Stable Control of a Haptic Interface System for Virtual Simulation

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Abstract. In this paper, stable control of a haptic interface system for virtual environment simulation is studied. Experimental results using a haptic interface system are presented. In experiments where both resetting and velocity threshold are applied, it is examined how fast stable contact can be achieved.

Keywords: stable control, haptic interface system, virtual simulation

1 Introduction

One of the most important issues in haptic interface design is to achieve stable interaction between the haptic display and the virtual environment for any operating conditions and for any virtual environment parameters. Vibration or divergent behavior caused by the instabilities is very distracting, can damage the hardware, and in some large systems, even pose a physical threat to the human operator. The facts that virtual environments of interest are always nonlinear and dynamic properties of a human operator are always involved, can make especially it difficult to analyze haptic systems in terms of known parameters and linear control theories. In many cases performance can be poor if a fixed damping value is used to guarantee passivity under all operating conditions. [1] proposed an energy based method, (termed the “Passivity Observer” (PO) and “Passivity Controller” (PC)). The PO measures the total amount of energy dissipated in the haptic interface system and identifies time samples in which this energy becomes negative (indicating active behavior). In this paper, some practical issues mentioned in the above are studied to improve the performance of a new energy based method of achieving stable control which includes virtual environment simulation.

2 Stable control of haptic interface systems for virtual simulation

A stable control example of a haptic interface system for virtual simulation is shown as Fig. 1, consisting of five elements (Fig 2).
Fig. 1. An example of stable control of a haptic interface system for virtual simulation: (a) “Excalibur”, a haptic device (b) virtual LEGOTM blocks used for virtual simulation.

Fig. 2. System component for haptic interface system: human operator (HO), haptic interface (HI), haptic controller (HC) having feed forward gravity compensation and friction compensation, the passivity controller (PC), and the virtual environment (VE).

2.1 Resetting

If the energy accumulated in the PO can be reset to zero properly, then faster stable contact can be achieved with smaller bounces. With this motivation, we want to derive a heuristic rule, called “resetting” throughout this paper, and based on the detection of free motion state. The rule is as follows.

\[ |f| < \varepsilon \text{ for } \tau \text{ sec, then Reset the PO to zero.} \]

where, we call \( \varepsilon \) the force threshold, and \( \tau \) the duration.

2.2 Velocity Threshold

Velocity estimates obtained by various differentiation methods are notorious for amplification of high frequency noise.\[2\] The sensor (encoder) resolution used in our haptic interface system is 0.008mm and the velocity is estimated from the measured position \[3\]. By magnifying the interval of interest, we find that there exist some oscillatory fluctuations of measured velocity of \( \pm 8\text{mm/s} \) during the contact, and this is caused inherently by the quantization in digital control system.
Fig. 3. Trajectories zoomed in t = 1.6sec to 1.7sec to show the noise effect at low velocity: each peak of the PC almost coincides with the noise at low velocity, even in PO ≥ 0 where the PC should not operate. (a) PO energy (b) PC force (c) velocity.

\[ |\text{velocity noise}| \approx \pm \frac{\text{sensor resolution}}{\text{sampling time}} = \pm \frac{0.008 \text{mm}}{1 \text{msec}} = \pm 8 \text{mm/sec} \]

Also, we find that each peak of the PC output almost coincides with the noise at low velocity, even in PO ≥ 0 where the PC should not operate. The amplitude of this fluctuation is consistent with the position resolution and sampling time (T = 0.001sec) and can cause perceptible (audible) noise in some circumstances. Therefore, our approach to avoiding this problem will be to introduce a velocity threshold: To eliminate effects of this quantized noise, we applied the following rule for velocity

\[ u_k = \begin{cases} \tilde{u}_k & \text{if } |\tilde{u}_k| > 10 \text{mm/sec} \\ 0 & \text{else} \end{cases} \quad (1) \]

where, \( \tilde{u}_k = \frac{x_k - x_{k-1}}{\Delta T} \) and \( x_k \) means the position measured at \( k \).

3 Experimental Results

We added resetting to the experimental system under the conditions of previous subsection. The results obtained from the experiments to get useful values for the resetting are summarized as follows

- When \((10^{-7} \times F_{\text{MAX}})\) was chosen for the force threshold and \( \tau \) was \(1 \times T\) or \(100 \times T\), we found a very sluggish feeling in free motion: the resetting was continuous and the PC was operating all the time.
- When a big value \((10^{-1} \times F_{\text{MAX}})\) was chosen as the force threshold with \( \tau = 100 \times T \), we found no resetting even during the contact.
- When the duration equals the sampling time \((1 \times T_{\text{sec}})\), there was too much resetting. In the case of \( \varepsilon = 10^{-1} \times F_{\text{MAX}} \) with such a short duration, resetting is being done when even a single noisy signal is less than the force threshold, and the PC operates too much. Still, faster stable contact was not achieved.
- Finally, we determined \( \varepsilon = 0.2\text{N} \), \((10^{-3} \times F_{\text{MAX}})\) and \( \tau = 0.01\text{sec} \), \((10 \times T)\) were useful values for the resetting.
In the other experiment, we studied how linear velocity filtering worked in our haptic system. The used filter equation is as following

\[ \hat{v}_{k+1} = \eta \hat{v}_k + (1 - \eta) v_k \]

(2)

where, \( 0 \leq \eta < 1 \) is the filter constant, \( \hat{v}_k \) and \( v_k \) are the filtered and estimated velocity, respectively.

We experimented with velocities filtered by various filter constants: \( \eta = 0.1 \) (1kHz), \( \eta = 0.25 \) (478Hz), \( \eta = 0.62 \) (97Hz), \( \eta = 0.9 \) (17Hz). At all of these values, the linear filter either had no effect or caused the system to be unstable. We added a nonlinear filter in the form of a velocity threshold to the experimental system under the condition of subsection 4.1. to study how the resetting and velocity threshold work together. The operator approached the virtual object twice in 4 seconds. The contact regime was a highly active one which generated energy after three bounces as shown previously.

4 Conclusion

In this paper, stable control of a haptic interface system for virtual simulation was studied. Two major issues such as resetting and threshold relating to the stable control were dealt. Experimental results using a haptic interface system were presented. In experiments where those issues were applied, it was validated that the faster stable contact can be achieved with smaller bounces as well as less sensitivity to noise at low velocity.

References