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The Effects of Scaling Factors and Quantization in Sensors on Free Motion of Teleoperation System

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Abstracts: One of the advantages of master-slave teleoperation is scaling concept such as position scaling, force scaling. Meanwhile, lots of quantization effects are generated from position and force sensors in the master and slave manipulator. In this paper, to show the output error caused by the quantization effects from the position sensor and position scaling factor, simulation is done for free motion without contact in slave side. Transfer function model in which the quantization effect is assumed to be a disturbance input to the system is derived. Model shows that Jacobian, scaling factors, and controller affect the output by quantization effects from sensors. One dof master and slave are used for simulation. In our study, the higher sensor resolution decreases the output error from quantization. Scaling factors can amplify the quantization effects from the sensors in master and slave manipulators.

Keywords: quantization effect, teleoperation, position scaling, encoder resolution

1. Introduction

Teleoperation was started to remove a human being from a dangerous working environment such as nuclear material handling. Human operator can perform a remote task using a intermediary tool of master and slave robots without direct contact with environment. Here-in the foremost issue is the degree of telepresence. Contrary, there is a new room made for many kinds of scaling between master and slave or between human operator and environment. Kinesthetic coupling [2] through force reflection and visual feedback are the most contributing factors to telepresence. Scaled teleoperation is needed when the object dimension is quite different from human being's. Quantization effects are generated during a computerized sensing process. Here, our interest is how the scaling factor and quantization effect from sensors make influence on the system outputs. In early research, a kinesthetic feedback design [2]. A time scaling concept suggested for scaled teleoperation [5]. The stability region of a scaled teleoperation system was shown in [4]. Several ways of analyzing quantization effects are reviewed in [1].

In this paper the teleoperation system control block diagram with quantization spot is shown and the transfer function matrix from the quantization input to the position output is derived. The position sensor resolutions in master and slave will be varied in each simulation. The position scaling effects is simulated with a fixed position sensor resolution in master and slave.

2. Scaling Factor and Quantization Effects

2.1 Scaling Factor

Among lots of scaling factors [2], position scaling is considered in this paper. Forward flow method is usually adopted in teleoperation (Fig.1), where the forward position scaling, s_p and the backward force scaling, s_f are defined as

$$s_p = \frac{\Phi_2}{\Phi_1} = \frac{v_s}{v_m} \qquad (1)$$

$$sf = \frac{\varepsilon_1}{\varepsilon 2} = \frac{f_m}{f_s} \qquad (2)$$

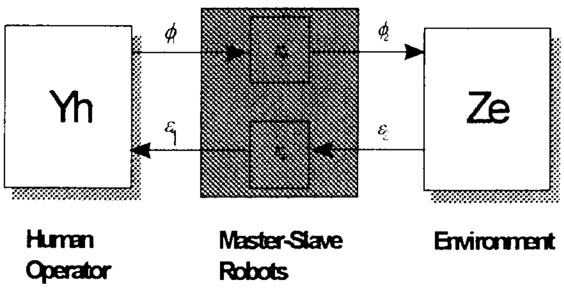

Fig. 1 Bilateral Scaling in a Teleoperation System

The feasible range of s_p and s_f is limited by overal system stability [4].

2.2 System Block Dagram with Quantization Effect

A typical teleoperation system has many kinds of sensors such as position sensors and force sensors in master and slave robots. In Fig. 2 the round-off error from quantization of AD conversion or of quadrature counting [7] can be regarded as a disturbance to system outputs [1].

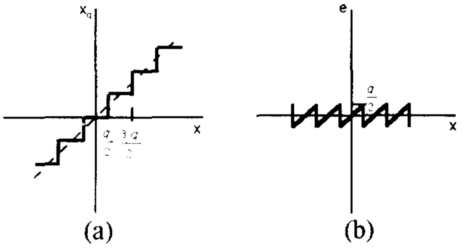

Fig. 2 (a) Variable versus rounded values (b) Round-off error

In Fig.3 we present a teleoperation system control block diagram with the quantization spots from the position and force sensors. A general global controller is assumed. For simplicity, the local controllers are not depicted. If each robot has n dof, the total number of quantization spot of sensing will be 4n. From Fig. 3, the quantization in the position sensors affects the Cartesian velocity at the end-effector which is computed through joint space measurement and Jacobian.

