Adding Haptic Feedback to Mobile TV

Figure 1: Prototype UltraTV concept. The user hears, sees and feels the content in the video stream.

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CHI 2011, May 7–12, 2011, Vancouver, BC, Canada.
ACM 978-1-4503-0268-5/11/05.

Abstract
With the abundance of large-screen displays, mobile device users currently have little motivation to stream video content and TV broadcasts to their device—the desire to watch content 'on the move' does not currently outweigh the necessity of viewing this content on a miniaturised screen. However, the value and appeal of mobile TV broadcasts can be increased by the addition of a haptic-feedback channel to supplement the traditional video and audio streams.

This paper discusses the development of mobile haptic TV systems. It describes the design constraints for these systems and presents one concept implementation, UltraTV. UltraTV is a mobile device that provides mid-air, multi-point, back-of-device ultrasonic haptic feedback to enhance the mobile TV experience (see Figure 1). The paper concludes with a look at avenues for further exploration within the realm of mobile haptic TV.

Keywords
Ultrasonic feedback, mobile TV, haptic feedback, back-of-device feedback

ACM Classification Keywords
H5.2 [Information interfaces and presentation]: User Interfaces - Graphical user interfaces.

General Terms
Human Factors

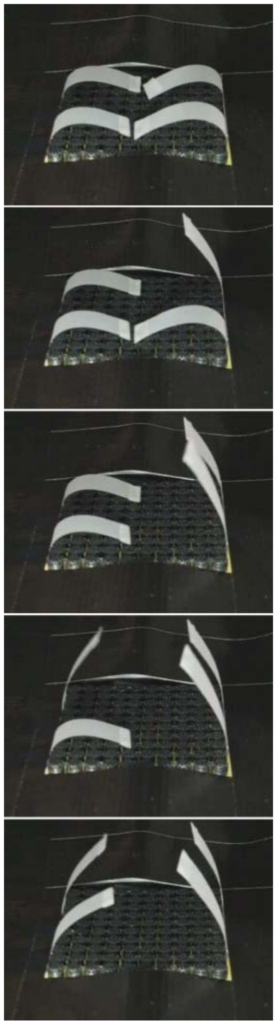

Figure 2: Pieces of tape placed over the array of ultrasonic transducers move as various regions of the array are triggered

Introduction

An ever-increasing number of mobile devices are capable of receiving and viewing live or on-demand streaming media. However, the widespread availability of large-screen displays mean users lack motivation to pay for and view such content (even the ability to view this content while 'on the move' does not provide sufficient motivation). One method to increase the appeal of these broadcasts is through the addition of a haptic output channel. This is especially appropriate on mobile devices as they are almost always grasped in the user's hands (as opposed to traditional TV where users passively sit on a couch).

A large body of work (for example Cha et al. [1]) has developed the architecture required to broadcast haptic events as part of a TV stream, however, there is still significant work required to address the design options for conveying these haptic sensations to the user. In this work, we investigate the design issues surrounding a mobile haptic TV system. We also present a prototype implementation that uses ultrasonic air pressure waves to create vibration feedback, along with a small user study validating its operation. Finally, we discuss our next areas for further research.

Related Work

Haptic TV

Haptically-enhanced TV broadcasts are often included in the design of next generation streaming media—with a haptic channel included when encoding the transmission data [2, 9]. However, many implementations focus on the technical issues with capturing and transmitting haptic information, with less consideration given to the device used to convey these sensations. Methods suggested for conveying this information include a "haptic display" [9], PHANTOM device [10], game controller and modified haptic remote control [11]. These scenarios all consider traditional TV viewing, on a couch in front of a large screen.

Mobile Haptic Feedback

Most research into mobile haptic feedback has focussed on enhancing touch-screen input with haptic feedback by adding actuators to the back of a PDA [3], guiding user's fingers along tactile surfaces [4] by employing multiple actuators [5] and by using multiple actuators on the back of the device to convey movement of on-screen objects [15].

Designing Haptically-Enhanced Mobile TV

Device Grasping

Figure 3 depicts a non-exhaustive classification of methods for grasping a mobile device. The top left and center images show single-handed grasping with the device in different orientations. This allows fullscreen viewing and interaction using the opposite hand. The top right and bottom image depict postures for single-handed and two-handed interaction.

These grasping techniques are all conducive to back-of-device feedback: in all cases, the palms and fingers are present behind the device to aid the grasping action. In line with Weinstein's findings, this exposes areas of the body with a high spatial acuity [14].

Output Style

The sensations created using vibrotactile haptic feedback can be varied by controlling the frequency, pulse and length parameters. These parameters allow us to create a variety of vibration textures.

