Exploring Surround Haptics Displays

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Abstract
In this paper we present the design and evaluation of a two dimensional haptics display intended to be used for enhancing experience for movies and rides. The display, haptics surface, utilizes an array of vibrators contacting the skin at discrete locations and creates static and dynamic haptic sensations derived from scenes and situations. For this regard, a set of haptic morphs are introduced that can be used as building blocks to create new sensations on the skin. A novel haptic sensation, *haptic blur*, is also introduced that gives an illusion of continuous motion across the skin using discrete vibrating points. A pilot study investigating the reliability of haptic blur along a two dimensional skin surface is presented along with conceptual discussion on future haptic feelings rendered through the haptics surface.

Keywords
vibrotactile display, haptic feedback, sensory illusions, apparent haptic motion.

ACM Classification Keywords
H.5.2. [Information interfaces and presentation (e.g., HCI)]: Haptic I/O; H.1.2 [User/Machine Systems]: Human information processing; H.5.1. [Multimedia Information Systems]: Artificial, augmented, and virtual realities.

General Terms
Design

Introduction

Today's entertainment technologies incorporate rich and highly immersive visual and audio effects for their audiences' experiences. Augmenting these effects with high-resolution multi-dimensional haptic feedback will significantly enhance the experience leading to the deeper sense of immersion and believability. In this paper we present the design and preliminary evaluation of a two dimensional (2D) tactile surface display. The display consists of an array of twelve independently controlled point contacts, arranged in three rows and four columns, and stimulates the user's skin with rich vibrational waveforms.

Haptic feedback has been incorporated in wide variety of applications. (for example, see [1], [2], [3], [4], [5].) Earlier efforts were to use skin as a sensory substitute for speech communication [6] and more recent works are focused on rendering force-feedback in highly immersed virtual environments [7]. The latter have been somewhat unsuccessful in displaying realistic and natural haptic effects due to limited actuator and controls technologies and due to lack of psychophysical data for understanding human force perception [8]; nevertheless these efforts are ongoing and some success have been reported in recent years. Haptic feedback has also been used in technologically advanced gadgets for displaying new experiences to users. For example, in order to enrich movie experiences, motors are placed inside the seats to display low-frequency subtle motion cues directly taken from the movie scenes [9].

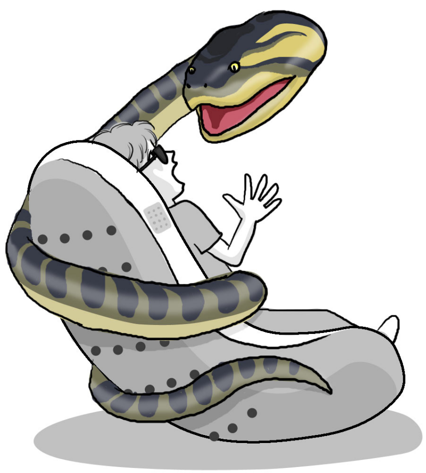


figure 1. In this conceptual drawing the user can see a realistic snake using stereoscopic 3D display technology, can hear it using 3D audio as well as physically feel the

The goal of the present study is to develop a library of haptic effects using a discrete set of vibrators stimulating the skin of the user's back. Many researchers have investigated the sensitivity and information processing capabilities of the skin [10]. The back is relatively less sensitive compared to the sensitivity of the hand or fingers; however, its large surface area provides an advantageous medium to communicate information through the skin. These sensitivity data as well as sensory illusion techniques, such as cutaneous rabbit illusion [11], are basis tools for designing new haptic effects in this study.

One challenge for investigating and using haptic feedback is unavailability of haptic platforms, which can be use to introduce new and immersive haptic effects. The motivation for this work is to develop a platform for stimulating the skin with complex waveforms. Such a platform can be used in different configurations for enhancing user experience in park attractions, such as rides, shows and gaming arcades, and can be placed in movie theaters for enriched movie effects. The haptic feedback combined with high-definition dynamic stereoscopic imaging techniques and high quality 3D surround sound effects for a new generation of multisensory user experiences.

Haptics Surface

The haptics surface consists of an array of twelve vibrating points, arranged in three rows and four columns, on a padded foam surface as shown in figure 2. Each vibrating point constitutes a highly versatile tactile actuator (C-2 tactor, Engineering Acoustics, Inc., Casselberry, Florida) and is computer controlled by a regular PC using audio speaker channels. The power to run actuators (or tactors) is provided by a custom made control board. Each actuators of the haptics surface is attached to a force sensitive resistor at the rear to monitor contact pressure between the stimulating skin of the user and the tactor. The pressure measurements are intended to be used in a closed-loop form to control the intensity of each tactor against the pressure distribution applied by the user skin. The tactors and the sensors are placed in a finely cut sheet of padding foam so that users cannot feel the metallic housing when in contact with the haptics surface. In the preliminary evaluation, the haptics surface is glued to the back of a typical chair such that it provides a suitable interface with the skin of the users sitting comfortably on the chair.

