Can We Increase the Perceived Intensity of Mid-Air Haptic Shapes Rendered With Dynamic Tactile Pointers?

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I. Introduction

Ultrasound mid-air haptic (UMH) devices use an array of ultrasonic transducers to emit phase-offset acoustic waves in such a way as to focus them at precise locations above the device, referred to as focal points, generating localized vibrotactile stimuli when they encounter a user's skin [1].

Rendering mid-air vibrotactile shapes is a fundamental building block in many applications of ultrasound mid-air haptics. Recently, Hajas et al. [2] introduced *Dynamic Tactile Pointers* (DTP) as an effective method for conveying clear shape information. By moving an amplitude-modulated (AM) focal point relatively slowly along a shape contour and marking pauses at vertices to highlight them, this method yields the best recorded shape identification performances for UMH to date.

In particular, DTP renders much clearer shapes than the other standard approach to UMH shape rendering, Spatio-Temporal Modulation (STM) [3]. In this method, an unmodulated focal point is rapidly moved between neighboring positions. By controlling the frequency at which the focal point cyclically returns to any given position (the *draw frequency)*, STM locally amplitude-modulates the pressure signal at each location along a traced contour, giving the sensation of a singular vibrotactile shape on the skin which is significantly more intense than shapes produced with AM [4]. A disadvantage of STM is that it produces rather blurry shapes [5] which negatively impacts shape identification performances [2], [6].

Despite its benefits relative to STM, shapes rendered with DTP rely on amplitude modulation, causing them to feel much weaker than STM shapes. In this work, we propose to investigate Spatio-temporally-modulated Tactile Pointers (STP), a novel approach for reproducing the behavior of DTP using spatio-temporal instead of amplitude modulation, with the aim of improving the perceived intensity of tactile pointers.

II. Spatio-Temporally Modulated Tactile Pointers

To render a shape, our method splits the contour into n linear or arc sections of identical length. Each section can then be rendered sequentially with STM, using a focal point moving at 2 m/s (value determined empirically). Since no amplitude modulation is performed, the full output power of the haptic interface is always used, which should result in higher stimulus intensity. Also, the sections located around the shape's vertices are rendered for a proportionally longer period of time so as to highlight them. The aim is to achieve similar improvements to shape identification performances as those obtained with conventional DTP [2].

III. Perceived Intensity

a) Materials and Methods: Prior to the experiment, participants were briefed about the experimental procedure and provided written informed consent to participate.

We followed a within-subject design, comparing **DTP** and **STP** in a 2-AFC protocol, where a given shape was rendered using two successive rendering techniques, and the user was asked to rate the intensity of the second stimulus compared to that of the first. Subjects responded by clicking on a button labelled either "Stronger" or "Weaker", presented in a random order at each trial.

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This work was funded under the ANR project "MIMESIS"

We evaluate STP on a set of four different shapes, all inscribed inside a 32 mm-radius circle, so that they can be fully rendered on the majority of hands. These were an equilateral triangle, a square, a regular hexagon, and a regular octagon, with respective side lengths of 55.4 mm, 45.3 mm, 32 mm, and 24.5 mm. In STP, all shapes were rendered for a total duration of 6 s, with a draw frequency of 0.5 Hz, and 80% of the rendering time spent on the vertices. In DTP, shapes were rendered for a duration of 6 s, with a draw frequency of 0.5 Hz and a 200 Hz amplitude modulation applied to the focal point.

We considered the 4 permutations of rendering technique pairs respectively for each of the 4 considered shapes ("triangle", "square", "hexagon" and "octagon"), yielding 16 trials per subject.

We measured P_1 (resp. P_2), the proportion "Stronger" answers when both stimuli were rendered with STP (resp. DTP), to assess potential biases in subject responses. We also measured P_{12}, the proportion of answers where a shape was felt stronger when rendered with STP than with DTP.

The experiment involved 18 participants (13M, 5F, 1N-B; 14 right-handed, 3 left-handed, 1 ambidextrous, age: 25.8 $\pm$ 9.8).

b) Results and Discussion: Distributions of the results are shown in Fig. 1. One-sample t-tests reported that P_1 (m: 56.94%) and P_2 (m: 51.38%) were not significantly different from chance-level answer, indicating an absence of systemic bias. P_{12} (m: 75.69%) was shown to be significantly higher, showing an increase in perceived intensity for STP.

IV. Perspectives

In the future we plan to investigate the effect of STP rendering parameters on perceived shape properties.We will also study shape identification performances, and compare the results to Hajas et al.'s DTP [2].

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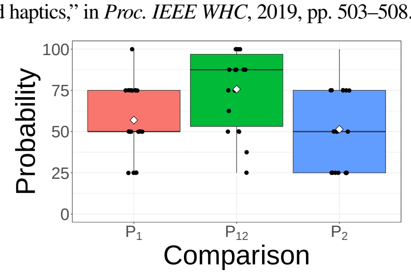

Fig. 1. Distributions of P_{12}, P_1 and P_2. P_1 and P_2 values are close to 50%, indicating an absence of systemic bias in participant responses in the case of uncertainty. An average above 50% for P_{12} shows that STP stimuli are perceived as more intense than DTP stimuli. Black horizontal lines show the median values, white diamonds represent the mean value, and black dots represent per-participant results.