Ian Oakley
Stephen Brewster (Eds.)

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Haptic and Audio Interaction Design

Second International Workshop, HAID 2007
Seoul, South Korea, November 2007
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Preface

Overview

The 2nd International Workshop on Haptic and Audio Interaction Design was held in November 2007 in Seoul, Korea and followed a successful first workshop in Glasgow, UK in 2006. The 2007 event was sponsored by the Korean Ministry of Information and Communication, the Korean Institute of Next-Generation Computing, and the Association of Next-Generation Computing Industry. We remain grateful to these institutions and the generous support they extended towards us. The main focus of the HAID workshop series is to draw together researchers around the theme of human – computer interaction using the modalities of sound and touch. It addresses questions such as how to combine sound and touch interaction together most effectively. Or, are there situations in which one modality offers benefits over the other? Are there situations in which sound and touch offer unique benefits, or alternatively, in which they are inappropriate? Which design formalisms and frameworks can specifically benefit researchers considering multimodal interfaces?

A total of 12 papers were accepted to HAID 2007, each containing novel work on these human-centric topics. Each paper was reviewed by a panel of experts composed of leading figures from both industry and academia. We extend our thanks to all our reviewers, without whom the workshop could not take place. Their diligent efforts and constructive criticisms enriched the quality of the papers considerably. Two invited submissions from our keynote speakers are also included in the proceedings. We were pleased to receive a full paper from James A. Ballas of the US Naval Research Laboratory and an extended abstract from Dong-Soo Kwon, who directs the Human – Robot Interaction Research Centre at the Korea Advanced Institute of Science and Technology. Dr Ballas presented an informative discussion about the links between the most intimate of sensory cues: the sounds and feelings produced by our own bodies. Professor Kwon provided an overview of the history of haptics research and speculated about its future, in particular highlighting how touch might be deployed in mobile devices.

The main track of papers covered considerable thematic ground, from design guidelines to technical implementations; this is an area which is developing on many fronts simultaneously. However, one trend which stands out is the focus on interaction with computational systems, but not computers. Mobile interaction and wearable displays feature prominently, as do tasks such as communication and real-world navigation. This suggests that the future of haptic and audio interactions may well be away from the desktop and out and about on streets and in homes. As computers disappear into the fabric of our living environments, it may well be that we increasingly rely on our senses of hearing and touch to command, control, and understand them. Indeed, there is a sense of inevitability to this. In a pervasive vision of the future, surrounded by a plethora of unseen devices, we must surely rely on our other senses for interaction.

We provide an overview of the topics and foci of the papers below.

Tactile Displays

Research on tactile displays has been developing rapidly, in part because of their wide deployment in mobile phones and other handheld devices. In many cases, the underlying technology is simple and cheap and there is a general feeling that it could be put to many more constructive uses than simply indicating the arrival of a call. One key way to achieve this is through using multiple tactile actuators, an approach adopted by all the authors in this session. Lee et al. describe a wearable system which displays tactile cues directly derived from the environment to a user's fingertip, allowing them to feel at a distance. Hoggan et al. discuss a system based on mounting multiple tactile actuators to the exterior of a PDA and relate several experiments determining whether its users can effectively discriminate from which ones stimuli originate. Finally, Kyung et al. describe a new design for a miniature tactile display which can stimulate the fingertip and several studies of its effectiveness in fundamental tasks such as texture and shape perception.

Communication and Games

Haptics and audio are indivisibly linked with communication and entertainment, and this session explores new ways to express this synergy. Seeking to add expressivity and richness to mobile communications, Brown and Williamson describe the design of a novel method of sending short messages based on gestural input and tactile and audio output. At the other end of the project lifecycle, Baurley et al. discuss the situated qualitative evaluation of a wearable computing system which can convey interpersonal gestures such as hugs and strokes to the forearm. Kim and Kim describe a racing game, intended for use on mobile phones, which incorporates tactile cues to overcome the fundamental restrictions of small screen sizes. Can haptics and audio cues effectively convey emotions and create immersion and presence? The papers in this session address this demanding question.

Accessibility and Navigation

Access technologies intended to support visually impaired users remain a key domain for haptic and audio interaction design: these users rely on non-visual feedback for everything they do. Consequently, they require efficient and effective interactive systems. Two papers in this session contribute to this body of research. Shin and Lim describe a wearable computing system which integrates range-finding sensors, body tracking and vibrotactile and audio displays to enable visually impaired users to navigate safely in their immediate environment, avoiding potential obstacles. Pielot et al. support the other stage of this process: route planning, rather than on-the-spot navigation. They describe a tangible interface which allows visually impaired users to explore an audio map, learning the locations of key landmarks by referencing the sounds they make. Kim and Kwon discuss a slightly different topic, namely, how haptic and audio cues can aid users in the complex task of accurately navigating around a three-dimensional virtual environment which is displayed on a flat, two-dimensional screen. As three-dimensional interfaces become more commonplace, this is a problem which will only become more widespread, and Kim and Kwon's work suggests multimodal interaction may be one way to address it.