Haptic Effects

A number of haptic effects are created for a preliminary evaluation of the haptics surface and new sensations are under consideration for future studies. Our goal is to create a set of haptic morphs that are treated as basic units for constructing new haptic effects. These morphs can be combined or interchanged to create feelings derived from movie and game scenes. These morphs are intended to create static and dynamic effects on user's skin through the haptics surface. Following are some examples of haptic morphs:

- *Onset* – turn ON the channel abruptly
- *Reset* – turn OFF the channel abruptly
- *Linear rise* – rises amplitude linearly
- *Linear decay* – decays amplitude linearly
- *Exponential rise* – rises amplitude exponentially
- *Exponential decay* –decays amplitude exponentially
- *Amplitude modulation* – linear modulation of amplitude from the start level to the final level
- *Frequency modulation* – linear modulation of frequency from the start level to the final level

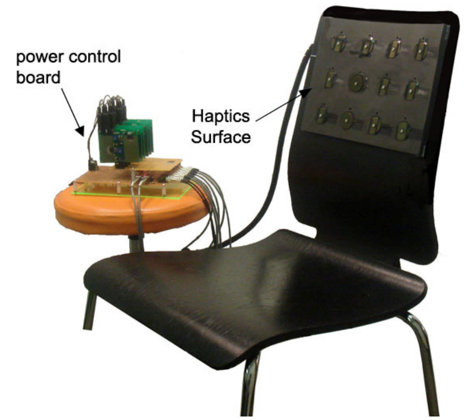


figure 2. The haptics surface mounted on the back of a chair.

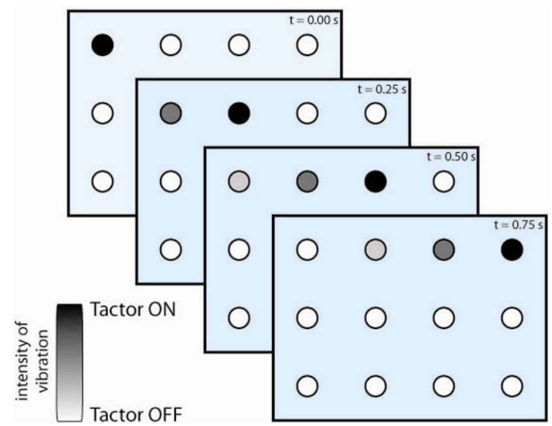
An important haptic effect is to create a sensation of continuous motion, in this case, on the back. One way to do this is to use large number of actuators and arrange them along the path of the motion. This subsequently increases the complexity and cost of the haptic platform. Our goal is to create the continuous motion sensation by using discrete number of vibrating points on the skin and vary the temporal shape of their waveforms. In this paper, we introduce the concept of *Haptic Blur*, a novel haptic effect to create illusion of continuous motion.

Haptic Blur

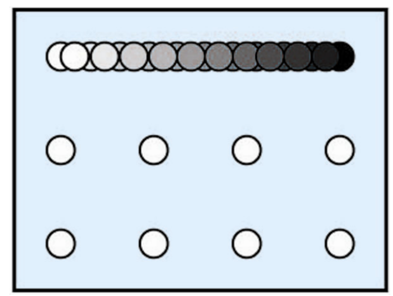
Haptic blur, similar to the visual blur, has a uniform intensity at the location of stimulation and the intensity steadily dies out away from the locus. Instead of the spatial locus (as in visual blurs) we define a temporal locus and the intensity of the waveform steadily decreases to zero at the temporal reset. The pictorial illustration of haptic blur in shown in figure 3(a) and its perceptual consequence is shown in figure 3(b). The decaying function of haptic blur is selected based on the frequency and duration of the waveform, and temporal separation between consecutive waveforms.

The effect of haptic blur is different than that of the cutaneous rabbit illusion (saltation) introduced in [11] and is more pronounced than that of the apparent haptic motion in [12]. The saltation creates an illusion of stimulated skin between two physical placed vibrators, whereas the haptic blur creates an illusion of continuous flow of vibratory motion between two vibrators. The apparent motion across the skin is created by controlling the onset time between two successive stimulations such that it elicits an illusion of fine motion. However, the haptic blur is created by designing onset (attack functions) and decay functions of successive stimuli. The haptic blur when combined with amplitude and frequency modulation create a sensation of creeping and circular (figure 4).

Preliminary User Studies
A preliminary evaluation of the haptic blur is conducted to determine the reliability of its perceptual effect. We asked four colleagues (3 males and 1 female; average age, 29 years old) to participate in three subjective evaluation experiments. In the first experiment, we presented directional cues on the back and asked participants to indicate if they felt continuous motion or not. Left and right directions were presented in 24 trials (right direction cues are shown in figure 3). One of the three rows was stimulated in each trial and the stimulation frequency, amplitude and duration were set differently for each row. Half of the trials were randomly presented with haptic blur and the other half without the blur effect.



