Medical Robotics

Part II: SURGICAL ROBOTICS

In the last decade, surgery and robotics have reached a maturity that has allowed them to be safely assimilated to create a new kind of operating room. This new environment includes robots for local surgery and telesurgery, audiovisual telecommunication for telemedicine and teleconsultation, robotic systems with integrated imaging for computer-enhanced surgery, and virtual reality (VR) simulators enhanced with haptic feedback, for surgical training. According to Satava\(^1\), “the operating room of the future will be a sophisticated mix of stereo imaging systems, microbots, robotic manipulators, virtual reality/telepresence workstations, and computer integrated surgery.”

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Human–Machine Interfaces in Surgery

Performing a surgical task involves three primary entities: the surgeon, the medium, and the patient. The medium is the means through which the surgeon sees, interacts, and communicates with the patient. It may include standard surgical instruments, an endoscopic camera system, laparoscopic instruments, a robotic surgery system, and/or various other technologies. Figure 2 schematically depicts the human–machine interfaces for various surgical setups. As the physician is moved farther away from the patient, the medium introduced between the surgeon and the patient becomes more complex and places more constraints into the audio, visual, and physical communication/interaction channels between the surgeon and patient.

Nevertheless, in some setups this complex medium may introduce valuable information by providing force feedback, enhancing vision, or enhancing the surgeon’s kinematic capabilities by scaling down motion and filtering out hand tremor.

In conventional open surgery, the surgeon interacts with the internal tissues through a relatively large open incision, using direct hand contact or surgical instruments (Fig. 2a). There is no mediator in any of the communication channels: audio, visual, motion, or haptic (force feedback). In the absence of constraints on the surgical tool, the surgeon can translate and orient it anywhere in the surgical scene, using six DOF. In a minimally invasive surgery (MIS) setup, the tools and endoscopic camera are inserted through ports into the body’s cavity (Fig. 2b).
Fig. 2 Modalities used in different configurations for performing surgery: (a) open surgery; (b) minimally invasive surgery; (c) robotic surgery; (d) telerobotic surgery; (e) telemedicine or teleconsultation during surgery; (f) surgical simulation. The type of information being transferred is denoted by (A)–Audio; (M)–Motion, Haptics or Force Feedback; (V)–Vision; and (P) Positioning.²

² John E. Speich, Jacob Rosen, Medical Robotics, Encyclopedia of Biomaterials and Biomedical Engineering
The port/tool and port/camera interfaces introduce a fulcrum, while decreasing the number of available DOF from six in open surgery to four in MIS, allowing only one (in/out) tool translation. The MIS setup requires at least two operators: the surgeon who is controlling the endoscopic tools and an assistant who is manipulating and positioning the endoscopic camera. The human assistant can anticipate the surgeon’s intentions and reposition or track the surgical tools with the endoscopic camera, using minimal directions from the surgeon. However, the assistant is subject to fatigue from holding the camera in one position for long time segments. The assistant can be replaced by AESOP, a voice activated 7-DOF robotic arm that automates the critical task of endoscopic camera positioning and provides the surgeon with direct control over a smooth, precise, and stable view of the internal surgical field.

The typical surgical robot architecture follows a classical master/slave teleoperation setup (Fig. 2c, d). This setup consists of two modules: the surgeon console (master) and the robot (slave). The surgeon console includes a set of handles, a vision system, and in some cases voice command components. The robotic system interacting with the patient includes at least three robotic arms: two to manipulate the surgical instruments and a third to control the endoscopic camera. The surgeon controls the position of the robot arms by manipulating the two handles at the console. The endoscopic camera arm is controlled by voice commands from the surgeon, and the view is transmitted back to the surgeon console. Only some of the currently available surgical systems incorporate force feedback. This feedback allows the surgeon to feel the forces generated as the surgical tools interact with the tissue, using a bilateral (position and force) teleoperation mode. Currently, the FDA has approved only robot-assisted surgical procedures in which the entire robotic system (master/slave) is located in the operating room. However, the same robotic system has been used to perform a surgery telerobotically across the Atlantic Ocean.

The Future of Robot-Assisted Surgery Analysis of the surgical robot’s role in the currently available operating room (OR) setup demonstrates that the surgeon can be
safely removed from the immediate surgical scene and still maintain interaction with the patient in a teleoperational mode. Although this revolutionary mode of operation may have benefits for the patient, it is far from being efficient because of the lack of supporting technologies. The increased setup and operational time of the current robotic systems is due to lack of automation and the presence of sophisticated interfaces. As a result, the simple act of changing tools or readjusting the robot’s position produces inefficient interactions between the clinical staff and the technology. These examples demonstrate the incomplete integration of surgical robotic systems into the OR.

The OR of the future has been envisioned as an integrated information system. Figure 3 shows a futuristic rendering of some of the subsystems that may be combined within the OR of the future. Much of the medical staff may be removed from the OR and replaced during surgery, in part by hardware in the form of supportive electromechanical devices and in part by software for documenting, assisting, and assessing the operation. The patient may be scanned by an imaging device, which will allow the surgeon to practice critical steps of the operation using the robotic console within a virtual reality environment based on patient-specific data. Then, the operation will be conducted by the surgeon utilizing the robot, tool changer, and equipment dispenser in an OR similar to a class 100 clean room.
Smart tags will be incorporated into tools and equipment, and once they are used, the billing process and the inventory updates will be executed immediately. Surgical performance will be monitored in the background, and critical decisions may be made through consultation with an expert system incorporated into the system. Much of the core technology for materializing this vision already exists, but whether this vision will become common practice in the next few decades is still an open question.

**OTHER MEDICAL ROBOTICS APPLICATIONS**

**Training**

Robotic mannequins have been developed for simulated medical training. The commercially available Medsim- Eagle Patient Simulator developed at Stanford University and the Veterans Affairs Palo Alto Health Care System has several computer-controlled electromechanical features, including eyes that open and close, arms that move, arms and legs that swell, and lungs embedded in the chest that breathe spontaneously.

**Tele-echography**

A French consortium has developed a telerobotic echography system consisting of a slave robot, with a real probe as its end-effector, and a master interface with a virtual probe. This system transmits motion and force information bidirectionally, allowing an expert interacting with the master interface to perform an examination at a remote location, using the slave robot.

**Robots for Special Education**

AnthroTronix has developed JesterBot™ and CosmoBot™ for the rehabilitation and special education of children. These robots combine therapy, education, and recreation
and can be controlled using body movements, voice commands, or an interactive control station.

**Robots for the Deaf and Blind**

Dexter, a robotic hand communication aid for people who are both deaf and blind, uses fingerspelling to communicate information typed on a keyboard, stored in a computer, or received from a special telephone.

**CONCLUSION**

Robotic technology has successfully produced valuable tools for rehabilitation, surgery, and medical training, as well as new and improved prosthetics and assistive devices for people with disabilities. Future applications of robotic technology will continue to provide advances in these and other areas of medicine. The most significant role of medical robots will most likely be to perform tasks that are otherwise impossible, such as enabling new microsurgery procedures by providing high-dexterity access to small anatomical structures, integrating imaging modalities into the OR, providing functional replacements for lost limbs, and enabling new human-machine interfaces and techniques for delivering neuro-rehabilitation therapy.