A velocity estimator for increasing the transparency and stability of haptic devices

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Abstract

Transparency and stability are two major issues in controlling haptic devices. Transparency highly depends on the quality of state observation while the stability range is mainly affected by the time-delay and sampling frequency. In this work, a velocity estimator is introduced, which observes low-delay and noiseless velocity based on the sampled-quantized position measurements performed by optical encoders. Consequently, the efficiency of the virtual damper is increased and the passivity of the haptic device is maintained at much higher values of virtual stiffness. Moreover, the transparency of the displayed environment is significantly increased with the CBVE method.

Keywords: Haptics, impedance control, velocity filtering, high virtual stiffness, optical encoder.

1 INTRODUCTION

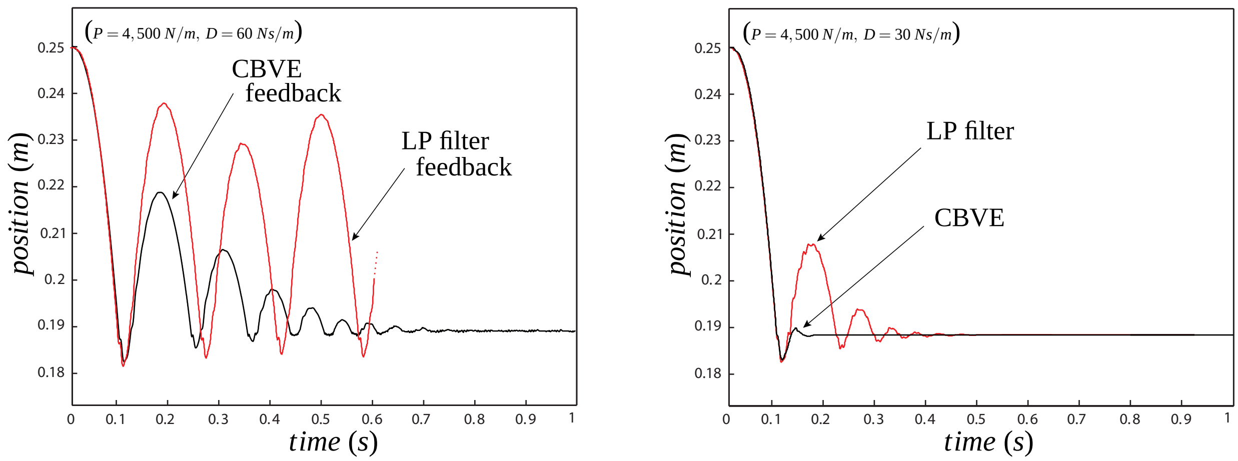
There are many applications for which a robotic device is used to recreate the sense of touch for a physical or a virtual environment. The illusion of reality, however, can be easily destroyed by undesirable aspects of the digital control. For instance, the position quantization stemmed from the limited encoder resolution, contaminates the measured velocity with high magnitude noises. This noise dramatically destroys the transparency. Therefore, low-pass filters are often employed to detect a smooth velocity profile. Low-pass filters conservatively over-damp the rate of change of the velocity estimation and introduce a significant delay which limits the stability even further. In this work, we introduce a fast and efficient algorithm to improve the velocity observation and cancel out the noise caused by differentiating the quantized position. Rendering highly stiff/damped virtual environments is the main target of this work.

2 THE CBVE PRINCIPLE OF OPERATION

Almost all of the conventional methods use a number of previous states to estimate a noiseless velocity. However, by now there has been no recipe suggesting the appropriate windows size of the useful older samples. Involving more data from the past would make the estimation more robust to noise, but at the same time it would slow down the observation of the actual movement. Curve Breaking Velocity Estimator (CBVE) breaks the actual curve into detectable lines and estimates the slope of these lines from their presenting sampled positions. In this way, at every sampling time, only an optimal number of older data is employed which can be useful to reduce the noise without adding unnecessary time-delay.

3 Experimental results

To evaluate the performance of the CBVE, a 2-DoF Quanser Pantograph was employed to display the virtual environment. As a benchmark test, we considered the example of interacting a falling ball with a virtual wall to examine the passivity of the wall for different values of virtual stiffness. The end-point of the robot was considered to be a ball to be released from $y = 25\ cm$ to hit a



(a) (b)

Figure 1: Comparison between experimental trajectories of the CBVE and the low-pass filter velocity feedbacks for (a) $P = 80,000\ N/m$ and (b) $P = 4,500\ N/m$ virtual stiffness.

Kelvin-Voigt virtual wall at $y = 19\ cm$ under a constant $F_y = -4\ N$ force. Fig. 1 compares the y direction end-point trajectories for the CBVE and a commonly used second-order low-pass filter (300 Hz Cut-off frequency) velocity feedbacks. As can be seen in Fig. 1.a, as a result of using the high performance velocity feedback from the CBVE, the system exhibits a stable behavior at high virtual gains of $80,000\ N/m$ stiffness and $60\ Ns/m$ damping, while the low-pass filter feedback caused instability. To experience a stable behavior with the low-pass filter feedback, the gains had to be readjusted to $4,500\ N/m$ stiffness and $30\ Ns/m$ damping. Fig. 1.b demonstrates that even at lower values of virtual stiffness the CBVE results to have more passive virtual wall. The setup was also simulated in MATLAB/Simulink® and the results were in a good match with the experiments. In the simulation environment, there was also a chance to have the real velocity feedback which resulted in a closely similar trajectory as that of the CBVE feedback.

4 Conclusions

This work briefly introduced the novel CBVE method and its advantages for haptic applications. The simulation and experimental results showed significant improvements over a commonly used second-order low pass filter using the CBVE. The high performance velocity estimation from the CBVE increases the efficiency of the virtual damper and much higher virtual stiffness can be rendered. The significant improvement of the stability and fidelity can also improve the security of robots for critical applications such as the tele-surgery. The CBVE algorithm is computationally cheap, easy to implement and flexible with various sampling frequencies.