are ultimately related to real advantages in treating patients. In working toward these Goals, it is important to have measurable and meaningful milestones and to emphasize rapid iteration with clinician involvement at all stages. Finally, it is essential that all team members recognize the level of commitment that is required to achieve success and that they enjoy what they are doing. Robotic surgery is in its infancy. Many obstacles and disadvantages will be resolved in time and no doubt many other questions will arise. Many questions have yet to be asked; questions such as malpractice liability, credentialing, training requirements, and interstate licensing for tele-surgeons, to name just a few. Many of current advantages in robotic assisted surgery ensure its continued development and expansion. For example, the sophistication of the controls and the multiple degrees of freedom afforded by the Zeus and da Vinci systems allow increased mobility and no tremor without comprising the visual field to make micro anastomosis possible. Many have made the observation that robotic systems are information systems and as such they have the ability to interface and integrate many of the technologies being developed for and currently used in the operating room One exciting possibility is expanding the use of preoperative (computed tomography or magnetic resonance) and intraoperative video image fusion to better guide the surgeon in dissection and identifying pathology. These data may also be used to rehearse complex procedures before they are undertaken. The nature of robotic systems also makes the possibility of long-distance intraoperative consultation or guidance possible and it may provide new opportunities for teaching and assessment of new surgeons through mentoring and simulation. Computer Motion, the makers of the Zeus robotic surgical system, is already marketing a device called SOCRATES that allows surgeons at remote sites to connect to an operating room and share video and audio, to use a “telestrator” to highlight anatomy, and to control the AESOP endoscopic camera.

Technically, many remains to be done before robotic surgery’s full potential can be realized. Although these systems have greatly improved dexterity, they have yet to develop the full potential in instrumentation or to incorporate the full range of sensory input. More standard mechanical tools and more energy directed tools need to be developed. Some authors also believe that robotic surgery can be extended into the realm of advanced diagnostic testing with the development and use of ultrasonography, near infrared and co focal microscopy equipment. Much like the robots in popular culture, the future of robotics in surgery is limited only by imagination. Many future “advancements” are already being researched. Some laboratories, including the authors’ laboratory, are currently working on systems to relay touch sensation from robotic instruments back to the surgeon. Other laboratories are working on improving current methods and developing new devices for suture-less anastomoses.When most people think about robotics, they think about automation. The possibility of automating some tasks is both exciting and controversial. Future systems might include the ability for a surgeon to program the surgery and merely supervise as the robot performs most of the tasks. The possibilities for improvement and advancement are only limited by imagination and cost.

FUTURE CLINICAL APPLICATIONS

Applications of robotic telepresence in patient care will extend into many other clinical Areas as more clinicians and managers become aware of the devices and their initial successes. The examples in the previous section illustrate only the initial uses of a technology with untapped capabilities to help combat labor shortages and access problems. In addition to deploying medical robots in service lines where they have not yet been tried, health care's creative leaders will undoubtedly develop applications that transcend any particular medical specialty. This author's analysis of current challenges in health care delivery suggests some interesting examples of clinical circumstances where medical robots might flourish:

- Isolating caregivers from patients whose conditions would put a caregiver at risk, such as using a medical robot to examine a patient affected by a deadly contagious disease (e.g., avian flu) or contaminated by an environmental hazard (e.g., radioactivity, toxic chemical) that could harm health professionals who come in direct contact with the patient.
- Establishing an interface between a remote caregiver and a blind, deaf, or mute patient, with the robot's sound system, video, or keyboard interfaces used to compensate respectively for the patient's inability to see, hear, or speak with a health professional in the same room.
- Overcoming cultural or religious barriers to care when on-site caregivers and patient are incompatible for non-clinical reasons, such as using a medical robot controlled by a remote female practitioner to examine a Moslem woman in hospital where all onsite practitioners are male.
- Providing an unbiased clinician when the onsite caregiver would have a potential conflict of interest with the patient, such as substituting the remote physician for adductor who is called upon to treat a family member or a patient with whom he or she has had a personal conflict.
- Expanding the use of advanced practice nurses (e.g., nurse practitioners, certified nurse midwives), clinical pharmacists, and other qualified non-physician practitioners who are delivering more services that were previously offered only by physicians that is, developing robotic telepresence in the context of nursing and pharmacy practice patterns. Creating an international community of medical specialists who can provide superior treatment to patients with whom they share medically relevant bonds, such as a physician in India using the robot to treat a Hindu patient in an American hospital without any clinicians who can speak the patient's language or make medical decisions in consideration of the patient's culture. (With their ability to connect a non-English speaking patient to a remote clinical who speaks the patient's language, medical robots have already proven their value in overcoming language barriers).

As new applications are developed, medical robotics will surely encounter the same problems that telemedicine had to address as it became an established platform for providing health care. Payment, licensure, liability, reliability, cost, and other issues will all arise because robotic telepresence is something new and different. Fortunately, medical robotics can learn important lessons by studying the history of telemedicine and accelerate the learning curve, if not avoid the problems. Telemedicine has moved from the periphery of common practice to widespread acceptance in approximately a decade. Given the technological similarities between robotic telepresence and telemedicine, the adoption of medical robotics certainly has potential to occur in considerably less than ten years.

IMPLICATION ACD CHALLANGES

Bon Secours is already a pioneer in medical robotics at its Baltimore Health System Hospital. In addition to drawing upon its existing experience with telepresence, BSHSI should consider several other related opportunities to enhance performance throughout the system:

- Prepare appropriate, concise information materials to inform clinical leader's and service line managers about the use of medical robots to improve productivity of overextended health professionals and to enhance performance in areas where robots have already demonstrated their value in health care. These materials should be disseminated to local and system-wide task forces that are revising care delivery processes. A focused, one-hour continuing education program on medical robots could be prepared to launch the awareness campaign throughout the system.
- Begin active pursuit of partnerships with research organizations and vendors to develop creative applications of medical robots in selected Bon Secours facilities. A group of senior managers could be organized to identify research and development opportunities and to enlist clinicians in the process of forming partnerships.
- Provide implementation support to physicians and other clinicians who decide to use a medical robot to enhance their services' efficiency and effectiveness. The supportive services should include readiness assessments and implementation assistance to prepare participating clinicians for successful adoption of the technology and related changes in patterns of care.

CONCLUSION

Although still in its infancy, robotic surgery has already proven itself to be of great value, particularly in areas inaccessible to conventional laparoscopic procedures. It remains to be seen, however, if robotic systems will replace conventional laparoscopic instruments in less technically demanding procedures. In any case, robotic technology is set to revolutionize surgery by improving and expanding laparoscopic procedures, advancing surgical technology, and bringing surgery into the digital age. Furthermore, it has the potential to expand surgical treatment modalities beyond the limits of human ability. Whether or not the benefit of its usage overcomes the cost to implement it remains to be seen and much remains to be worked out. Although feasibility has largely been shown, more prospective randomized trials evaluating efficacy and safety must be undertaken. Further research must evaluate cost effectiveness or a true benefit over conventional therapy for robotic surgery to take full root.

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