Improving Haptic Rendering Quality by Measuring and Compensating for Undesired Forces

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I. Introduction

The first necessary criterion for an effective haptic interface is that free space must feel free [1]. However, grounded force-feedback (GFF) devices apply different levels of forces on the user's hand even when they are unpowered [2]. These undesired forces are due to gravity, friction, inertia, and characteristics of other components of the device, such as the transmission. These forces still occur when the device is active and is rendering a virtual environment, so they degrade the quality of virtual interactions [2]. We hypothesize that removing them via software compensation would greatly improve a device's ability to actively render haptic content.

II. Methods

We began exploring our hypothesis through experiments with a Novint Falcon, a common three-degree-of-freedom grounded haptic device that costs less than 300 USD. We used Haptify (a benchmarking system for GFF devices [2]) to measure the undesired force vector at the Falcon's end-effector while a user was holding the unpowered device handle and moving freely in the workspace with a speed of less than $6\,\mathrm{cm/s}$ (Fig. 1a). We then repeated the experiment for the same device while it was plugged in but not actively commanded to render any forces. In the third experiment, we commanded zero forces in all directions and measured the forces that actually occurred during motions similar to the first and second experiments.

III. Preliminary Analysis and Future Plans

The average magnitude of the undesired forces for the unpowered device and plugged-in device were $6.13 \pm 1.14\,\mathrm{N}$ and $6.15 \pm 1.17\,\mathrm{N}$, respectively. This similarity shows that the Novint Falcon does not automatically compensate for any undesired forces when it is plugged in and calibrated. The average magnitude of the measured forces for the third experiment was $4.27 \pm 1.67\,\mathrm{N}$, which indicates that this device compensates for approximately 30% of its undesired forces when it is commanded to output zero force. This change in the force magnitude was pleasantly perceivable to the user and improved the realism of rendering free space, though further improvements are certainly possible.

In the future, we aim to model the undesired background force vector using the non-linear Hammerstein-Wiener (NLHW) models that have shown good agreement with experimental data for other haptic devices such as Touch and Touch X [2]. The inputs for the models will be the haptic device's joint angles, velocities, and accelerations, and the output will be 3D forces. We will first train these models on the dataset recorded in the third experiment. Next, we will develop and implement a strategy for using the real-time model to command the device to cancel a portion of the calculated force while rendering both free space and virtual content. Though there will certainly be limits to the performance gains possible, we believe that compensating for the actual measured undesired force vectors in software will substantially improve interaction quality without requiring one to purchase a more expensive haptic interface.

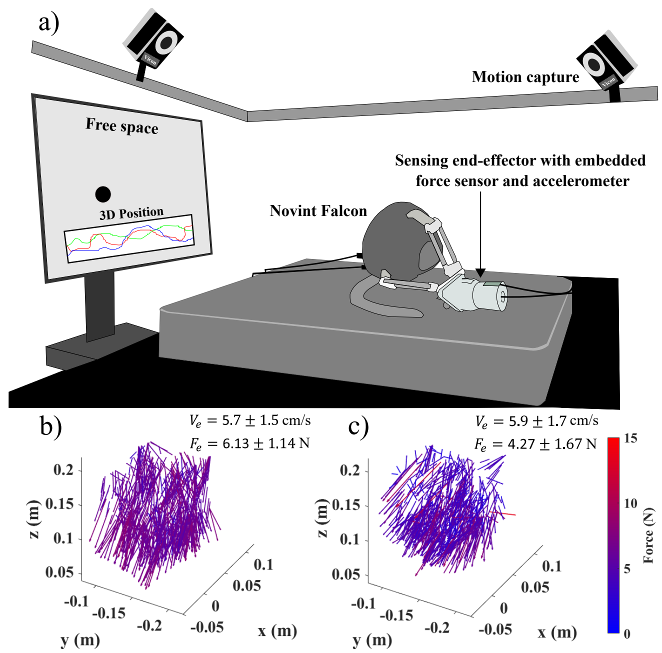

Fig. 1. a) A Novint Falcon is placed at the center of the experimental setup, Haptify [2]. The difference between the magnitude of the measured force vectors for b) the unpowered experiment and c) the experiment where we actively commanded zero forces shows that this device's software compensates for about 30% of its undesired background forces. Here, V_e and F_e show the magnitude of the externally measured end-effector velocity and end-effector force, respectively (mean ± standard deviation).

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References

[1] T. H. Massie and Salisbury, "The PHANToM haptic interface: A device for probing virtual objects," in *Proceedings of the ASME Winter Annual Meeting, Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*, vol. 55, no. 1, 1994, pp. 295–300.

[2] F. Fazlollahi and K. J. Kuchenbecker, "Haptify: A measurement-based benchmarking system for grounded force-feedback devices," *IEEE Transactions on Robotics*, vol. 39, no. 2, pp. 1622–1636, Apr. 2023.