NSF / CCC / CRA Roadmapping for Robotics Workshop:
A Research Roadmap for Medical and Healthcare Robotics

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1) Automating Surgery: Combining Imaging, Mechanical Models, and Robotics

Current surgical robots are teleoperated: the surgeon must specify every move of the instruments. By combining three-dimensional imaging and mechanical models, we can envision methods for automating much of soft tissue surgery. Interactive image processing will identify the target anatomy. Mechanical models can be created from these images, so that the outcome of different surgical approaches can be compared before surgery using model predictions. Robotic instruments will then execute the optimum approach, using real-time image processing and modeling for guidance.

Automating surgery will focus research efforts in many areas. New automated image processing techniques are needed for preoperative organ segmentation and real-time tissue tracking during procedures. Automatic mechanical model generation and stable execution are major challenges, as these processes now require expert intervention for large-deformation nonlinear tissue simulation. Additional sensing and signal processing capabilities, such as tactile and force perception, must be developed. Issues of reliability and safety in real-time robot control have been largely unexplored in this context. Each of these developments will have important and far-ranging applications in beyond robotic surgery.

In reality, human surgeons must remain an essential part of surgical treatment because of their ability to integrate diverse information and exercise high-level judgment. The proposed new techniques will be immediately useful, however, to augment human capabilities. This will enhance today’s image-guided procedures, a well as enable new levels of accuracy, efficiency, and safety in the future.

2) Microsurgical Robotics

Microsurgery remains the unfulfilled promise of surgical robotics. Many current procedures in neural, vascular, ophthalmic, and fetal surgery are at the limits of human ability to manipulate tissues and structures. Robotic assistance can scale human motion commands and sensory feedback to enable new capabilities. While initial research efforts have begun to explore the issues, practical systems have not emerged. Real impact will require new approaches to manipulator design that provide unprecedented dexterity at this small scale, as well as new end effectors based on an understanding of the mechanics of tissue manipulation at the microscale. These systems must also have the ability to relay haptic, visual, and physiological sensory information to the surgeon.

While conventional telemanipulation can address immediate needs in microsurgery, a number of nontraditional approaches are highly

promising. Microvehicles that move freely within the body can allow noninvasive access to deep tissues. New procedures at the cellular scale may be enabled through the use of scanning probe microscopes used as manipulators. In all of these approaches, effective microscale manipulation will require integration of new mechanisms, sensors, control, and human interfaces.