Design

As human – computer interaction matures as a discipline, the role of design is becoming more and more important. As it lacks a basis in widely applicable theories which yield consistent and predictable results, more informal structures have come to the fore: methodologies, guidelines, and principles. The papers in this session contribute to this practical, hands-on body of work. Bjelland and Tangeland discuss how the use of early-stage haptic prototypes might benefit a user-centered design process and present a case study of this in action. They conclude with recommendations for best practices to adopt while prototyping haptic interfaces. Oakley and Park discuss how to best design for eyes-free interaction, referring to systems which enable simple, rapid, and confident input without occupying visual attention. They review the literature, present a set of design principles, and describe a case study embodying these. Finally, Pirhonen et al. present a design methodology for creating rich, detailed, and effective audio interfaces. Based on detailed use scenarios and personas, the technique espouses iterative presentation of audio interfaces to panels of designers to generate consistent and refined feedback schemes. As with the other papers in this session, they conclude with a detailed case study illustrating their technique.

User interfaces remain predominantly visual, but these papers show there are many specific scenarios, and indeed much to gain, by incorporating haptic and audio elements. Our environment is composed of not only sights, but also a vibrant range of sounds, touches, smells, and tastes. HAID 2007 presented research motivated to making our interactions with computational systems equally rich.

November 2007

Ian Oakley
Stephen Brewster

Organization

The 2nd International Workshop on Haptic and Audio Interaction Design was organized by the Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea and the University of Glasgow, UK.

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Self-produced Sound: Tightly Binding Haptics and Audio

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Abstract. This paper discusses the concept of self-produced sound and its importance in understanding audio-haptic interaction. Self-produced sound is an important stimulus in understanding audio-haptic interaction because of the tight binding between the two modalities. This paper provides background on this type of sound, a brief review of the asynchrony and neurophysiology research that has addressed the cross-modality interaction, and examples of research into self-produced sound, including a unique but common instance: sound produced when consuming food.

Keywords: Haptics, self-produced sound, hearing, psychoacoustics.

1 Introduction

No formal definition of self-produced sound exists. Here, it is sound that is produced by one's own body or body movements[1]. The sound waves are produced by movement of the limbs or mouth interacting with the body itself or with external surfaces or objects. Examples of interactions between body components include teeth grinding, finger snapping, and coughing. Examples of interactions between the body components and external surfaces include footsteps, clothing sound, and chewing of foods. These sounds are transmitted to the ear not only through air conduction, but in the case of many sounds, also through bone conduction. For example, the hearing of chewing sounds will be transmitted primarily via bone conduction.

At the onset, it is fair to ask whether this type of sound involves haptics in any reasonable sense of that term. Using the Gibsonian definition [2] of the haptic system as "the perceptual system by which animals and men are *literally* in touch with the environment," self-produced sound is produced whenever the touching behavior is the physical cause of the auditory event. Because the actuator of the sound is the haptic system, and the sensing of both haptics and sound are self-contained with the actuation mechanism, there is a tight binding between haptics and sound in both actuation and reception.

This forms the basis of the special character of self-produced sound in understanding the interaction of haptics and audio. The binding between the haptic

[1] Obviously the sound of one's own voice is a self-produced sound, but is not included in this paper because it doen not involve haptics in the common sense of that term. See Truax [1] for an excellent description of the voice as a self-produced sound.

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system movement and the sound is tightly coupled such that it seems unlikely that this coupling can be dissociated through task instructions. That is, the associative linkage between the haptic and sound for self-produced sound might be an obligatory outcome of sensory-perceptual processing. The test for obligatory processing typically involves neuroimaging techniques. Studies have demonstrated that obligatory processing is present when neuroimaging shows processing of a particular type or form has occurred even when the subject's task does not require it (see [3] for an example of an obligatory processing study). To my knowledge, no such studies of haptic-audio interaction have been done; this would be a topic for future research.

Some insight into the special character of self-produced sound can be obtained by examining studies that have examined haptic-audio asynchrony. It is reasonable to hypothesize that these studies should show lower asynchrony thresholds for self-produced sound because this type of sound embodies neural activity of both haptic and sonic events. In effect, the judgmental bias that can be present in a temporal decision, i.e., the Greenwich Observatory phenomenon documented by Maskelyne, is less likely to occur for self-produced sound. Three studies are briefly reviewed that address this topic.

