Mechanical Engineering Doctoral Defense

Biomechanics-Based User-Adaptive Variable Impedance Control for EnhancedPhysical Human-Robot Interaction

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Abstract

This dissertation consists of different studies that focus on improving physical human-robot interaction through the development and implementation of various control methods. The first study investigates the lower bounds of robotic damping that humans can stably interact with in different arm postures. The results indicate that the human arm is less capable of adjusting to the unstable environments when it is close to the body and laterally displaced for the anterior-posterior (AP) and the medial-lateral (ML) directions, respectively. The second study proposes a multi-degree-of-freedom variable damping controller that balances stability and agility and reduces user effort in physical human-robot interaction. The controller effectively reduces user effort while increasing agility without compromising stability. The third study presents a variable stiffness control method to provide intuitive and smooth force guidance during physical human-robot interaction. This controller significantly reduces robotic force guidance and user effort while maintaining speed and accuracy of movement. Based on the findings from these studies, a biomechanics-based user-adaptive variable impedance control is proposed, which can be applied in a diverse set of applications to enhance the overall performance of coupled human-robot systems. This controller accounts for impedance properties of the human limbs and adaptively changes robotic damping, stiffness, and equilibrium trajectory based on online estimation of user's intent of motion and intent of movement direction while minimizing energy of the coupled human-robot system. Bayesian optimization was used to evaluate an unknown objective function and optimize noisy performance. The presented adaptive control strategy could reduce energy expenditure and achieve performance improvement in several metrics of stability, agility, user effort, smoothness, and user preference. All studies were validated and tested through several human experiments. Overall, the dissertation contributes to the field of physical human-robot interaction by providing insights into the dynamics of human-robot interactions and proposing novel control strategies to enhance their performance.

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