2.3 Derivation of Transfer Function Matrix

To simulate the effects of quantization on the system outputs, we derived the transfer function matrix from quantization spots of position sensor to system ouputs based on Fig. 3. In the following equations, the subscript, 'r' means remote slave side instead of 's' for clarification from Laplace variable, 's'. The general outputs resulting from quantization will be

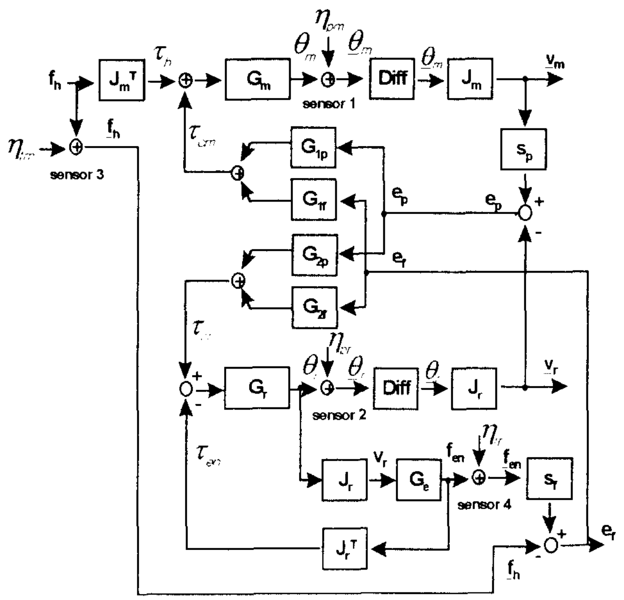

Fig. 3 Quantization spots and a system control block diagram

$$x_\eta = H_p \eta_p + H_f \eta_f \tag{3}$$

Free motion case removes the second term of the right hand side of (3).

$$\begin{bmatrix} x_{\eta m} \\ x_{\eta r} \end{bmatrix} = \begin{bmatrix} h_{p11} & h_{p12} \\ h_{p21} & h_{p22} \end{bmatrix} \begin{bmatrix} \eta_{pm} \\ \eta_{pr} \end{bmatrix} \tag{4}$$

From Fig. 3, the position error between master and slave,

$$e_p = s_p v_m - v_r \tag{5}$$

$$v_m = J_m s(\eta_{pm} - G_m \tau_{cm}) \tag{6}$$

$$v_r = J_r s G_r \tau_{cr} \tag{7}$$

$$h_{p_{11}} = [I + A_1(I - (I + B_1^{-1})^{-1})]^{-1} J_m \tag{8}$$

$$h_{p_{21}} = s_p (I + B_1^{-1})^{-1} [I + A_1(I - (I + B_1^{-1})^{-1})]^{-1} J_m \tag{9}$$

where,

$$A_1 = s J_m G_m G_{1p} S_p \tag{10}$$

$$B_1 = s J_r G_r G_{2p} \tag{11}$$

$$h_{p12} = -(I - s_p d_1)^{-1} d_1 [I + c_2 + c_1(d_1^{-1} - s_p I)^{-1}]^{-1} J_r \tag{12}$$

$$h_{p22} = [I + c_2 + c_1(d_1^{-1} - s_p I)^{-1}]^{-1} J_r \tag{13}$$

where,

$$c_1 = s J_r G_r G_{2p} S_p$$

$$c_2 = s J_r G_r G_{2p}$$

$$d_1 = s J_m G_m G_p$$

The derived transfer functions show key parameters such as position scaling, Jacobians, controllers, and dynamics of master and slave.

3. Simulation Results

3.1 Simulation

For simplicity, free motion which has no physical contact with environment in the slave side is simulated. In our simulation, one dof system is assumed. Jacobians are assigned 1. Master and slave dynamics, G_m and G_r [4] are same. Identical global controllers of G_{1p} and G_{2p} having a PID structure are used. In a real situation the quantization input (Fig. 2) has a varying period of time depending on the signal to be sensed. In our simulation, 20 Hz saw tooth wave was used as the disturbance input of quantization. 0.1Nm as the torque from human operator was applied to 1dof master for 1 second.

3.2 Results

Fig. 4 shows the position tracking of master and slave with the position scaling, s_p=2 while the disturbance input of quantization is only at master position sensor with 500 line, 2000 quadrature optical encoder [7].

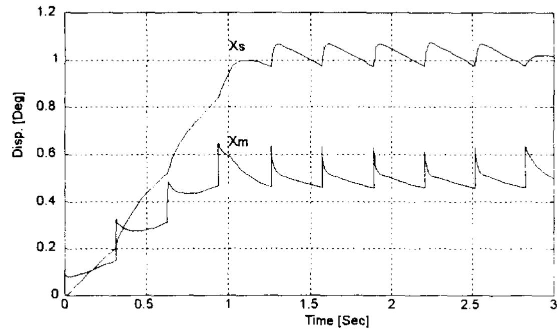

Fig. 4 Master and slave positions (x_m, x_s) with master sensor of 500 line optical encoder and s_p=2.

Fig.5 shows the position tracking error between master and slave with the variation of master position sensor resolution when the position scaling is fixed at s_p=2.

