Factors Affecting the Stable Range of Damping and Mass in Admittance Type Haptic Devices

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***Abstract*—This work investigates the stability of admittance type haptic devices in the context of a wider range of impedances than previously considered. More specifically, we consider the stable range of mass and damping. The coupled human driving impedance, actuator position control bandwidth, and loop delay are identified as major factors affecting the range of stable impedances. Finally, theoretical results are experimentally verified using a custom one degree of freedom admittance type haptic device.**

I. INTRODUCTION

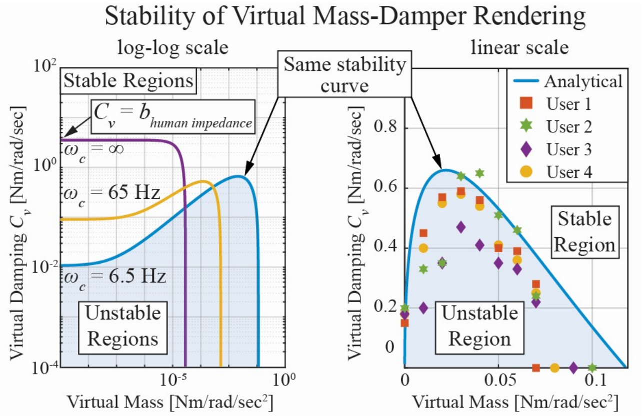
Admittance Control, a method of haptic rendering, has attractive characteristics. These include the ability to render large forces and high impedances (typically Mass, Springs, and Dampers) in a compact form factor. However, this class of haptic devices has difficulty rendering small impedances which often limits widespread use.

A typical admittance control topology utilizes a high impedance environment and the smallest stable pure mass to represent free space. Guidelines to improve the performance of admittance devices include increasing the position control bandwidth, limiting delay, and adding some virtual damping; all of which aim to reduce the minimum mass of the environment [1][2]. With these guidelines in mind, we have examined the range of stable mass and damping to better understand factors affecting the range of stable impedances.

II. COUPLED MINIMUM STABLE MASS AND DAMPING

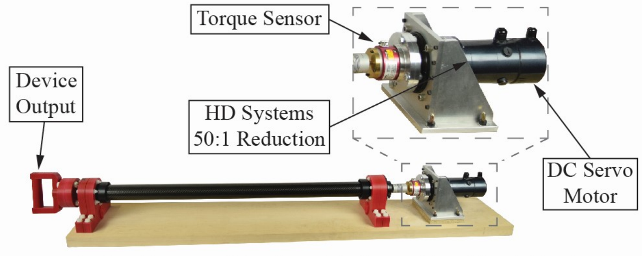
Prior work considering the minimum stable virtual mass utilized a human impedance model, a model of a position control bandwidth, and a pure delay [1]. A similar analysis using the same model and simplifications can be applied to a pure virtual damper with infinite control bandwidth and delay. Using a high frequency approximation for a human's impedance and evaluating the magnitude of the simplified open loop transfer function yields the expression shown on the damping axis of Fig. 1a.

Numerical analysis, via bode plots, confirms this expression, and shows the impact of the position controller on stability. In the case of a high position control bandwidth, ω_c, our expression shows minimum virtual damping, C_v, is proportional to the high frequency damping added by a human's impedance, $b_{human\ impedance}$. Fig. 1a shows that a reduction in position control bandwidth increases the minimum renderable virtual mass. Contrary to virtual mass, a reduction in position control bandwidth decreases the minimum virtual damping required for a system to be stable.



(a) Stability Regions Varying Bandwidth

(b) Experimental Data Overlayed on 6.5 Hz ω_c Stability Curve



(c) One Degree of Freedom Admittance Type Haptic Device

Fig. 1 a) Log-log scale of virtual damping and mass stability curves at three position control bandwidths, and delay of 0.125 [ms]. b) Experimental results overlayed on 6.5 Hz ω_c stability curve using human impedance model from [1]. c) SDOF haptic device used to evaluate the stable regions.

To validate the results in Fig. 1a, we experimentally determined the minimum renderable virtual damping and mass of four participants, as shown in Fig. 1b. For a given virtual mass, the stability of the SDOF device, Fig. 1c, was determined by decreasing virtual damping until unstable oscillations were observed.

III. CONCLUSION FUTURE WORK

The experimentally measured minimum mass and damping values generally match the shape of the stability curve, as seen in Fig 1b. Differences can be attributed to unmodeled device dynamics and variations in the user's grasp and resulting human impedance. Future work includes expanding analysis to virtual stiffness and the impact of higher order modes on minimum stable impedances.

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