Toward Vibrotactile Rendering for Irregular 2D Tactor Arrays

Nicholas G. Lipari* University of Louisiana at Lafayette
Christoph W. Borst University of Louisiana at Lafayette

ABSTRACT

We motivate further study of vibrotactile rendering schemes for the sensation of arbitrary points in irregular grids or meshes, outline a conceptual approach, and propose a study for assessing and comparing approaches. A conceptual model presents the combination of vibrations from multiple elements (tactors) as a two-stage pairing of tactors into virtual tactors, considering the 2D dimensionality. To support irregular triangle meshes, we suggest parameters to characterize triangle shape and a future study to measure sensations for varying shape. Gathered data will be used to assess and compare perceptual combination models and to develop precise rendering functions for irregular triangle meshes.

Keywords: Haptics, vibration, perception.

Index Terms: H.5.2 [Information Interfaces and Presentation]: User Interfaces—Haptic I/O

1 INTRODUCTION

Vibrotactile feedback in 3D VR interfaces supports direction cues, other spatial or contact cues, and non-verbal communication between users. For this, 2D tactor arrays can be mounted on handheld controllers or specialized clothing. Due to ergonomic or other design constraints, regular grids may be impractical, e.g., tactors may need to be placed across unusual shapes or away from garment seams or joints. To address this, we study irregular triangle meshes by considering the combination of three tactor vibrations into a combined (funneled) sensation, taking triangle shape into account for relative tactor spacing.

The sensation of an arbitrary point (virtual tactor) in a tactile mesh can be approximated by identifying the surrounding mesh cell and activating the tactors defining it (e.g., vertices of a triangular cell) at certain amplitudes. A perceptual funneling effect (combined summation and inhibition) can create a single phantom sensation from the multiple tactors [1], [2]. Lines and other shapes can be traced by moving the point [3].

Much work on multi-tactor combination is based on 1D arrays, e.g., logarithmic interpolation between two tactors [4]. Alles [2] suggested interpolating 2D cues with three or four total tactors, and more recent work shows 2D arrangements of several or more tactors, e.g., [3] [5] [6] [7] [8]. Tactile Brush [5] used a virtual tactor analogy to describe tactor combination in rectangular grid cells. Amplitude-based summation along one dimension was combined with activation time offsets in the second dimension. This supported pre-defined traces ending on gridlines. A related study [8] considered a point moving in equilateral triangle mesh cells, with tactors controlled based on its barycentric coordinates.

We recently considered how 1D interpolation generalizes to square 2D cells [7]. We now consider amplitude-based control in irregular triangle meshes to support arbitrary point sensations.

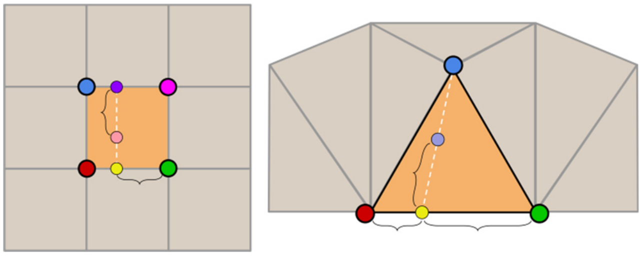

Figure 1: Tactors in square (left) and triangular (right) cells. On left, the bottom two tactors (red and green) form a virtual tactor (yellow), which combines with another virtual tactor from the upper tactors (blue and magenta). Similarly on right, with only one upper, real, tactor (blue). Vibrations are simultaneous.

2 PROPOSED MODELS

2.1 Tactor Pairing Model

For 2D meshes, we propose a conceptual model of two-stage tactor pairing using a 1D model per pairing. As seen in Figure 1 (left), for a square cell, this consists of two pairings along one dimension (here, horizontal) followed by a vertical pairing of the two resulting virtual tactors into a final interior (perceived) point.

