CCC Research Roadmap Proposal

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Research Roadmap Proposal:

Bridging the gap between medical imaging and medical robots: Motion planning algorithms for image-guided medical procedures

The development of robotic surgical assistants such as the da Vinci surgical system are enabling physicians to perform surgical procedures with greater reliability, mobility, and precision compared to traditional human control of medical instruments. In parallel to the development of new robotic devices for medicine, recent advances in medical imaging are enabling clinicians to non-invasively examine anatomy and metabolic processes deep below the skin surface. From computed tomography capable of displaying the patient's 3-D anatomy with sub-millimeter resolution, to magnetic resonance spectroscopy imaging that can identify the location of metabolic compounds in tissue, the quantity and detail of patient-specific imaging data available to clinicians is rapidly increasing.

Fully integrating the wealth of digital information obtained from imaging with advances in robotic hardware has the potential to significantly improve patient care. To harness the full potential of robotic surgical assistants, new motion planning algorithms are needed to help physicians transform the information obtained from medical images into actions for robotic surgical assistants to perform.

(1) Motion planning for medicine: Motion planning algorithms and frameworks have been developed for many traditional robotics applications, including manipulator arms in manufacturing and mobile robots in field and indoor environments. However, the medical domain introduces new challenges, including deformable workspaces and motion uncertainty. A new generation of motion planning algorithms needs to be developed that explicitly addresses these challenges. These methods should compute actions that will guide a robotic surgical device to reach a clinical target or achieve a clinical goal while avoiding anatomical obstacles and considering the effects of tissue deformations and uncertainty.

(2) Image-based sensing for motion planning: Motion planning algorithms for medical robots will need to utilize anatomical and clinical information extracted from medical images and other

sensing modalities. These modalities include x-ray fluoroscopy, CT scans, MR images, ultrasound images, magnetic position sensors, and emerging technologies such as mega-voltage cone-beam images or optical coherence tomography. Just as the robotics community has developed vision-based algorithms for mobile robot navigation, we must develop new algorithms to process medical sensing data for robot-assisted medical procedures. These new algorithms must utilize the images and other sensing modalities available in healthcare settings and must explicitly handle the properties and constraints of medical sensing, including the costs of acquisition in terms of time and tissue damage.

(3) Integration of motion planning with medical robotic systems: Realizing the full potential of robot-assisted medical procedures will require research on how to more tightly integrate robot technology into the clinical routine. Integrating robot motion planning, control, sensing, and procedure optimization into a single robotic system introduces numerous algorithm and design research challenges. Meeting these challenges will require development of new robotic hardware, new optimization software for computing procedure plans based on imaging data and physician-specified requirements, and new sensor processing to enable updating the procedure plan and robot motion plans in real-time to correct for unexpected tissue deformations and complications.

The research challenges described above arise in a variety of medical robotics applications. At the UCSF Medical Center, I am working directly with clinicians on using robotics to automate and optimize one such procedure, brachytherapy, a cancer treatment in which radioactive sources are placed inside cancerous tissues. Medical robotics has the potential to help physicians provide more accurate, precise, and patient-specific treatments that will ultimately improve patient care and quality of life. The development of new motion planning algorithms is crucial to transform the information obtained from medical images into actions for robotic surgical assistants.