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Transparency Improvement by External Force Estimation in a Time-Delayed Nonlinear Bilateral Teleoperation System

Teleoperation systems have been developed in order to manipulate objects in environments where the presence of humans is impossible, dangerous or less effective. One of the most attractive applications is micro telemanipulation with micropositioning actuators. Due to the sensitivity of this operation, task performance should be accurately considered. The presence of force signals in the control scheme could effectively improve transparency. However, the main restriction is force measurement in micromanipulation scales. A new modified strategy for estimating the external forces acting on the master and slave robots is the major contribution of this paper. The main advantage of this strategy is that the necessity for force sensors is eliminated, leading to lower cost and further applicability. A novel control algorithm with estimated force signals is proposed for a general nonlinear macro–micro bilateral teleoperation system with time delay. The stability condition in the macro–micro teleoperation system with the new control algorithm is verified by means of Lyapunov stability analysis. The designed control algorithm guarantees stability of the macro–micro teleoperation system in the presence of an estimated operator and environmental force. Experimental results confirm the efficiency of the novel control algorithm in position tracking and force reflection. [DOI: 10.1115/1.4029077]

1 Introduction

Teleoperation systems have become an extensive and interesting field for researchers in the last decade. The main function of teleoperation systems is to operate from a remote location [1,2]. A useful application of teleoperation systems is to control a robotic vehicle in hazardous situations. Other applications include telesurgery, space technology, and underwater exploration [3–5]. A new emerging application area is called macro–micro teleoperation where the operator is restricted in directly manipulating micro objects. Macro–micro teleoperation systems enable the manipulation of tasks in the microworld. Smart actuators, such as the piezoelectric stage, have been widely used as slave manipulators in applications of macro–micro manipulation [6–10]. In bilateral teleoperation systems, the main purpose is to control the remote manipulator and sense the forces exerted on the robot in a remote environment. Therefore, stability and transparency are two