Robust control-based linear bilateral teleoperation system without force sensor

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Received: 18 May 2013 / Accepted: 9 June 2014 / Published online: 1 July 2014
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Abstract Among the prevalent methods in linear bilateral teleoperation systems with communication channel time delays is to employ position and velocity signals in the control scheme. Utilizing force signals in such controllers significantly improves performance and reduces tracking error. However, measuring force signals in such cases, is one of the major difficulties. In this paper, a control scheme with human and environment force signals for linear bilateral teleoperation is proposed. In order to eliminate the measurement of forces in the control scheme, a force estimation approach based on disturbance observers is applied. The proposed approach guarantees asymptotic estimation of constant forces, and estimation error would only be bounded for time-varying external forces. To cope with the variations in human and environment force, sliding mode control is implemented. The stability and transparency condition in the teleoperation system with the designed control scheme is derived from the absolute stability concept. The intended control scheme guarantees the stability of the teleoperation system in the presence of time-varying human and environment forces. Experimental results indicate that the proposed control scheme improves position tracking in free motion and in contact with the environment. The force estimation approach also appropriately estimates human and environment forces.

Keywords Teleoperation systems · Time delay · Force estimation

1 Introduction

Teleoperation systems have been designed for their potential to function in environments that are perilous, have low efficiency, or where humans cannot be present. Applications include telesurgery [1], telepresence, and remote controlled spacecraft [2]. Two key objectives of teleoperation systems are stability and transparency. In fact, the main purpose is to design a stable control scheme for transmitting position, velocity, and force signals from the master robot to the slave robot and vice versa. The stability and transparency of teleoperation systems are directly influenced by the amount and type of information being transmitted. For instance, if it is possible to transmit force signals besides position and velocity signals, more efficient stability and transparency would be available. This is due to gathering more accurate information from system conditions, which is an advantage of using force signals in teleoperation system control approaches. One of the typical means of controlling teleoperation systems is to employ position and velocity signals in the control scheme [3, 4]. Some structures enhance system transparency by applying force signals in addition to position and velocity signals [5, 6, 7]. A basic problem with these structures lies in measuring force in the control scheme. There are several