A Bilateral Teleoperation Control Scheme for 2-DOF Manipulators with High Reduction Ratio Joints

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Abstract

Since the dynamics of the slave manipulator with high reduction ratio joints is likely to be much slower than that of the master manipulator, the control input the slave manipulator is so frequently saturated. This paper proposes a bilateral teleoperation control scheme for 2-DOF manipulators with high reduction ratio joints, which can effectively compensate the control input saturation. In the proposed scheme, the controllers of the slave manipulator are designed with an anti-windup feature and forces caused by the saturation are reflected to the operator holding the operating handle of the master manipulator. When the control input of the slave manipulator is saturated, the master manipulator moves slowly due to the reflected forces. In this way, the position tracking performance of the slave manipulator with high reduction ratio joints can be enhanced regardless of saturation. The proposed scheme is shown to give excellent position tracking performance through a series of experiments.

1. Introduction

Telerobotic systems present a technical alternative for intelligent robotic systems performing dexterous tasks in unstructured environments. Since telerobotic systems include continuous human intervention into the control loop, it is important to provide realistic sensory feedback of the environmental interactive forces to the operator. Much research is going on in the field of force reflecting control schemes[2][3][5][7]. Kim[2] suggested simplified models for the force reflecting control schemes. Luo and Ito[5] suggested the compliant control scheme in dynamic environments, and Kim et al.[3] suggested the compliant control scheme on telemanipulators with a time delay. Uebel et al.[7] suggested the impedance control scheme using 2-port network model. To achieve a sensitive force reflection capability, it is generally required that the slave manipulator has a drive mechanism with low reduction gears. However, such a low gear ratio results in a low weight-to-payload ratio, which makes it unsuitable for many potential application areas of telerobotic systems. For example, the dismantling of a nuclear facility is such an area that critically requires the use of telerobotic systems with a high payload because the elementary cutting tasks undergo intensive interactive forces. The heavy-duty power manipulator consisting of high reduction ratio joints is widely used to treat heavy weight materials. Since the dynamics of the slave manipulator with high reduction ratio joints is likely to be much slower than that of the master manipulator, the control input is so frequently saturated[4] that the position tracking performance of the slave manipulator and the system stability are deteriorated.

This paper proposes a bilateral teleoperation control scheme for 2-DOF manipulators with high reduction ratio joints, which can effectively compensate for the control input saturation. The main advantage of the proposed scheme is that the 2-DOF slave manipulator with high reduction ratio joints can be precisely controlled regardless of saturation. The control problems of the bilateral teleoperation control for a 2-DOF slave manipulator with control input saturation are formulated in section 2, and an enhanced bilateral teleoperation control scheme is proposed in section 3. In section 4, the proposed scheme is applied to the heavy-duty power manipulator and the control performance is shown through an experimental study.

2. Problem Formulation

The bilateral teleoperation control scheme for the slave manipulator with control input saturation is shown in Fig. 1[2][7].

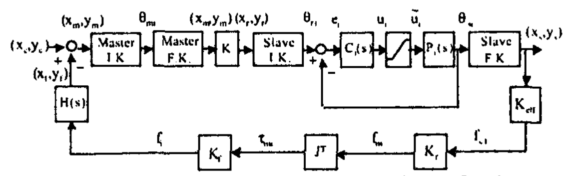

Fig. 1. The bilateral teleoperation control scheme for the slave manipulator with control input saturation.

In Fig. 1, (x_c, y_c) is the position of the operator's command, (x_f, y_f) is the position caused by the reflected forces, (x_m, y_m) is the position of the master manipulator, (x_r, y_r) is the reference position and (x_s, y_s) is the position of the slave manipulator. θ_m is the angular position of the master manipulator and θ_s is the angular position of the slave manipulator. K is the position command scale factor, K_r is the feedback scale factor of the contact force, K_f is the ratio from joint torque of the master manipulator to the reflected force on the operator. τ_{mi} is the joint torque of the master manipulator. f_{ct} is the contact force of the slave manipulator and is achieved through a gravity compensation from the signal output of the F/T sensor. f_i is the reflection force to the operator. K_{eff} is the effective stiffness which represents a parallel combination of the slave manipulator stiffness and the environment stiffness. $P_i(s)$ is the transfer function of the slave manipulator which represent the angular position of the slave manipulator for the control input. $H(s)$ is the transfer function of the master handle, relating the position of the master manipulator to the reflected forces. $C_i(s)$ is the controller of the slave manipulator. The actual control input of the slave manipulator, $u_i(t)$, has the following saturation characteristics:

$$\tilde{u}_i(t) = \begin{cases} u_{i\max} & u_i(t) > u_{i\max}, \\ u_i(t) & -u_{i\max} \le u_i(t) \le u_{i\max}, i = 1,2. \\ -u_{i\max} & u_i(t) < -u_{i\max}, \end{cases} \quad (1)$$