Velocity estimation for affordable force feedback devices by time stamping and adaptive windowing

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***Abstract*— We propose combining high-resolution time stamping and adaptive windowing to improve velocity estimation in affordable kinesthetic devices with low-cost sensors and limited computational power. Preliminary results with simulations and a test bench suggest an improvement in accuracy.**

I. Introduction

To render realistic contacts, kinesthetic devices calculate forces using models that require position and velocity values. While position is typically measured directly from encoders at the joints, velocity is generally estimated by differentiating position readings. With a simple estimator such as the two-point backward difference, the resolution of the velocity estimate is proportional to the resolution of the encoder, but inversely proportional to the sampling period. In affordable devices, the combination of high sampling rate (for high stiffness rendering) and low-resolution encoders (for affordability) creates a worst-case scenario.

Low-pass filters increase the resolution and reduce high-frequency noise amplified by differentiation, but a fixed cut-off frequency is not optimal for haptics [1]. Adaptive estimators compensate for limitations of fixed causal filters [1], [3], and time stamping also addresses issues in velocity estimation through fixed-time methods. Low-Resolution Time-stamping (LRTS) has for example been used to avoid over-sampling and to establish error margins used for window adaptation [3]. High-Resolution Time Stamping (HRTS) has been shown to completely eliminate errors due to quantification and discretization [2] but is still impacted by noise.

We propose to associate adaptive windowing and HRTS to provide reliable velocity estimation. The algorithm is based on the First Order Adaptive Windowing (FOAW) proposed in [1], modified to consider HRTS as presented in [2]. FOAW was further adapted by using empirical parameters to adapt the window instead of values based on digitization errors.

II. Preliminary Results

Simulated position data with quantization and discretization errors were first used to evaluate estimators. In these comparisons, simple finite difference using HRTS without further filtering was found to yield the most reliable results compared to other methods, including fixed-time finite difference associated with different filters (fixed low-pass filter, FOAW) and analytical differentiation of linear and polynomial fitting. While these results are promising, the simulation does not recreate other noise found in real systems.

An experimental test bench was then developed to drive a low-resolution encoder system to admissible velocity inputs found in haptic rendering and expose the estimators to abrupt velocity changes. Fig. 1 shows velocity estimations at very low driving velocities (2.5 to 4.5 deg/s). This test bench is limited as it adds noise from the driving system and ideal velocity inputs are considered as ground truth for estimator comparisons. However, as shown in Fig. 1, it demonstrates the superiority of the HRTS estimator with adaptive windowing compared to fixed-time methods with both fixed and adaptive windowing (5th-order Butterworth filter with 100 Hz cut-off frequency and FOAW). These methods show significant inaccuracies and small changes in velocities can not be accurately estimated. Unlike in simulations, HRTS without adaptive windowing also yields poor results, justifying the need for filtering. Overall, HRTS with adaptive windowing produces more accurate and higher-resolution estimations of velocity than other tested methods.

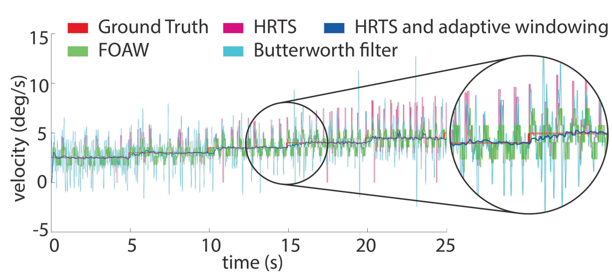

Fig. 1. Comparison of low velocity estimations (2.5 to 4.5 deg/s)

III. Conclusion

This early work demonstrates the potential of combining HRTS and adaptive windowing. Future work will focus on better understanding the noise distribution in time stamps (due to the measurement system) in order to provide more efficient design rules for optimized adaptive windowing.

References

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