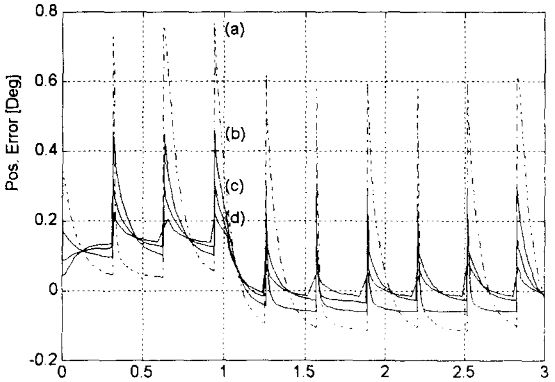

Fig. 5 Tracking error between master and slave position with the variation of master sensor resolution; (a) 250 (b) 500 © 1000 (d) 2000 line and position scaling. s_p=2 .

The position outputs with the quantization effect of the slave position sensor are shown in Fig. 6. Fig. 7 shows the tracking error with the quantization effect of slave position sensor. The resolution was varied from 250 to 2000 lines.

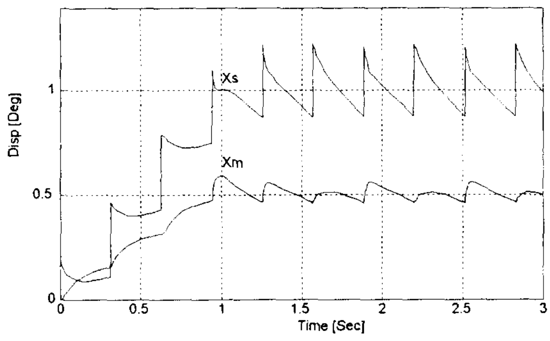

Fig. 6 Position outputs with the quantization effect of slave position sensor, 250 line resolution and s_p=2.

In Fig. 8 we present the tracking error of the master and slave position with the variation of position scaling, sp from 0.5 to 4.0.

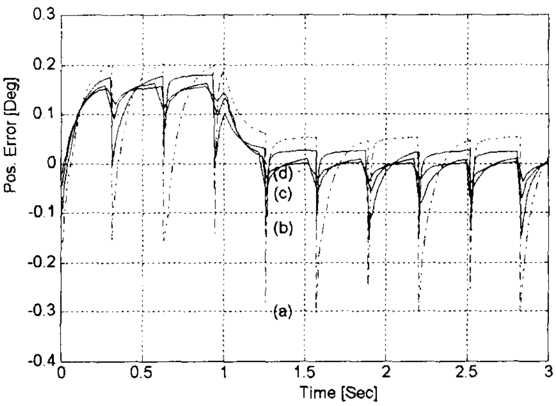

Fig. 7 Tracking error with quantizaton effect of slave position sensor. (a) 250 (b) 500 © 1000 (d) 2000 line resolution. s_p=2.

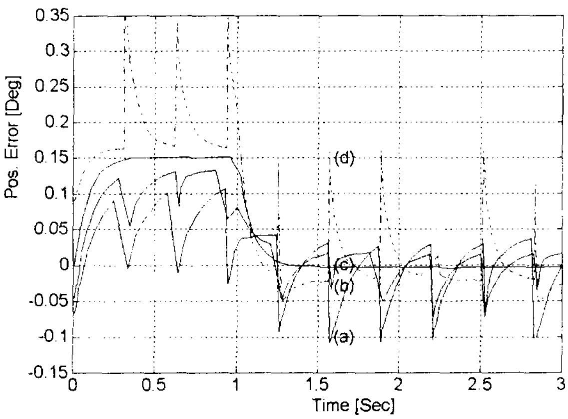

Fig. 8 Tracking error with variation of position scaling from 0.5 to 4. Sensor resolution; master of 1000 line and slave of 500 line.

3.3 Discussion

The friction forces in master and slave are not modeled in the system block diagram. The oscillated signal at the steady state is due to the continuing input of quantization used in the simulation. The steady state oscillation will be absorbed into the friction in real motion. This magnitude of oscillation will increase the randomness of the output variables of the system. Also, this random effect can give the human operator a noised feel in the kinesthetic coupling.

We can derive the following points based on the simulation results.

- The saw tooth spikes from master or from slave sensor are filtered by the scaling factor, controller and dynamics of master and slave.
- The high resolution of the master and slave position sensors decreases the quantization effects on position outputs almost linearly in this 20 Hz saw tooth input.
- A set of the master and slave resolutions and scaling factor can minimize the quantization effect, but the scaling factor beyond this increases the error by quantization.
- The selection of sensor resolution can be made with the output norm from the transfer function of (3),(4) though this is not realistic in a real multi dof situation.

4. Conclusions

In this paper, we showed the teleoperation system control block diagram with the disturbance input of quantization from position and force sensors. The transfer function matrix from quantization spot to position output was derived. From the limited simulation, the higher sensor resolution decreases the output error from quantization. A set of scaling factor and sensor resolutions in master and slave can minimize the quantization effect.

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