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Effect of haptic device's position resolution on stability

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Abstract. Relation between position resolution of haptic device and stability problem is discussed in this paper. Based on virtual wall model and passive characteristics of contact interaction, violation of passive dynamic criteria and energy accumulation of motor output are proved to be the factors that influence system stability. Influence of device parameter on stability is discussed and the criterion about selecting position resolution is proposed. Experiments based on Phantom are carried out to evaluate the validity of the criterion.

1. Introduction

Key problem in design of haptic system is to get tradeoff between transparency and stability [1]. How to enlarge the Z-Width through effective design of haptic device, so that contact against stiff object can be simulated, which is the goal of this paper.

Virtual coupling and time domain passivity method have been used to analyze the stability of haptic system [1][3]. These methods didn't answer how the design parameters of the device influence the virtual stiffness limit of the system.

Colgate points out that the stiffness limit of a pure spring virtual environment are decided by sampling frequency and damping of the device [2]. However, the influence of the device's position resolution on stability has not been analyzed. In this paper, the relation between the maximum simulated stiffness and the position resolution is proposed, which will be the criteria for selecting the position sensor.

The remainder of this paper is organized as follows. Section 2 discusses the reasons that lead to unstable interaction and proposes the relationship among device's position resolution, operating speed, and virtual stiffness. Section 3 gives experiment result about the relationship. Section 4 gives the conclusion and future work.

2. Effect of device's position resolution on stability

Virtual wall is usually used as a benchmark experiment to test the performance capability of a haptic device [4]. Apart from using two-port network theory [2], the dynamics of the system is used to analyze the stability of the virtual wall system. For single dof haptic system, the dynamic is

$$M\ddot{x} = F_h - F_e \tag{1}$$

where F_h is active force imposed by human. In physical world, when human moves a probe to push the wall, resistance force F_e is always smaller than active force

$$F_e \leq F_h \tag{2}$$

In haptic interaction system, assumed that the device locates inside free space at t_i, and enters into constraint space at t_{i+1}. Because the motor's output force F_m is zero at t_i, dynamics of the device can be described

$$F_{hi} = M\ddot{x} \geq 0 \tag{3}$$

When device moves into constraint space, if the following condition occurs

$$F_h(i+k) - F_m(i+k) < 0 \cdots k = 2 \sim n \tag{4}$$

the device will manifest "active" effect, i.e., the device and the human will be pushed away by the output force of the motor. When the device moves inside the constraint space, the active effect will also occur when the criteria (2) is violated.

Because human's output force channel has low bandwidth, active force from human at two adjacent time stamp can be assumed constant under high sampling frequency. According to the model of the virtual wall, it can be derived

$$F_m(i+1) = F_e(i+1) = K_e \cdot (X_{i+1} - X_0) \leq F_{hi} \tag{5}$$

Where F_{hi} is human's active force inside free space. Furthermore

$$(X_{i+1} - X_0) = \delta \cdot (v_h \cdot T) \tag{6}$$

Where v_h is human's operating speed, δ describe the discrete effect of the haptic system [4], T is the sampling period of the haptic loop. It seems that penetrated depth is only decided by T when v_h and δ is decided. However, another potential factor, the resolution of the position sensor η_X, will influence the penetrated depth. And this value must obey

$$\eta_X \leq (X_{i+1} - X_0) \leq F_{hi}/K_e \tag{7}$$

Otherwise, no matter how high the sampling frequency is, the system cannot be stable against virtual wall with big virtual stiffness. Furthermore, the relationship between operating speed of the human and virtual stiffness can be derived

$$v_h \leq \frac{F_{hi}/K_e}{\delta \cdot T} \tag{8}$$

3. Experiment

In order to validate the relationship in equation (7) and (8), experiment based the Phantom desktop is carried out. For a virtual wall with given stiffness, different position resolution is used to check the stability performance of the system. Re-sampling method is proposed to change the resolution of the position signal.

Figure 1&2 give the performance of system under different position resolution at. It can be clearly seen that unstable phenomena occurs when the position resolution exceed a given threshold. Vibration occurs when operating speed exceeds $100 mm/s$.

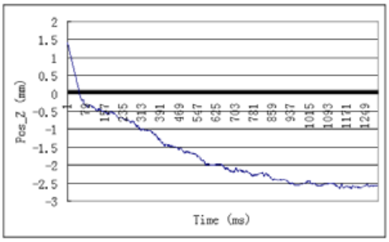

Figure 1 $K_{Z\max} = 1.2N/mm, \eta = 0.1mm$

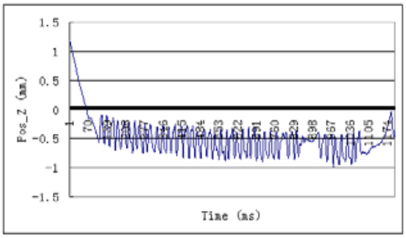

Figure 2 $K_{Z\max} = 1.2N/mm, \eta = 0.4mm$

4. Conclusion

In this paper, the reason that lead to the vibration of haptic device when simulating contact against a virtual wall with big stiffness is analyzed. The reason of unstable interaction is because the passive dynamics criteria of the haptic device is violated.

Relationship among the maximum virtual stiffness, position resolution and operating speed is derived. In order to achieve specific contact stiffness, position resolution must be bigger than a threshold; on the other hand, it is unnecessary to adopt too high position resolution at given operating speed.

Future work will analyze the relationship between position resolution and the maximum virtual stiffness in multiple-dof haptic device.

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References

1. R. J. Adams, B. Hannaford, "Stable Haptic Interaction with Virtual Environments", IEEE Transactions on Robotics and Automation, VOL. 15, NO. 3, 1999
2. J. E. Colgate, J. M. Brown, Factors Affecting the Z-Width of a Haptic Display, in Proc. IEEE Int. Conf. Robot. Automat., Los Alamitos, CA, 1994, pp. 3205–3210.
3. B. Hannaford, J. H. Ryu, Time-Domain Passivity Control of Haptic Interfaces, IEEE Transaction of Robotics and Automation, No. 1, 2002
4. B. Gillespie and M. Cutkosky, "Stable User-Specific Rendering of the Virtual Wall", Proceedings of the ASME International Mechanical Engineering Conference and Exposition, DSC-Vol. 58,Atlanta, GA, Nov 17-22, 1996. pp. 397-406.