Medical Robotics and Computer-Integrated Surgery

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The impact of Computer-Integrated Surgery (CIS) on medicine in the next 20 years will be as great as that of Computer-Integrated Manufacturing on industrial production over the past 20 years. A novel partnership between human surgeons and machines, made possible by advances in computing and engineering technology, will overcome many of the limitations of traditional surgery. By extending human surgeons' ability to plan and carry out surgical interventions more accurately and less invasively, CIS systems will address a vital national need to greatly reduce costs, improve clinical outcomes, and improve the efficiency of health care delivery. As CIS systems evolve, we expect to see the emergence of two dominant and complementary paradigms: *Surgical **CAD/CAM** systems* will integrate accurate patient-specific models, surgical plan optimization, and a variety of execution environments permitting the plans to be carried out accurately, safely, and with minimal invasiveness. *Surgical Assistant* systems will work cooperatively with human surgeons in carrying out precise and minimally invasive surgical procedures. Over time, these will merge into a broader family of systems that couple information to action in interventional medicine.

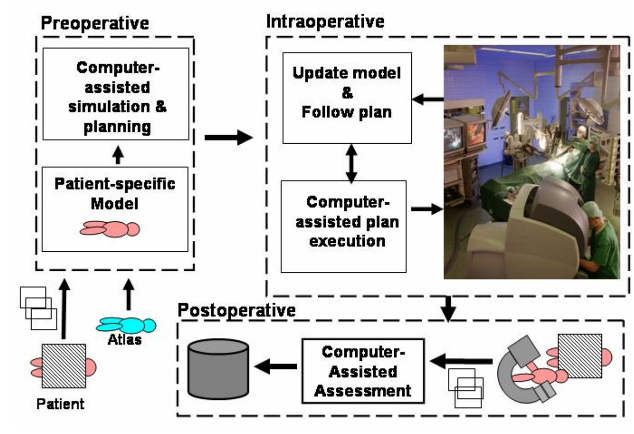

Figure 1: Information flow in CIS

The overall information flow associated with CIS systems is illustrated in Figure 1. These systems combine images and other information about an individual patient with "atlas" information about human anatomy to help clinicians plan how to treat the patient. In the operating room, the patient-specific plan and model are updated using images and other real-time information. The system has a variety of means, including robots and "augmented reality" displays to assist the surgeon in carrying out the procedure safely and accurately. The same technology will be used to assist in subsequent patient follow-up and in enabling statistical quality control to help improve the overall efficacy and safety of surgery and interventions.

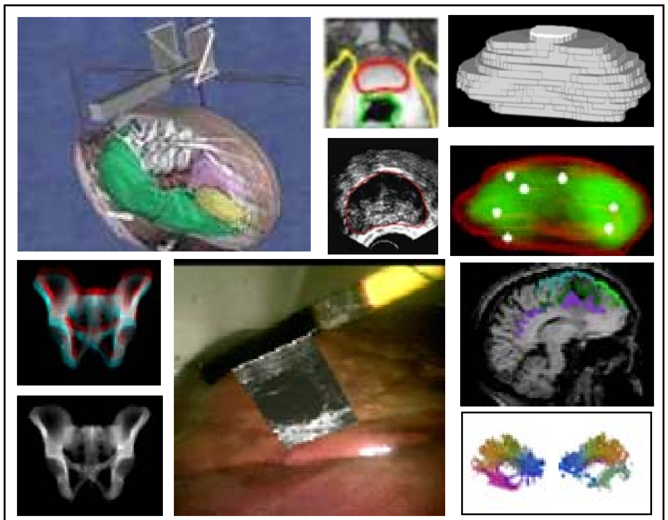

Figure 2: (Top) Image-based planning & control for in-CT biopsy; atlas-based segmentation of the prostate from MRI & ultrasound images; patient-specific prostate model with superimposed statistical map of where cancer is likely to be found & optimal biopsy strategy; **(bottom)** Atlas-based reconstruction of pelvis from x-ray images; laparoscopic ultrasound superimposed on 3D video display in a surgical robot console; statistical model of brain deformation during cancer growth; nerve fiber tract analysis in diffusion tensor MRI Imaging. (All images from projects in the CISST ERC)

CIS research inherently involves three synergistic areas: a) **modeling and analysis** of patients & surgical procedures in order to support more effective planning, execution assistance, and follow-up of surgical procedures; b) **interface technology**, including robots & sensors, connecting the "virtual reality" of computer models and surgical plans to the "actual reality" of the operating room, patients, and surgeons; and c) **systems science** to develop improved techniques for ensuring the safety and reliability of systems, for characterizing expected performance in the presence of uncertainty, for analysis of how subsystems and components will interact, and for system performance validation. Examples are shown in Figure 2.

This talk will explore these themes, with examples drawn from our own research and elsewhere.