Ph.D. DISSERTATION DEFENSE

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Title: Hybrid Force-Motion Control and Telemanipulation Strategies Using Redundancy Resolution Methods for Surgical and Manufacturing Applications

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ABSTRACT

This thesis explores advanced hybrid force-motion control and telemanipulation strategies using redundancy resolution methods for surgical and manufacturing applications. The research focuses on developing control algorithms for robotic tasks under constraints, specifically in surface finishing manufacturing processes and in robot-assisted minimally invasive surgery (MIS).

In the manufacturing domain, we introduce a novel hybrid force-motion control framework that leverages real-time surface normal estimation to enhance robustness in surface finishing tasks. By integrating F/T sensory feedback to compensate for friction biases and estimate the surface normal, this method significantly improves the performance of robotic manipulators in complex manufacturing environments. For surgical applications, we develop a novel adaptive admittance control framework for robot-assisted laparoscopic surgery, addressing the challenge of maintaining precise task control with a remote center of motion (RCM) constraint despite the intrinsic physiological movements of the patient. This adaptive RCM control is integrated into a teleoperation framework for robot-assisted MIS, effectively maintaining precise instrument manipulation while compensating for patient motion.

Additionally, we address the challenge of teleoperation of laparoscopic continuum instruments for robot-assisted MIS, focusing on executing multiple tasks with varying priority commands. A teleoperation framework and a novel, compact, modular instrument module are developed, featuring a rigid segment and a miniature continuum instrument tip. Using redundancy resolution methods, we formulate three levels of task priority, enabling the prioritization of linear versus angular commands at the continuum segment tip in diverse scenarios. Thereby, the task priority method serves as an investigation tool to show quantitative insights on responses during teleoperation.

Simulations and experimental validations demonstrate the effectiveness of the proposed strategies, contributing to the advancement of robotic capabilities in constrained environments for both manufacturing and surgical applications.