This approach is validated for square cells by considering our prior results [7] showing that a 2D bilog model, mathematically matching the pairing approach proposed here, may outperform other models like sum of squares [5], distance-based log summing [6], and area sampling [9], which do not specifically capture 2D dimensionality. Our results were based on measuring perceived intensity at critical points in square cells. Critical points included the cell center (4 equal tactor activations) and edge centers (2 equal activations). At these points, perceived intensity is expected to vary maximally from a simple sum of tactor levels. We also included 3-tactor activations to provide preliminary triangle data, and 1-tactor (corner) baselines to help validate measurements.

Pairing can be applied to triangles (Figure 1, right) by first pairing along one edge and then pairing the resulting virtual tactor with the remaining real tactor. However, we expect triangle shape, which may vary, affects perception, because relative (and absolute) distances between tactors can affect perceived intensity. Vibration loudness decreases when spread over an area and funneling occurs most strongly for nearby vibrations when considering two point stimuli [1]. 1D work exists to show the effect of varying intertactor distance, but 2D summation studies are sparse and either lack precision for control algorithm development or do not explicitly handle interior 2D cell points.

2.2 Triangle Shape Component

There are various ways to characterize or parameterize triangle shape. We propose to first characterize shape using angle and radius values as defined in Figure 2, because these values relate intuitively to relative intertactor spacing. We want to study the relationship between such parameters and perceived vibration to account for related effects in new tactor control algorithms and to assess significance of shape for existing approaches. Incorporating shape parameters into the second pairing step may capture effects.

---

* ngl3747@louisiana.edu

10.1109/3DUI.2016.7460068

We suggest the first pairing should be along the shortest edge, since the strongest summing effect occurs between nearby tactors [1]. Grouping the more distinct vibrations first may best capture summation and inhibition effects. Alternatively, averaging over all three order choices may remove possible order bias.

2.3 Other Models

Whereas most rendering schemes, including the above, reflect a pragmatic or phenomenological approach, we can also consider neural summation models, e.g., incorporating recursive nonlinear processes [10]. In a two-tactor magnitude estimation study, Mahar [11] found 2Γ, a recursive nonlinear dynamics model, better predicted funneling than logistic fits. For $n\Gamma$, per-tactor functions model "real, observable" sensations; parameters are gain values for the excitatory and inhibitory responses. With two stimuli (2Γ), excitatory parameters are proportional to stimulus amplitudes, and inhibitory parameters are quotients of lambda (proportional to distance) and the opposing excitatory parameter. A tactor in a triangular cell would be represented with its excitatory (as above) and inhibitory parameters (lambda divided by the maximum of the other two excitatory parameters) [10]. With sufficient recursions to converge, the functions sum to the total observed sensation.

Various other models did not explicitly address 2D aspects of vibration combination but can be considered for comparison. Tactile Brush [5] used a sum-of-squares energy model in one dimension that could be considered in 2D. T-hive [6] controlled tactors as independent with a sum of distance-based terms – elsewhere, we explain how such approaches lack the degrees of freedom to model our 2D study results [7]. Area sampling [9] has a similar limitation [7], and so does barycentric interpolation. Standard parametric triangle interpolation, with various interpolants, would resemble pairing without considering shape.

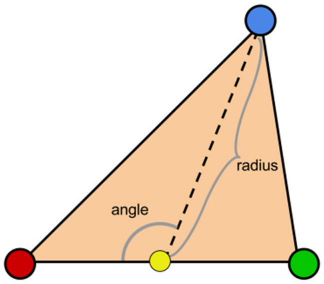

Figure 2: Triangle model with first-paired tactors at base and a third tactor with varying angle and radius (relative distance) from their effective combined point (virtual tactor). In an experiment using critical points, the bottom tactors will vibrate equally and the third tactor level will be set to match their combination. Overall perceived level will be measured for varying shape.

3 PROPOSED STUDY

A proposed experiment will collect data about perceived intensity for various triangle shapes. This will test the importance of shape and provide data for evaluating triangle rendering methods in general. We will first examine intensity at a few critical points, with later work considering position control.

C2 tactors (linear resonant actuators) will display 250 Hz vibrations on both inner forearms. Two of three tactors contacting one forearm will be placed a fixed distance apart. As illustrated in Figure 2, we will vary the position of a third tactor to vary angle and radius. The positioning apparatus will consist of several attachment points using connectors such as Legos®. Other hardware will follow our prior work [7].

