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Research Paper

BILATERAL TELEOPERATION OF TWO MASS SPRING DAMPER SYSTEM WITHOUT TIME DELAY

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A Bilateral Tele-operation system is composed of a local master site, which is driven by a human operator, and a remote slave site, which is in contact with the environment. In such a system, the slave follows the movement of master and the master receives feedback information from the slave. The slave do not track master properly due to instability caused by time delay present in communication channel. In this paper, dynamic equation of two mass spring damper system has been solved and synchronized using proportional derivative controller in the absence of time delay. Two PD controllers have been used at both end of the system, i.e., at master end and slave end for proper tracking. Here, slave will flow the trajectory of master in controlled way.

Keywords: Bilateral teleoperation, Mass spring damper system, PD control, Trajectory tracking

INTRODUCTION

When bilateral telerobotic system was first introduced, the main issues were precise tracking and stability. With the recent advances in the telerobotic system (Hokayem and Spong, 2006), it reduced the human involvement in the various fields where it was dangerous to reach there, like exploratory missions, hazardous environment, Space exploration and operation in geosynchronous orbits. This not only works out economical and safe but also avoids unwarranted human exposure to potentially dangerous environment. Certain common applications being referred to are the cleanup of toxic waste, nuclear power plant decommissioning, search and rescue missions, security, surveillance, and reconnaissance tasks which have elements of danger in which human casualties are possible, or even likely. In all of these applications, it is desirable to reduce the risk to humans through the use of telerobotic system technology. In the medicine field, telesurgery was being used by the technology of bilateral teleoperation. The application discussed above are but a few and many recent advances are occurring in this area making it an exciting field to work in. It basically helps us understand more about human-robot interactions and connects the fields of control theory, communication, artificial intelligence and robotics.

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MECHANICAL TO ELECTRICAL CONVERSION

In this section, the force/effort are analogous to voltage and velocity/flow analogous to current. This conversion is described below elaborately (Anderson and Spong, 1989).

The Mass of the Manipulator Represented by an Inductor

In the mechanical system, the relation between force and acceleration is

$$F(t) = M\dot{\neg}(t) \qquad ...(1)$$

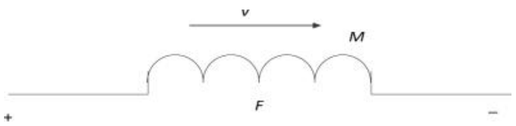
where *M* is an inertial element.

In the electrical system, the relation between voltage and current is

$$V(t) = L\S(t) \qquad ...(2)$$

By comparing Equations (1) and (2) then

$M = L$



The Damping of the System Can be Represented by a Resistor

In mechanical system, damping force will be,

$$F(t) = B\neg(t) \qquad ...(3)$$

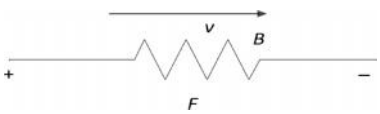
where *B* is a damping constant

In electrical system, voltage applied to the system will be,

$$V(t) = R\S(t) \qquad ...(4)$$

By comparing Equations (3) and (4) then

$B = R$



The Spring Constant or Environmental Stiffness can be Represented by a Capacitor

In mechanical system, restoring force will be,

$$F(t) = K\int \neg(t)\,dt \qquad ...(5)$$

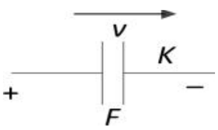
where *K* is a stiffness element

In electrical system, voltage applied will be

$$V(t) = \frac{1}{c}\int \S(t)\,dt \qquad ...(6)$$

By comparing Equations (5) and (6) then

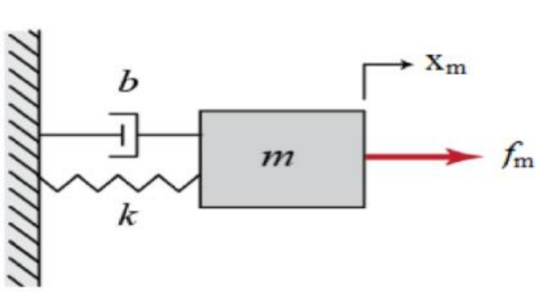
$$K = \frac{1}{C}$$



WORKING OF THE SYSTEM

Two mass spring damper system has been used. One is used as master shown in Figure 1. and second is used as slave shown in Figure 2. By combining two mass-spring-damper systems are working as master slave tele-operator. Input is given to the master by the human and the output of the master pass to the slave. This output is input to the slave and slave show output which exact mimic of the master input. Feedback controllers are designed to track (Chopra *et al.*,

