Curvature Discrimination for Dynamic Ultrasound Mid-Air Haptic Stimuli

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I. INTRODUCTION

Ultrasound mid-air haptic interfaces are ideal for displaying tactile geometries [1], and can thus provide tangible sensations for 2D and 3D virtual shapes in human-computer interaction applications. Spatial and temporal sampling parameters, such as e.g. the number of points sampled on a shape, impact user's perception of a given shape [2]. The *sampling strategy* is thereafter defined as a combination of a spatial discretization of a shape and a set of rules for the temporal display order of the resulting points. This paper investigates the influence of sampling strategies on a user's ability to differentiate arc curvatures.

II. USER STUDY ON CURVATURE DISCRIMINATION

We focused our study on dynamic mid-air ultrasound tactile stimuli [1] displayed to a user's palm parallel to and centered 10 cm above an Ultraleap STRATOS Explore array. We aim to find the Just Noticeable Difference (JND) in curvature and its relation to the number of sampled points for simple sampling strategies. These were designed as a spatially uniform division of n points displayed from the thumb towards the pinkie while dwelling on each point for $\frac{2}{n}$ seconds, and modulating the focal point intensity at 200 Hz. The experiment was divided into five blocks, for $n = \{10, 50, 200, 400, 800\}$ points. Each block used the same four arc curvature radii r, ranging from a semi-circle to a flat line (see Fig. 1). We considered the flat line as an arc having the smallest radius to length ratio so that the height difference at the edges of the arc does not exceed the radius of a focal point. The stimuli were created using a custom software and the experiment was conducted using Psychopy [3]. Trials followed a 2-AFC protocol, with two stimuli displayed with

a 1500 ms break between them, followed by a request to identify the stimulus closest to a straight line. Each pair was displayed three times per block. Pair order within blocks block order were randomized for each user. We recruited 19 right-handed subjects (2 fem., 1 non-bin., 20-26 y.o.).

III. RESULTS AND DISCUSSION

Cumulative Gaussian curves centered on 0 (corresponding to a radius ratio of 1) were fitted to the mean response values for each stimulus-reference pair, yielding 4 estimates for JND in curvature, expressed as a radius ratio (see Fig. 1). JNDs ranged from 2.91 to 3.78 in the best performing sampling strategy ($n = 200$), and from 3.81 to 7.72 in the worst ($n = 800$), which may be explained by the greater difficulty for some subjects to perceive the stimuli for this sampling strategy. The presence of results exceeding 50% in every graph and the good fit of the psychometric curves show that curvature discrimination is possible using dynamic ultrasound haptic stimuli, regardless of the sampling strategy. Only stimuli at the limits of our range of radii yielded success rates above 75%. The fact that discrimination never occurred with 100% accuracy indicates difficulties in perception of spatial features of ultrasound tactile stimuli in line with literature results (e.g. [1]).

As a next step, we will perform statistical analysis to determine whether sampling strategies have a significant effect on the curvature JND, and may conduct additional experiments to increase the JND estimates' accuracy. If a significant effect is found, we will attempt to replicate it and measure the curvature JND for static stimuli, to gain insight into optimal rendering parameters for ultrasound haptics.

REFERENCES

[1] D. Hajas et al., Mid-Air Haptic Rendering of 2D Geometric Shapes with a Dynamic Tactile Pointer, *IEEE Transactions on Haptics* (2020).
[2] W. Frier et al., Sampling Strategy for Ultrasonic Mid-Air Haptics, *Conference on Human Factors in Computing Systems* (2019).
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(B)

	10	50	200	400	800
$1/\pi$	3.46	3.4	3.63	4.32	3.81
$3/2\pi$	4.01	3.61	2.91	6.37	7.84
$5/2\pi$	3.83	3.53	3.78	3.94	5.85
1.99	4.15	3.85	3.46	5.31	7.72

JND estimates for each sampling strategy, expressed as ratios of radii
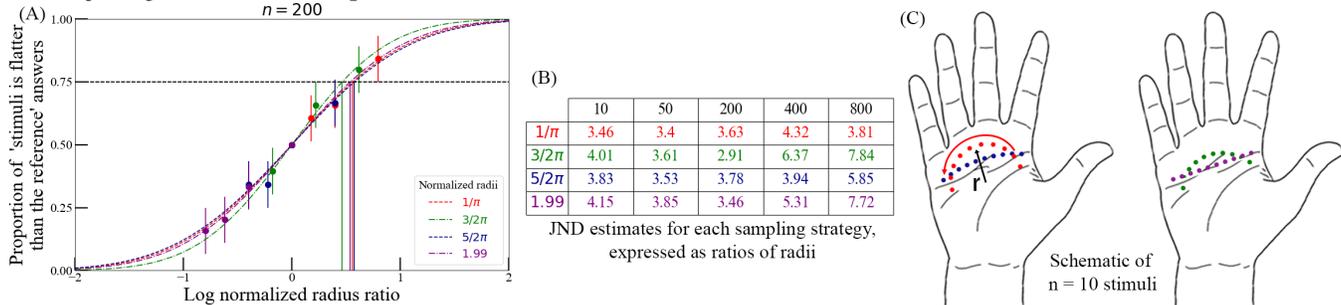
Fig. 1. (A) Example of mean proportion of "stimulus is flatter than the reference" answers as a function of the log stimulus to reference arc radius ratio, for the $n = 200$ points sampling strategy. The red, green, blue and purple curves show the results for each of the reference radii in ascending order of value. Points and associated vertical lines show the mean answer proportion and associated 95% confidence interval. (B) 75% JND estimates for each radius (row) and strategy (col). (C) $n = 10$ stimuli schematic: the focal point moves from the thumb toward the pinkie, spending 200 ms on each point.