Hilbert Curves: A Tool for Resolution Independent Haptic Texture

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ABSTRACT

Haptic systems usually stimulate the kinesthetic aspects of the sense of touch, i.e. force feedback systems. But more and more devices aim to stimulate the cutaneous part of the sense of touch to reproduce more complex tactile sensations. To do so, they stimulate one's fingertip in different locations, usually in the fashion of a matrix pattern. In this paper we investigate the new possibilities that are offered by such a framework and present an ongoing project that investigates the benefits of Hilbert curves to display resolution independent mid-air haptic textures in comparison with other implementation approaches.

Author Keywords

Mid-air haptic; texture; Hilbert curves; resolution; rendering;

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Texture is an important haptic property, which helps to discriminate objects. For example, texture helps one to differentiate wood from laminate. However, it's not the amount of force exerted on the fingertip that codes for the texture, but all the macro and micro-irregularities that are present at the contact between the skin and the textured surface [5]. Furthermore, the human sense of touch can identify elements as small as 10nm amplitude [9]. Consequently, researchers have developed new haptic systems that can stimulate the fingertip in different ways. Some systems take the form of pin-arrays and can either apply normal force [4] or shear force [10]. Another approach uses mid-air haptic devices that can either produce multi-point stimulation [2] or one fast moving point stimulation [8].

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Such devices actually produce what one could call a "haptic frame" which is analogous to an image frame from a video. For historical reason (in CRT displays) an image frame is commonly refreshed using a raster scanning technique. However, one could come up with plenty of different methods to refresh a frame. Considering the possibilities of alternative techniques, can one find a method that provides significant benefit over raster scanning? In light of the huge resolution differences between devices, a refresh method that could be used across devices, without additional computation and that gives consistent feeling is valuable. Here we propose a novel approach to address the haptic frame-refreshing problem using Hilbert curves.

TEXTURE

When fingertips rub a textured surface, surface asperities at a macro and micro-level come to deform the fingertip skin surface. These deformations are then coded through mechanoreceptors embedded underneath the skin. Therefore, the spatial information one extracts is not a single frequency component but rather the ratio of all the frequency components that compose the texture signal [11]. However, textures are not only felt actively (i.e, by the finger moving across a static surface), but also passively (say when a texture is moved under static finger); and in both cases, the texture perception is similar [6]. This suggests that temporal frequency also conveys texture sensation [7]. Actually, that is supported by a study showing that vibrating a textured surface can actually alter its perceived roughness [1].

THE CHOICE OF HILBERT CURVES

More often than not, haptic points need to be addressed one at a time. Therefore, the update procedure can be seen as a one-dimensional process where points are presented in a specific and predefined order. The raster scanning method is often preferred due to its simplicity of implementation and historical use in displays. In some alternatives, a method that sweeps back and forth the display in a horizontal fashion can be chosen, due to its continuous property that limits explored distance. Additionally, there is a whole family of curves referred as space-filling curves that can scan through the entire frame in a continuous manner. In other words, these curves map a one-dimensional signal (the refresh order) to a two dimensional space (the frame).

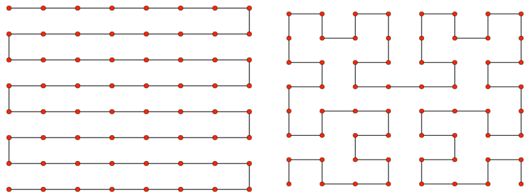

Figure 1–Scanning Methods: Horizontal sweep (left) Hilbert Curve (right).

But the risk is that when the display resolution changes, the refresh method used won't preserve the information locality. The locality preservation is the fact that a particular sample of a one-dimension signal will always have the same location in the two-dimension space. In other words, consider a normalized one-dimensional coordinate that parameterizes the curve. One sample of that signal will map to approximately the same position in the two-dimensional space whatever the resolution used. This condition is violated for horizontal sweep and raster scan refresh methods.

But among the space-filling curves, a specific sub-category called pseudo-Hilbert curves does not suffer from that issue. The pseudo-Hilbert curves are a family of curves that discretize a two-dimensional space into 2^n subdivisions. Each curve is identified through its order, which is n in the case of a curve that divides the space into 2^n subdivisions In the case of a tactile display, the 2^n divisions could be considered as the "pixel" of the haptic frame. Regardless of the pseudo-Hilbert curve order, a specific sample from the one-dimensional representation of the pseudo-Hilbert curve will have relatively the same position in its corresponding two-dimension representation. Consequently, we propose to use pseudo-Hilbert curves to refresh a haptic frame.

First, an initial pseudo-Hilbert curve can be used to transform the two-dimensional data set into a one-dimension signal, then the one-dimension signal can be downsampled to obtain a lower order pseudo-Hilbert curve that can dynamically match the device resolution and display the texture while preserving locality..

Secondly, since texture can be tuned through signal processing, the one-dimensional representation of the pseudo-Hilbert curve will be faster to process than the two-dimensional frame. Indeed, if using a one-dimensional signal, a simple low pass-filter will shift the frequency distribution to the low frequency, which will result into a rougher texture. And on the other hand, a high-pass filter will result into a smoother texture. One can thus imagine an implementation, with only one texture data set, represented as a pseudo-Hilbert curve, kept in memory and adjusted through one-dimension signal processing.

CONCLUSION AND FUTURE WORK

Here we propose a method to render resolution independent mid-air haptic textures using Hilbert curves. However, does this new method affect the perceptual sensation? What are the perceptual time constraints on the refresh frame rate? To what extent does the resolution gap affect the perceived texture? We aim to address these questions through psychophysical experiments in the near future.

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