Figure 1: Master System



2006) the position of the master without time delay. Two PD controllers (Spong *et al.*, 2006) are designed on both sides, i.e., master controller and slave controller. The master controller is getting force feedback from the slave when that system is in contact with an environment as shown in Figure 3.

Figure 2: Slave System

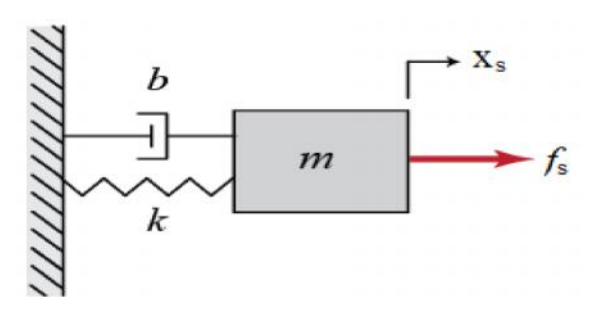
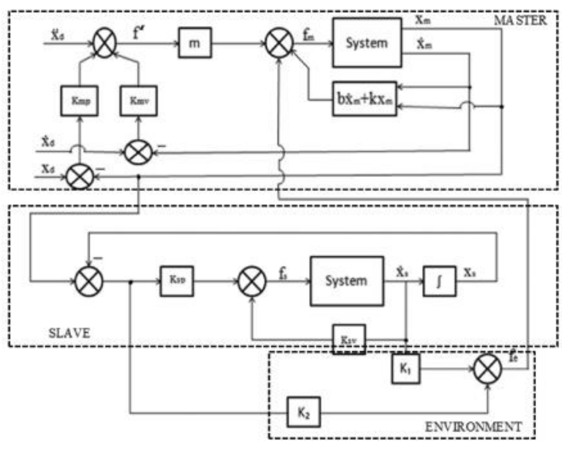


Figure 3: Bilateral Tele-Operation Using Two Mass Spring Damper System



DYNAMICS OF MASS SPRING DAMPER SYSTEM

There have been two systems (John Craig, 2005) taken for analyzing the stability analysis and tracking purpose without time delay.

Dynamics of Master

Master equation of bilateral teleoperator given below,

$$m\ddot{x}_m + b\dot{x}_m + kx_m = f_m$$

$$f_m = f'm + b\dot{x}_m + kx_m + f_e \quad ...(7)$$

$$f' = \ddot{x}_d + K_{mp}(x_d - x_m) + K_{mv}(\dot{x}_d - \dot{x}_m)$$

$$f_e = K_1\dot{x}_s + (x_m - x_s)K_2 \quad ...(8)$$

Dynamics of Slave

Slave equation of bilateral teleoperator given below,

$$m\ddot{x}_s + b\dot{x}_s + kx_s = f_s \quad ...(9)$$

$$f_s = (x_m - x_s)K_{sp} + \dot{x}_s K_{sv} \quad ...(10)$$

where x_m and x_s are the positions of master and slave respectively. x_d is the desired trajectory given to master. f_m and f_s are the controlling forces applied to master and slave respectively. *m* is the mass, *b* is the damping constant, *k* is the spring constant. K_{mp}, K_{sp}, K_2 are the proportional gains and K_{mv}, K_{sv}, K_1 are the derivative gains.

