Enabling Medical Robotics for the Next Generation of Minimally Invasive Procedures

Howie Choset
Robotics Institute
Carnegie Mellon University

Marco Zenati
Department of Surgery
University of Pittsburgh

Minimally invasive interventions have the potential to revolutionize surgical practice by offering reduced pain, faster recovery, and fewer complications. We believe the key to achieving such potential is to eliminate the need for multiple (up to 8) ports by using natural orifices, when available, or single port entry, when a natural orifices are not present. Single port access approaches may facilitate existing procedures but perhaps more importantly, they will enable new ones, and at a lower cost. This reduced cost has the added benefit of making therapies available to a larger portion of the general public.

Already, we have seen the single port trend with the introduction of natural orifice transluminal endoscopic surgery (NOTES) where a procedure is performed with a minimally invasive surgical device or endoscope that enters a natural orifice, such as the mouth, nasal passage, vagina, or anus, and then passes through an internal incision to access anatomical targets deep in the body. For the heart, the closest thing to natural orifice access is to reach the pericardium space via a single port in the subxyphoid process using a linear rigid device; this approach does not require general anesthesia nor a heart-lung machine while providing access to a beating heart.

The common denominator for single port entry is the need for dedicated robotic technology that can operate without access limitation and full feedback from a single entry point. Although they have great visual feedback, conventional surgical robots, such as the Intuitive Surgical's DaVinci System™, are not adequate for single port entry because the three or four large robot arms manipulate linear chop-stick laparoscopic-like devices which have limited access to line-of-sight regions from the ports. A small articulated device or a miniature mobile/crawling unit, not a conventional robot, is key to accessing many anatomical targets from a single port.

We believe that future medical robot will be ubiquitous and not be recognizable by today's standards of what we call a robot. It will not look like the monolithic DaVinci or former Computer Motion robots, which appear similar to a factory robot. Instead, we will see everyday tools become robotic, such as Hansen Medical's Sensei™ Robotic Catheter System. Moreover, computer controlled catheters and other single port medical robots will significantly cost less than anthropomorphic robot systems, as they do not require large, bulky, and expensive robot arms, which take up much precious space in the operating room. It is this lower cost, less obtrusiveness, and seemingly "logical" evolution from existing tools to computer controlled ones that makes us believe that single port medical robots will gain more widespread acceptance.

In fact, single port robotic technology can be adopted by all medical interventionalists, not just surgeons. With the right development, four to five years from now, tools and capabilities will appeal to a number of individuals who are drawn from fields that are not just surgical. This immediately enables a large palette of therapies, which previously bared a high cost and were relegated only to medical centers of excellence where surgeons generally operate. This potentially further drives down post-operative discomfort and reduces costs because there is no surgery, per se. This further brings a host of interventions to the general public in all areas of the country as a result of single port medical robots.

choset@cs.cmu.edu
http://biorobotics.org

We are truly at the dawn of a new era of minimally invasive interventions and hence face new challenges that require a new set of tools to enable new approaches. More importantly, a new design process to develop these tools, and associated procedures, must be developed. The original monolithic medical robots, copies of factory robots, were originally intended for cardiac use but it was urologists who eventually used the robot to extend their laparoscopic reach. Despite the technical ingenuity behind these devices, this still shows how roboticists applied their pre-conceived notion of a robot to a medical problem. The future development of medical devices should start with the medical doctor and include him at every level of development: we should go from bed-side, to bench-side and back to bed-side. This will result in the development of new tools that enable new procedures, as opposed to facilitating, at best, existing ones. With the medical doctor and roboticist working together, specific technologies that need to be developed can be broken down into three categories:

Access: In order to overcome the limitations of current minimally invasive approaches, new technologies that provide superior access are required. So far, research and development in access technologies fall into three categories: (1) articulated probes or snake-like robots (Choset, Wolf & Zenati, Simaan & Taylor, Hirose, Darzi, Sarcos), (2) mobile or crawling units such as Heartlander (Riviere) , the miniature mobile camera (Farritor), an 18mm in diameter SMA based worm like manipulator which clamps itself into the environment and then manipulates itself forward (Dario et. al.), and (3) steerable needles (Cowan et. al., Riviere, Goldberg).

Manipulability: Once a device arrives at a target location, it must perform a function. Already, there exists a cadre of minimally invasive tools including a clamp, coagulator, forceps, and stapler, just to name a few. These tools, however, are largely mechanically operated and may not work with a highly articulated robot, a crawling robot, or a steerable needle. Therefore, an electro-mechanical solution is required. The benefit of placing a microchip between the device and the surgeon, i.e., make the minimally invasive device a true robot, has considerable impact on the operability of the device.

Feedback: Many areas of surgery have been revolutionized by the development of minimally invasive surgical procedures developed after the introduction of fiber optic technology (i.e., arthroscopy, endoscopy, laparoscopy, etc.). We are seeing advances in ultrasound (Jamaraz, Stetton) as low-cost portable alternatives to visualization. Also, recent work in force feedback (Okamura) shows some potential for tactile/force information to be translated back to surgeon for better manipulation of the tissue.

Single port medical robotics will clearly have a socio-economic impact, both in the creation of jobs within the field and in keeping people at their jobs in other fields. Therefore, this is a core competency that must be developed. Right now, large companies set the development agenda where the GE's and Intuitive Surgical's focus on capital equipment and the Boston Scientific's center on the devices. By doing so, they control development, which frankly is limited to two isolated points on opposite sides of the spectrum. Single port robotics encompasses all devices throughout the spectrum. It is in this interior where most ground-breaking technology in the next 20 years is going to be developed and hence this should be part of any roadmap charting out future research and development directions.

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