Impact of hybrid actuation on the perception of complex signals

Paul Mefflet[1], Thanh-Loan Sarah Le[1], Mokrane Boudaoud[1], David Gueorguiev[1], Sinan Haliyo[1]

I. Introduction

Hybrid haptic devices have been developed to render a large bandwidth of frequencies in order to stimulate both kinesthetic and vibrotactile dimensions. To that end, low-frequency actuators such as DC motors and high-frequency ones like voice-coils are typically used [1]. When the haptic signal is sent to the user, high and low frequency components are separated and rendered by distinct actuators, according to a predefined cut-off frequency chosen regarding the frequency responses of the mechanical components [2], [3]. This study aims to understand how changes in the balance between the different actuators outputs impact users' perception.

II. Material and Procedures

We conducted psychophysical experiments using the *Pantograph MkII*, augmented with an haptuator (*Actronika Hap-Coil One*) mounted inside the end-effector.

Ten subjects aged from 23 to 33 years old partook in a 2-AFC psychophysical experiment in which participants were asked to explore the Pantograph's workspace and tell if two designated zones were identical or different. A two-component harmonic signal, 50 Hz + 100 Hz was sent through the Pantograph's actuators. The signal could be either fully delivered by one actuator or in a hybrid way (50 Hz to the Pantograph and 100 Hz to the haptuator). Prior to the experiment, a single frequency calibration was conducted for each component: both zones where actuated respectively via the DC motors and the haptuator. Participants reported the zone where the stimulus felt more intense ; the amplitude was adjusted until perception was identical in both zones. Afterwards, participants where given five training trials to familiarize with the exploration procedure, which consisted in a back and forth movement from one end of the workspace to the other. The signal was delivered only if the handle moved, but its parameters did not depend on the exploration speed. In each trial of the experiment, participants had to report whether the two zones felt different. 6 comparison types were implemented: 100% haptuator (VV) vs. other combinations, 100% DC motors (PP) vs. others, and hybrid (PV) vs. others. 10 repetitions were presented in randomized order for each combination, the identical catch trials totaling 60 randomized trials.

[1]All authors are with Sorbonne Université, CNRS, Institute of Intelligent Systems and Robotics (ISIR), Paris, 75005 FRANCE. mefflet@isir.upmc.fr

III. Results

A One-Way ANOVA was performed to analyze the effect of modifying the actuation mode on the percentage of felt difference for a given comparison. The three analyses showed a statistically significant difference ($P_{VV} < 0.0001$, $P_{PP} = 0.0003$, $P_{PV} < 0.0001$). A post-hoc Dunett's test showed that compared to the baseline comparison of identical signals (*"(CT)"*), participants significantly perceive the signal as different when the frequency distribution of the stimulation is actuated differently by the haptic device. However, no specific impact of the type of actuation change was observed on the perceived difference (see Fig. 1).

IV. Discussion

The results could indicate that the different skin mechanoreceptors respond differently when the same signal is delivered through a single or a hybrid actuation. However, the perceived differences can also be inherent to limitations of the actuators that could have generated artefacts that triggered user responses. Next, we aim to test a broader range of frequency components in the range of kinesthetic and vibrotactile perception, and detect the optimal cut-off parameter which would optimize both the perception and energy consumption of the device.

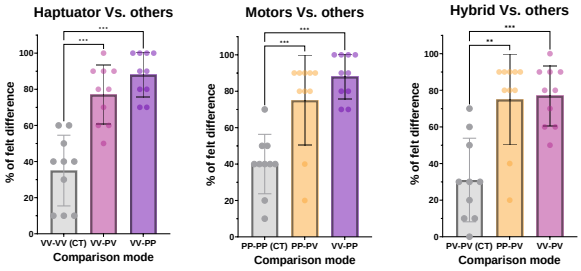

Fig. 1: Percentage of felt difference when comparing zone 1 and 2. Dots represent the mean of each participant. (Post-hoc tests : **: $p \leq 0.01$, ***: $p \leq 0.001$)

References

[1] F. Conti and O. Khatib, "A new actuation approach for haptic interface design," in Experimental Robotics: The 10th International Symposium on Experimental Robotics, O. Khatib, V. Kumar, and D. Rus, Eds., Berlin, Heidelberg: Springer Berlin Heidelberg, 2008, pp. 441–450, ISBN: 978-3-540-77457-0. DOI: 10.1007/978-3-540-77457-0_41.

[2] T. Lu, C. Pacoret, D. Hériban, A. Mohand-Ousaid, S. Régnier, et V. Hayward, "KiloHertz Bandwidth, Dual-Stage Haptic Device Lets You Touch Brownian Motion", IEEE Transactions on Haptics, vol. 10, no 3, p. 382-390, jul. 2017, doi: 10.1109/TOH.2016.2644613.

[3] S. Shin et S. Choi, "Hybrid Framework for Haptic Texture Modeling and Rendering", IEEE Access, vol. 8, p. 149825-149840, 2020, doi: 10.1109/ACCESS.2020.3015861.