RESULTS

The parameters values [22] are, $m = 1$, $b = 0.1$, $k = 1$, $K_{sp} = 16$, $K_{sv} = 1$, $K_{mp} = 16$, $K_{mv} = 1$, $K_1 = 0.1$, $K_2 = 0.1$, x_d 2cosμt, $x_0 = [0.1, 0.1]$. In this section, desired trajectory of amplitude 2 unit has been given to master as shown in Figure 4. The output

Figure 4: Desired Position Trajectory Given to Master

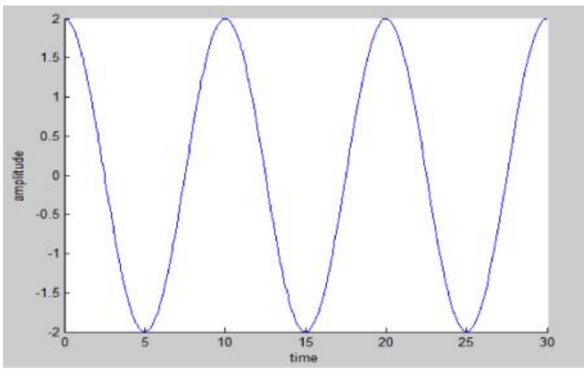


Figure 5: Master Position Output

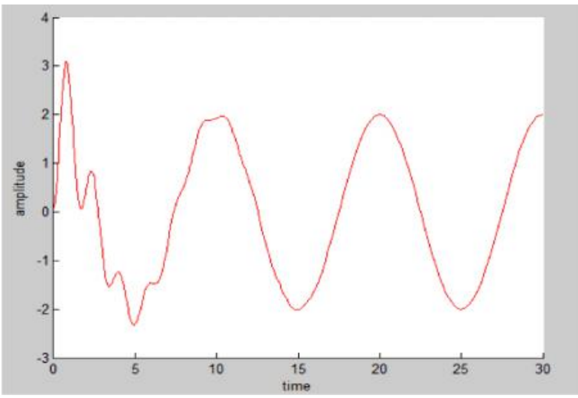


Figure 6: Slave Position Output

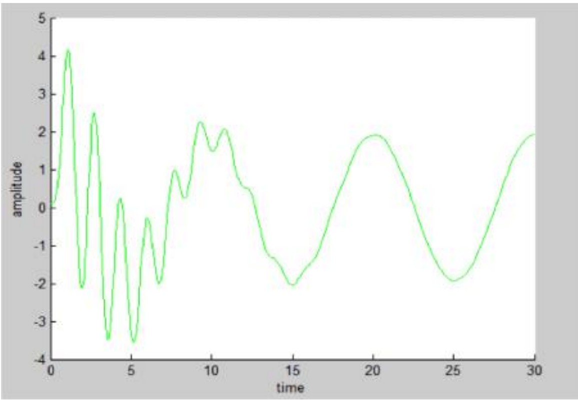
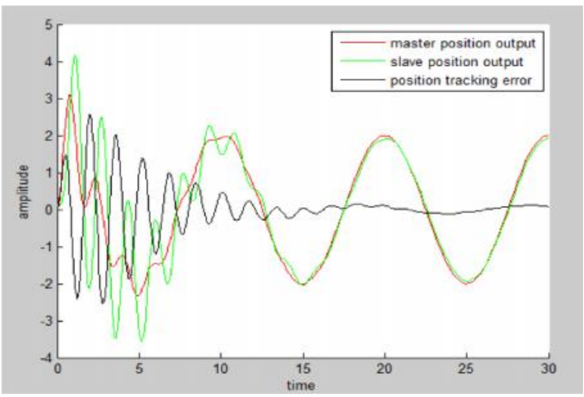


Figure 7: Position of Master and Slave with Tracking Error



of master position has been shown in Figure 5. The slave output position shown in Figure 6. The simulation of dynamics equation of bilateral teleoperator (7), (8), (9) and (10) has been shown below.

In Figure 7, it has been shown that slave tracking master and tracking error going to zero. This shows that in the absence of time delays, it has been shown through simulation that the bilateral teleoperation of two mass-spring damper systems is stable and slave is tracking position of master appropriately.

CONCLUSION

In this paper, we have used the dynamics of two mass spring damper system for understanding the working of teleoperation. We used Proportional-Derivative (PD) controller for tracking and stability of the system. It can be concluded that with the use of PD controller, slave is tracking the trajectory of master and tracking error has decreased in the absence of time delay. With the use of PD controller, it also assured the stability of the system.

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