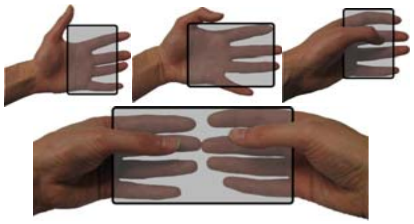

Figure 3: Device grasping postures. Top (left to right) portrait mode, landscape mode, portrait interaction. Bottom: two-handed interaction

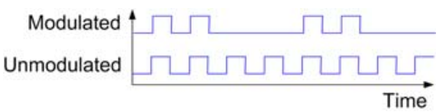

Figure 4: Modulated vs. Unmodulated input signals

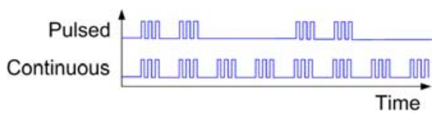

Figure 5: Continuous vs. Pulsed Input Signals

Modulation Frequency

The human hand 'feels' a change in modulation frequency as a change in output intensity. 'Feelable' haptic feedback is created by modulating the transducer input signal in the range of 40–1000Hz. The skin is most sensitive to vibrations at 250Hz [13]—increasing or decreasing the signal around this value provides the illusion of decreasing intensity output. An example modulation is plotted in Figure 4: the bottom unmodulated signal shows the input, the top shows the modulated signal.

Continuous vs. Pulsed Feedback

The primary output from the haptic feedback system can be provided to the user in a continuous or pulsed fashion. Continuous feedback leaves the output signal unmodified from the primary output modulation (see Figure 5, bottom). Pulsed feedback provides very short bursts of the primary output (Figure 5, top). Altering the length of burst and the time between bursts controls the texture of the output.

Length of Feedback

The human skin becomes desensitised to vibrations after they are applied for a long period of time. 'Bursty' multi-second feedback should be applied to salient events, rather than continuous feedback throughout an entire video.

The UltraTV Concept

UltraTV provides multi-point, contactless haptic feedback on a single side of a mobile device. This feedback supplements a traditional audio and video stream by creating ultrasonic air pressure waves that the user feels as vibrations on their hand. The concept is demonstrated in Figure 1. The user wears headphones for the audio, while viewing the screen and feeling the haptic feedback on the fingers and palm of both hands.

Mid-air Haptic Feedback Using Ultrasound

Ultrasonic haptic feedback uses the phenomenon of acoustic radiation pressure—where a pressure field is exerted on an interfering object—to provide haptic feedback to the user [7]. This is demonstrated in Figure 2, where small pieces of tape rise when the feedback is triggered. Iwamoto et al. [8] first proposed ultrasound as a method of providing point feedback to the user; Hoshi et al. [6] later improved this using a system that could sweep the focal point from side-to-side.

By using low frequency ultrasound (~40kHz) a beam can be formed such that >99% of the ultrasonic waves will reflect from human skin, producing a tactile sensation at the surface of the skin. This is of lower frequency than phased arrays of transducers that are used for medical purposes to pass through the skin and reflect off internal organs (which run higher than 1MHz) [12]. Pilot testing found that altering the duty cycle of the first modulation did not provide noticeably different haptic sensations. Therefore, the duty cycle of the input signal remains a constant 50%.

Device Construction and Operation

We extend Iwamoto's concept to create a multi-point ultrasonic haptic feedback system. This allows UltraTV to provide finer-grained feedback. The UltraTV hardware consists of a 10×10 array of ultrasonic transmitters, with electronic circuitry to individually trigger each transmitter (as shown in Figure 6). Each transmitter is driven at 40kHz by an 8-bit microcontroller and an amplifier based on a MOSFET

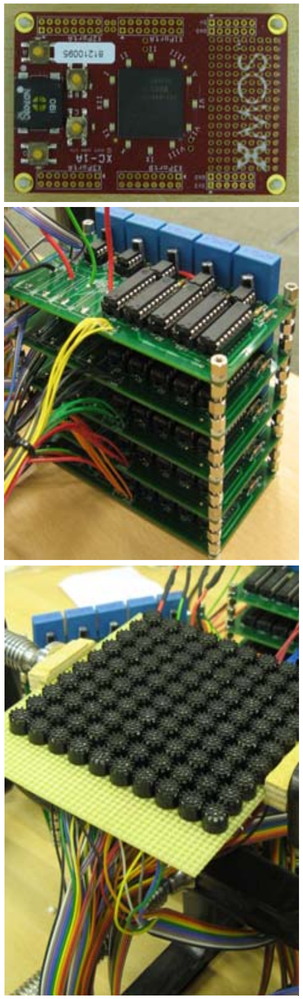

Figure 6: Ultrasonic haptic feedback components: (top) XMOS XC-1A board (middle) Microcontroller and amplifier boards, (bottom) Ultrasound transmitter array

driver IC. Overall control of the phase differences between transducers is performed using an XMOS XC-1A running at 400MHz. The XMOS board manages the timing of each individual transmitter, such that transmitters can be triggered individually or in groups with microsecond resolution. This is necessary for fine control over the phase differences between transmitters.

Individually controlling each transmitter allows us to produce multiple points of feedback in the space above the array. There are two methods for achieving this multi-point feedback: spatial multiplexing and temporal multiplexing.

