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Stability Analysis of the Linear Discrete Teleoperation Systems with Stochastic Sampling and Data Dropout

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Abstract: This paper addresses the stability conditions of the sampled-data teleoperation systems consisting continuous-time master, slave, operator, and environment with discrete-time controllers over general communication networks. The output signals of the slave and master robots are quantized with stochastic sampling periods which are modeled as being from a finite set. By applying an input-delay method, the probabilistic sampling system is converted into a continuous-time system including stochastic parameters in the system matrices. The main contribution of this paper is the derivation of the less conservative stability conditions for linear discrete teleoperation systems taking into account the challenges such as the stochastic sampling rate, constant time delay and the possibility of data packet dropout. The numbers of dropouts are driven by a finite state Markov chain. First, the problem of finding a lower bound on the maximum sampling period that preserves the stability is formulated. This problem is constructed as a convex optimization program in terms of linear matrix inequalities (LMI). Next, Lyapunov-Krasovskii based approaches are applied to propose sufficient conditions for stochastic and exponential stability of closed-loop sampled-data bilateral teleoperation system. The proposed criterion notifies the effect of sampling time on the stability-transparency trade-off and imposes bounds on the sampling time, control gains and the damping of robots. Neglecting this study undermines both the stability and transparency of teleoperation systems. Numerical simulation results are used to verify the proposed stability criteria and illustrate the effectiveness of the sampling architecture.

Keywords: Teleoperation Systems, Slave-Master Robots, Networked Control Systems, Transparency, Stochastic Sampling, Linear matrix inequality (LMI).