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IMPEDANCE CONTROL OF HYDRAULIC MASTER-SLAVE ROBOT

1. Introduction

Teleoperation extends human intelligence and dexterous manipulation capacity to remote robotic applications. In most traditional applications of bilateral manipulation, a design goal is to achieve transparency, i.e., minimize the extent to which the bilateral manipulator alters the feel of the task.

Here to achieve transparency, we propose a novel method that is distinctly different from the previous works of coupling the master and the slave into a single entity. Two subsystems are juxtaposed and impedance matching is conducted so that the master and the slave should fulfill their own different roles. We show experimental results that have confirmed the validity of our method.

2. Making up Two Subsystems

In the conventional method, the master and the slave are coupled as a single entity, presenting the same impedance characteristics both to the operator and the task, transmitting both the force information of the slave to the operator and motion commands of the operator to the slave. With the single entity to fulfill two different jobs, a trade-off has to be made in setting of the impedance of the entity.

Because the performance of teleoperation is ultimately dependent upon the dynamic interaction between the operator, the master, the slave, and the task, it may turn out to be a central problem to take into account the human arm's impedance characteristics when designing teleoperation (human-machine) control systems. Our idea is grouping the operator, the master, the slave, and the task into two subsystems and matching the impedance characteristics of them to each other.

As shown in Figure 1, one of the subsystem is the [operator-master], the other is the [slave-task]. To obtain a good sense of "feel", in the subsystem of the [operator-master] we project the impedance of the task into the master (i.e. matching the impedance of the master with that of the task) so that the operator

can act as if he were directly interacting with the remote task, since the "feel" of the task is embodied in the impedance of the master. Consequently the force information is indirectly transmitted faithfully, without the force feedback usually used in a conventional method.

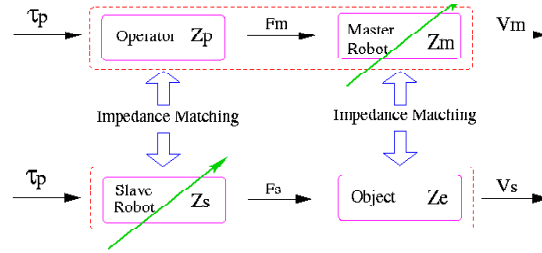


Fig. 1. Two subsystems with impedance matching

In the subsystem of [slave-task] we project the operator arm's impedance into the slave in order that the slave could reproduce the versatile operator arm's motions in the remote environment, as if it were human arm's alter ego, not only in action but also in skill. In one word, the new concept of building two subsystems in dealing with the teleoperation is a feasible way to achieve the ideal responses of a hydraulic master-slave robot.

3. Analysis of Impedance Matching

The original dynamics of the master and slave are given as follows:

$$U_m + F_m = Z_m(s)V_m \quad (1)$$

$$U_s - F_s = Z_s(s)V_s \quad (2)$$

where: Z, V, U denote impedance, velocity, actuator-driving forces, and suffix m and s imply the master and slave respectively, F_m denotes the force that the operator applies to the master, and F_s denotes the force that the slave applies to the task

Assuming that the slave may not depart from the task, the dynamics of the task interacting with the slave is modeled as the follow:

$$F_e = F_s = Z_e(s)V_s \quad (3)$$

where: F_e denotes the reaction force of F_s .

It is also assumed that the dynamics of the operator arm can be approximately represented as a simple spring-damper-mass system:

$$\tau_p - V_m = Z_p(s)V_m \quad (4)$$

where: τ_p means forces generated by the arm's muscles.

To realize the impedance matching of the two subsystems, we consider the following two equations:

$$U_m = (Z_m(s) - Z_e(s))V_m \quad (5)$$

$$U_s = \tau_p + (Z_s(s) - Z_p(s))V_s \quad (6)$$

By applying above two equations into Equations (1) and (2), we can obtain the following two Equations describing the new dynamic characteristics of the master and slave.

$$F_m = Z_e(s)V_m \quad (7)$$

$$\tau_p - F_s = Z_p(s)V_s \quad (8)$$

Comparing Equation (3) and (7), we come to the conclusion that the force information is replicated by the master completely and the feel by the operator can be improved. From Equation (4) and (8), we can conclude that the slave not only shows the same dynamics of operator's arm but also replays motions of the operator's arm which helps to stabilize the whole system because human's arm can cope with soft or hard task naturally and smoothly.

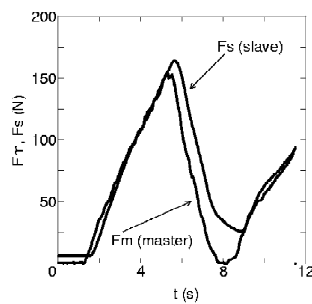


Fig. 2. Force response of the master and slave

4. Experiment

With regard to the test rig, the master is 1DOF LM guide driven by AC servomotor while the slave is 2DOF hydraulic manipulator. To be simple, we set the task just as a spring now. As shown in Figure 2 and Figure 3, the force and displacement responses of the master and slave agree with each other. So it is clear that the ideal response is realized.

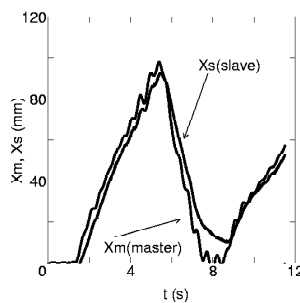


Fig. 3. Displacement response of the master and slave

5. Conclusions

The key idea underpinning this study is the impedance matching. There are threefold significations of grouping the operator, the master, the slave and the task into two subsystems and carrying out impedance matching: improving the feel of the remote task without direct force feedback, replicating the operator arm's motion in the slave, and improving the stability of the whole system regarding various task.

Reference

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