Development of Next Generation Medical Robotic Systems for Surgery, Surgical Training, and Rehabilitation

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Robotic Telesurgical Systems for Beating Heart Bypass Surgery

For the last several years, our research group has been leading a project on development of intelligent robotic tools for performing off-pump (beating heart) coronary artery bypass graft (CABG) surgery, with clinical partners from Cleveland Clinic. In this context, off-pump CABG surgery means that the surgery is done while the heart is still beating instead of using a cardiopulmonary bypass machine and stopping the heart to perform heart surgery. The intelligent telerobotic tools that are developed in this project will actively track and cancel the relative motion between the surgical instruments and the heart by Active Relative Motion Cancelling (ARMC), allowing CABG surgeries to be performed on a beating heart with technical perfection equal to traditional on pump procedures.

As part of this project, an algorithm for model based tracking and canceling of heart motion for robotic assisted off-pump cardiac surgery was developed. The developed model-based algorithm employs biological signals, such as electrocardiogram (ECG), in estimation of heart motion, and uses this in a predictive control fashion. The developed algorithm has integrated arrhythmia detection and handling to provide safety during the operation. The algorithm was implemented and tested on a realistic 3 degrees-of-freedom robotic test-bed system, with root-mean-square tracking errors (305 μm) 5.5 times better than the best results reported in the literature. As part of this project, we have designed and characterized a 5-mm diameter needle holder with a novel integrated hybrid actuator that combines shape memory alloy and DC motor actuators. The developed end-effector, will eliminating the need to transmit mechanical power through the wrist, and therefore enable the design of smaller, lighter weight, and more dexterous robotic mechanism.

For the next three years, our research will focus on development of sensory system for in vivo measurement of heart motion, and the design of the robotic telesurgical system for minimally invasive CABG surgery. A major focus of the research will be on developing complementary sensing systems and algorithms for intelligent and model based fusing of information supplied from different systems for superior performance. Design of the overall telerobotic system will be done in an integrated fashion (see below), to achieve highest fidelity telemanipulation abilities possible, which is especially critical since cardiothoracic surgery involves very fine and delicate manipulations.

Haptic Systems for Next Generation Medical Robotic Systems

Current generation of robotic telesurgical systems are still far from reproducing the dexterity and sensation of open surgery. The next generation telesurgical systems require design of smaller and higher degrees-of-freedom manipulators for use in applications such as cardiac and fetal surgery; and more importantly design of systems with higher dexterity and higher fidelity haptic feedback. The focus of our research is to develop a common framework for haptic interfacing to real and virtual environments that also would make it possible to study the kinematic design, actuation mechanisms, sensory subsystem, and controller design aspects of haptic systems within a single framework to optimize the performance of the system with respect to application-based performance criteria and the human sensory-motor abilities. Such a framework will be an invaluable tool for the development of next generation medical robotic systems that can achieve the required dexterity and manipulation fidelity, as it unifies all of the performance critical aspects of the system design.

Within this framework, we are studying more fundamental scientific questions about medical robotic system design, including studying what are proper performance objectives for the specific tasks (i.e., understanding what is meant by high performance for the surgical manipulation tasks), what are the critical and limiting factors in performance, what are the underlying critical trade-offs in the design process, and what are the relevant psychophysical factors, along with our efforts on development of next generation robotic systems for coronary artery bypass surgery and forms of minimally invasive surgery.

Intelligent Robotic Surgical Assistants

The longer term project we are pursuing is the development of intelligent robotic surgical systems that are capable of autonomously performing image guided surgery. Development of such systems require breakthroughs in these general areas: *i)* Automatic segmentation and annotation of medical diagnostic images; *ii)* Automatic planning of surgical interventions using spatial reasoning to determine the intervention plan; and *iii)* Autonomous execution of the surgical plan using intra-operational imaging in a manner robust to the uncertain and unstructured nature of the surgical environment. Our research activity is centered around themes *(ii)* and *(iii)*, focusing on algorithms for spatial reasoning necessary for surgical planning and manipulation, planning of manipulation of deformable objects, and intelligent agent architectures.

Virtual Environments for Surgical Training

Our research group has been leading an effort on development of an open source/open architecture framework, named GiPSi, for developing virtual environment-based surgical simulations. The goal of the project is to develop a software framework that facilitates shared development of reusable models and algorithms for interactive surgical simulations. The emphasis was accommodating heterogeneous models and providing a framework for interfacing multiple heterogeneous models. We have also been working on development of algorithms for high fidelity haptic rendering of manipulation of deformable objects in virtual environments. These research activities are being conducted in the context of the development of a training simulator for endoscopic neurosurgery, in collaboration with the Rainbow Babies' and Children's Hospital.

Robotic Assisted Rehabilitation of Stroke Survivors

In collaboration with the Stroke Motor Control and Motor Learning Laboratory of the Functional Electrical Stimulation Center at the Cleveland Veterans Affairs Medical Center, we have developed new protocols for robotic-assisted rehabilitative therapy for upper limb stroke patients. We have also conducted some preliminary studies on EEG signal characteristics in stroke survivors with motor deficits to explore the feasibility of using EEG signals as brain-computer interface signals to utilize in robot-assisted stroke rehabilitation.

Short Biography of the Author:

M. Cenk Cavusoglu received the received the Ph.D. degree in Electrical Engineering and Computer Science from the University of California, Berkeley, in 2000, the M.S. degree from the University of California, Berkeley, in 1997, and the B.S. degree from Middle East Technical University, Ankara, Turkey, in 1995. He is currently an Assistant Professor in the Electrical Engineering and Computer Science Department of Case Western Reserve University, Cleveland, OH.

His research involves applications of robotics and control engineering to biomedical and biologically-inspired engineered systems. Specifically, his research interests include, robotics, systems and control theory, and virtual environments, with emphasis on Medical Robotics, Haptics, Teleoperation, Surgical Simulation, and Bio-System Modeling and Simulation.