Levitin et al. [4] utilized two observers in an asynchrony experiment that involved a type of drumming that was heard and either felt or seen. They compared the asynchrony estimates made by an observer who saw the action and heard the impact sound to those of an actor who performed the action thus feeling the event and also heard the sound. The asynchrony of the impact and the sound was manipulated. Their results clearly showed that the actor who produced, felt and heard the impact made more accurate simultaneity judgments than the observer. However, this study involved a comparison between haptic-audio and visual-audio asynchrony, and does not explicitly address the tight coupling between haptics and audio that occurs with self-produced sound.

Two other asynchrony studies separately used self-produced and externally generated sound. Adelstein et al. [5] developed a system that produced the type of self-produced sound that occurs when you use a hammer to strike an object. They attached an accelerometer to a hammer and conditioned the signal that was produced when the hammer hit a surface so as to produce a TTL pulse upon impact. This pulse was then used to generate an audio pulse, with variable delays introduced. The base processing latency of the system was ~7 ms, so the experimental design was limited to only producing audio-lagging of ~7 ms or more. In contrast to other asynchrony studies, they did not include any stimuli with the audio leading the haptic event. Their analysis included calculation of Point of Subjective Equality (PSE) and Just Noticeable Differences (JNDs). They found JNDs that were much smaller than Levitin found, and with the best subject, saw asynchrony judgments that approach the limits of auditory fusion (1-2 ms). It bears noting that they intentionally masked the actual self-produced sound of the hammer hitting the target object.

Externally generated sound sources were used in an asynchrony study by Martens and Woszczyk [6]. Their system produced whole body vertical movement for the haptic event and an indirect audio signal from an array of 5 low-frequency drivers and 32 high frequency drivers. The sound signal was an impact recorded from dropping a stack of telephone books on the floor. They used a staircase tracking paradigm with a 2-alternative forced choice between whether the audio was earlier or later than the haptic movement. The asynchrony was varied between +/- 40 ms with a minimum asynchrony of 10 ms. They found that simultaneity accuracy (both presented simultaneously) was .7 and .8 for the two subjects. Haptic leading asynchrony was almost never judged to be simultaneous. Haptic lagging asynchrony was misjudged to be simultaneous about 20-40% when the asynchronies were 10-20 ms. There was little difference in accuracy between 20-30 ms asynchronies. Although their data cannot be compared directly with Adelstein, the lack of a difference between 10-20 ms suggests that the JNDs for their task were greater than those found by Adelstein.

At this time, the limited research on asynchrony judgments cannot provide any definite answer as to whether the tight binding between haptics and audio with self-produced sound will support more accurate synchrony judgments. But the work to date is consistent with the hypothesis that this type of sound involves tightly coupled haptic-audio interaction. The basis of this binding would lie in the neurophysiology of haptic-audio convergence, which is briefly described in the next section.

2 Neurophysiology of Audio-Haptic Interaction

The traditional view of multisensory convergence is that unisensory processing must be essentially complete before multisensory processing can occur. This view assumes that multisensory convergence occurs at the higher cortical areas thought to be used for integration functions. However, this traditional view has been challenged by recent work that has shown that convergence occurs not only early in cortical processing but also subcortically (Fig. 1).

2.1 Subcortical Convergence

An example of subcortical convergence is the work by Kanold and Young [7], who studied the interaction between the auditory and somatosensory systems in the cat, which has a moveable pinna that can be oriented for active auditory exploration. They found that the dorsal cochlear nucleus (DCN), which is one level above the cochlea, receives information from the medullary somatosensory nuclei (MSN) that are associated with pinna muscle movement. They found that stimulation of the cervical nerves associated with pinna muscle movement produced activation in the DCN. They speculated that this subcortical convergence is used to correct for changes in the auditory spectrum produced by pinna movement. The analogous process in the human system would be a subcortical interaction that would connect a neural coding of head azimuth position to the auditory system so that spectral changes due to the head-related transfer function could be used to correct the spectrum of a heard sound.

2.2 Cortical Convergence

Several studies have shown that cortical convergence is found in early sensory processing areas of the auditory cortex [8,9]. Fu et al. [8] investigated somatosensory inputs to the caudomedial (CM) auditory cortex, which is a second stage cortical structure. They found that cutaneous stimulation of head, neck and hand areas produced CM activation, concurrently with activation from auditory stimuli. They