University of Victoria | Graduate Studies

Notice of the Final Oral Examination for the Degree of Master of Applied Science

of

YUAN YANG

BEng (Harbin Institute of Technology, 2015)

"Stable Bilateral Teleoperation with Time-Varying Delays"

Department of Mechanical Engineering

Monday, June 19, 2017
10:00 A.M.
Engineering Office Wing
Room 230

<u>Supervisory Committee:</u>
Dr. Daniela Constantinescu, Department of Mechanical Engineering, University of Victoria (Co-Supervisor)
Dr. Yang Shi, Department of Mechanical Engineering, UVic (Co-Supervisor)

<u>External Examiner:</u>
Dr. Wu-Sheng Lu, Department of Electrical and Computer Engineering, UVic

<u>Chair of Oral Examination:</u>
Prof. Patricia Kostek, School of Music, UVic

Dr. David Capson, Dean, Faculty of Graduate Studies

Abstract

A teleoperation system is a master-slave robotic system in which the master and slave robots are at different geographical locations and synchronize their motions through the communication channel, with the goal of enabling the human operator to interact with a remote environment. The two primary objectives of bilateral teleoperation systems, position tracking and force feedback, are necessary for providing the user with high fidelity telepresence. However, time delays in communication channels impede the realization of the two objectives and even destabilize the system. To guarantee stability and improve performance, several damping injection-based controllers have been developed in this thesis for two channel and four channel teleoperation systems. For two channel teleoperation, an adaptive bounded state feedback controller has firstly been proposed to address teleoperation with time-varying delays, model uncertainties and bounded actuations. Next, an augmented globally exponentially convergent velocity observer has been designed and incorporated in the conventional P+d control to obtain stable bilateral teleoperation without using velocity measurements. Then, the more challenging bounded output feedback control problem has been solved by combining the bounded state feedback control and output feedback control two techniques with more conservative control gains. In four channel teleoperation, a hybrid damping and stiffness adjustment strategy has been introduced to tightly constrain the master and slave robots and achieve robust stability. Further, the nonsingular version is developed to conquer the singularity problem in the hybrid strategy, which has been proved to avoid unexpected torque spikes due to singularity at zero velocities. Besides, this thesis has also provided a reduced-order controller to guarantee position coordination for arbitrarily large position errors and maintain the tight coupling between the master and slave sites. After concluding all the research results, future study directions are pointed out at the end of this thesis.