# Admittance-based Semi-passive Cooperative Control Frameworks for Safe Physical Human-Robot Interaction

Name DANG VAN TRONG

Laboratory's name Human Robotics Laboratory

Supervisor's name Takahiro Wada

Abstract (should be within 1st page)

Physical human-robot interaction (pHRI) has received widespread attention across industrial and everyday applications, where robots are expected to understand human intentions and move accordingly to accomplish shared tasks. However, due to environmental uncertainties and the stochastic nature of human behavior, perfect intention estimation cannot always be achieved in practice, inevitably resulting in human-robot conflicts. Given such situations, to guarantee safety, conventional approaches heavily rely on strict passivity-based control; yet, enforcing rigid passivity at all times introduces excessive conservatism, which severely degrades task performance. To address this fundamental trade-off, the objective of this thesis is to propose and theoretically validate novel cooperative control frameworks that simultaneously ensure interaction safety and enhance task performance. The core methodology establishes dual-loop control frameworks. In the outer loop, an admittance-based reference generator corrects the estimated human intention in real-time based on interaction forces to mitigate conflict levels. In the inner loop, a semi-passive control is developed to track the modified reference trajectory. This inner loop extends fully passive control into a semi-passive formulation, which guarantees strict passivity only when the system's energy exceeds a safety threshold, while permitting non-passive, proactive behaviors to prioritize task execution when the energy level is low. The main contributions of this thesis are as follows: 1) the properties of the closed-loop system, including passivity, finite-time energy convergence, stability, are rigorously proven, 2) the framework is extended to an adaptive control scheme where control parameters, energy saturation, and rate constraints are automatically tuned online, 3) a model-free control technique is investigated to overcome the dependence on dynamic model, and 4) the feasibility and effectiveness of the developed frameworks are empirically validated through both numerical simulations and human-in-the-loop co-carrying experiments, demonstrating enhanced safety, task performance, and reduced human workload.