Subjects will adjust overall intensity (scalar gain) of the 3-tactor set to match a single-tactor reference on the other arm. The two stationary tactors (bottom two in Figure 2) will maintain a combined intensity of the third tactor, as we have developed previously [7]. In our summing model, intended perceived vibration position is halfway between the 2-tactor midpoint and the third tactor. We will also include two-tactor (edge midpoint) conditions as baselines for models and to verify our expectations.

Tactor positions mirrored about the 90° angle will be treated as equal, averaging trials from both sides and reducing location bias. Orientation bias can be reduced by varying tactor roles (three choices of moving vs. fixed tactors) or rotating the apparatus. We expect gain to be lowest when tactors are near collinear (angle = 0°) and highest when forming an isosceles triangle (angle = 90°).

Empirical results will relate physical and virtual tactor levels, corresponding to three physical tactors combining to match the reference stimulus. Results will provide targets for candidate models (constraints to fit). In a bilog model for squares [7], we performed a standard coefficient fit (least sum of squared error) in one dimension and validated a symmetry assumption for generalizing to 2D. A triangle cell breaks the assumption, calling for extended models or fits. We will compare proposed models (triangle shape and neural summation [10]) to possible 2D interpolations and variations on other prior models (§2.3).

Further work will consider how an intensity-preserving model interacts with position display. The pairing model extends to position control based on per-pair 1D models. Seo and Choi [4] noted 1D logarithmic interpolation for two tactors better preserved intensities, but linear interpolation was preferred for position. The neural summation alternative refers to overall stimulus intensity, not perceived position. Arbitrary point rendering in triangles would be a further extension to explore with summing models.

REFERENCES

[1] G. von Békésy, "Funneling in the Nervous System and its Role in Loudness and Sensation Intensity on the Skin," *Journal of The Acoustical Society of America,* vol. 30, no. 5, pp. 399-412, 1958.

[2] D. S. Alles, "Information Transmission by Phantom Sensations," *IEEE Trans. Man-Mach. Syst.,* vol. 11, no. 1, pp. 85-91, 1970.

[3] C. W. Borst and V. B. Baiyya, "A 2D Haptic Glyph Method for Tactile Arrays: Design and Evaluation," in *IEEE WorldHaptics*, Salt Lake City, Utah, 2009.

[4] J. Seo and S. Choi, "Initial study for creating linearly moving vibrotactile sensation on mobile device," in *Haptics 2010*, Waltham, MA, 2010.

[5] A. Israr and I. Poupyrev, "Tactile brush: drawing on skin with a tactile grid display," in *CHI 2011*, Vancouver, BC, 2011.

[6] D. Ryu, G.-H. Yang and S. Kang, "T-Hive: Bilateral Haptic Interface Using Vibrotactile Cues for Presenting Spatial Information," *IEEE Trans. Syst. Man, Cybern.,* vol. 42, no. 6, pp. 1318-1325, 2012.

[7] N. G. Lipari and C. W. Borst, "Study of 2D Vibration Summing for Improved Intensity Control in Vibrotactile Array Rendering," in *Proceedings of the 10th International Symposium on Visual Computing (ISVC)*, Las Vegas, NV, 2014.

[8] O. Schneider, A. Israr and K. MacLean, "Tactile Animation by Direct Manipulation of Grid Displays," in *UIST 2015*, Charlotte, NC, 2015.

[9] C. W. Borst and A. Asutay, "Bi-level and Anti-aliased Rendering Methods for a Low-Resolution 2D Vibrotactile Array," in *IEEE WorldHaptics*, Pisa, Italy, 2005.

[10] R. A. M. Gregson, n-Dimensional Nonlinear Psychophysics: Theory and Case Studies, Hillsdale, NJ: Lawrence Erlbaum Assoc., 1992.

[11] D. Mahar, "The psychophysics of tactile amplitude summation: a test of the n-Gamma nonlinear model," *Nonlinear dynamics, psychology, and life sciences,* vol. 9, no. 3, pp. 281-296, 2005.