(a)



(b)

figure 3. (a) The tactors in the top row of haptics surface turn ON from left to right at 0.25 sec interval. Instead of abruptly resetting to zero, the previously set tactors reset at a predefined rate. The filling of circles defines the intensity of vibration, darker for higher intensity, as the time goes from 0 to 0.75 sec. (b) The perceived sensation of the haptic blur is continuous left to right motion.

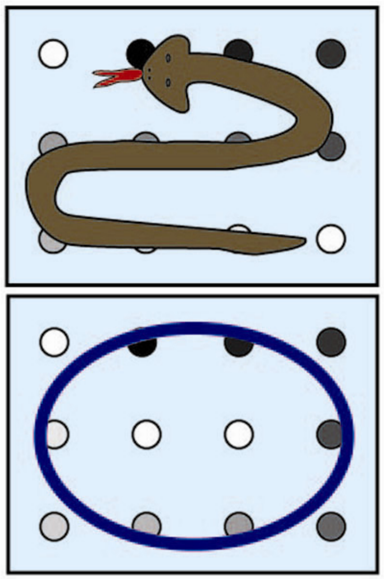


figure 4. Vibration stimulation pattern and perceptual effects created by haptic blur. Perceived effect of *creeping* (top) and *circular* (bottom) motion.

In the second experiment, the participants were presented with vibration patterns for pre-designed creeping effects (figure 4, top). Four effects were designed in which creeping started from the top-left, top-right, bottom-left or bottom-right corners and ended at the bottom-right, bottom-left, top-right or top-left corners, respectively. An illustration of the last pattern (creeping starting at the bottom-right corner and ending at the top-left corner) is shown in figure 4 (top). Eight trials (half with haptic blur and half without the blur effect) were randomly presented to each participant. Participants were asked to rate the effects on the scale of 0-5, where 5 being a perfect creeping illusion. No feedback or visual representation of creeping was presenting along or after the haptic cues. The third experiment was similar to the second experiment except that instead of a creeping motion a circular motion effect was presented in the counter clockwise direction (figure 4, bottom). Ten trials per participant were recorded in which they rated the clarity of a circular motion on a 0-5 scale, where 5 being a clear circular illusion.

Results

A preliminary evaluation of the haptic blur is conducted to determine its reliability in creating continuous and curvilinear motion. The summary of results is shown in Table 1. The results clearly suggest that haptic feedback adds another dimension to perceptual experiences, and blurred patterns were felt more continuous than their non blurred counterpart. Inter-participant variations were substantial in all experiments. It was not clear if these variations were due to lack of familiarity with the haptic sensations or due to some physical and/or perceptual factors. Nevertheless, all participants indicated that perceptual effects were realistic and new, yet they need more training trials to get familiar with and peculiar about haptic sensations. It is however acknowledged that true evaluation of haptic blur will be assessed after conducting a well designed experiment.

Table 1. Summary of preliminary user study results

Experiment	Blurring effect	Results
1: Directional Cueing	OFF	50% of time participants felt continuous motion sensation
	ON	67% of time participants felt continuous motion sensation
2: Creeping motion	OFF	Average subjective rating: 3.6
	ON	Average subjective rating: 3.7
3. Circular motion	OFF	Average subjective rating: 2.6
	ON	Average subjective rating: 3.4

Future Directions

The objective of this study is to create a set of haptic effects that can be used to deliver novel, immersive and rich experience to a viewer. One of such effect is presented in this paper, where time-controlled variations of vibratory locations give an illusion of continuous motion on the skin. More understanding of this effect is necessary and will be focus of our future investigations. Other dynamic effects, such as, objects approaching towards or away from the viewer, objects accelerating and decelerating, objects exploding, splashing, echoing, dropping, striking, bouncing, converging and diverging, etc. will also be explored with well designed human studies. In addition, static representation of events and shapes will be explored by varying the amplitude, frequency and location of the vibrations of the haptics surface.

Another direction of focus will be to understand spatial integration characteristics of the skin. It will be interesting to determine if the skin integrates motion and vibratory cues as a low-pass recursive model. In this case complex static images or dynamic events can be rendered on the skin by stimulating neighboring

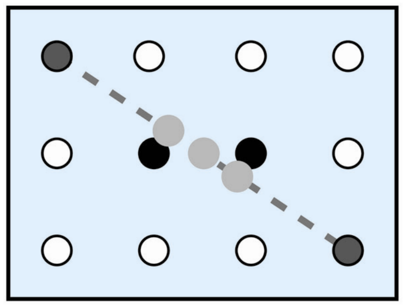


figure 5. A hypothetical illustration of skin's spatial integration. The tactors at the corner locations are stimulated simultaneously with solid filled tactors to create an illusion of tactors stimulating along a diagonal line.

tactors, as shown in figure 5. It is also desirable to investigate two-dimensional sensory saltation (cutaneous rabbit illusion) in order to produce complex patterns on the skin. Our long term goal is to form haptic morphs that can be used as building block for producing new generation of sensations. Such effects can be combined with high quality video and audio to deliver a rich immersive experience.

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