Multi-point Feedback Using Spatial Multiplexing

To move the focal point laterally using spatial multiplexing, we move the central point of the rings within the array. The focal point will always be located directly above the centre of the rings of ultrasonic transducers (see Figure 7). By generating more than one set of rings, around different centre points, we can produce multiple feedback points. However, this method is limited by the number of available transmitters in the array, as two rings cannot use the same transmitters without temporal multiplexing.

Multi-point Feedback Using Temporal Multiplexing

Temporal multiplexing also creates rings around multiple centre points, but not simultaneously. Instead, each set of rings is activated in sequence. Thus a set of rings will be turned on for a set number of cycles of 40kHz ultrasound, before being turned off. The next set of rings will then be triggered for the same number of cycles. This continues until all rings have been triggered. By cycling through the different points in this manner we can produce a much larger number of independent points of tactile feedback than by using spatial multiplexing.

Distance from the Feedback Source

Non-contact systems require the user's hand to be positioned in the space *above* the output area of the transducers. This provides the air gap required to create 'feelable' pressure waves. This can be achieved by placing the transducers behind a grill. Future developments will allow the feedback to be felt at varying heights above the array

User Study

To validate our multi-point haptic feedback system, we conducted a simple user evaluation. We asked participants to place their hand over the output array and indicate the location and number of points that they could feel.

The system generated permutations of four fixed position points of feedback—one in each quadrant of the square array resulting in a total of 16 permutations. Eight participants took part in the study and each of them tested all 16 permutations. This resulted in a total of 128 tested permutations. Each permutation was 'displayed' for three seconds, participants were asked to circle the areas of activity on a diagram on a piece of paper. Each participant was explained what was expected of them and were asked to wear a headset which played white noise to cancel any audible sound from the haptic system. The experiment took a total of about 10 minutes per participant.

In order to calculate how well participants could identify and locate active feedback points, we counted the

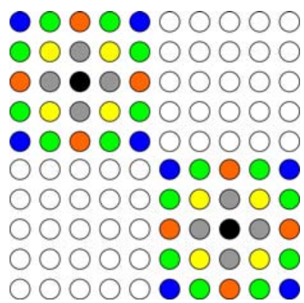

Figure 7: Generating two feedback points using spatial multiplexing. The focal points are above the black center-point of each region. Transmitters that are the same colour are triggered simultaneously, in the order: blue, green, orange, yellow, gray, black.

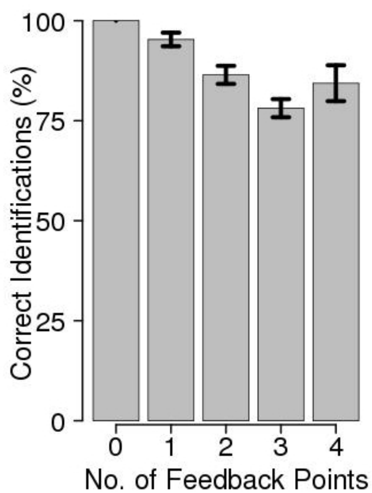

Figure 8: Point identification results

number of regions whose activity was correctly indicated on the diagrams on the paper. This means that for each permutation, participants were scored out of a maximum of four regions.

Results showed that the participants could correctly identify which of the feedback points were active with 87.3% accuracy (112 out of 128). Figure 8 shows the percentage of correct identifications of active feedback points.

Looking at those instances when participants were unable to correctly identify the active feedback points, we found that 75% of the errors (12 out of 16) were due to active points that were missed by the participants. The remaining 25% (4 out of 16) of errors came from the participants incorrectly identifying a region as being active when it was not.

Finally, we found that participants were 100% effective at detecting the presence or absence of feedback overall. That is, all of the participants perceived feedback if one or more feedback regions were active.

Towards Mobile Haptic TV

Our study of low-level recognition has demonstrated users' ability to recognize information with high accuracy using the UltraTV system. However, there are several more challenges to address before this is a complete haptic TV solution. These include:

1. Investigating users' ability to differentiate different intensity output and textures produced by UltraTV. We intend to conduct a series of perceptual studies to determine how well users' can differentiate ultrasonic variations and whether this correlates with observations from traditional vibration motors.

2. Exploring users' ability to detect points that move across the back of the device. A further series of perceptual studies will examine the accuracy and number of moving points a user's hand can detect when holding the UltraTV device. This is particularly applicable if the UltraTV system is providing feedback that follows, for example, a football or tennis ball travelling across the back of the device.

3. Understanding how haptic feedback should be correlated with visual and audio output from the video stream. A series of studies will aim to answer questions such as: does the haptic feedback have to match the visual feedback? What delay tolerances are acceptable? Can haptic feedback be used to provide non-visual TV?

4. Examine what types of content are best suited to mobile haptic TV presentation: e.g. sports, movies, etc. This will consider factors such as the difficulty in collecting suitable haptic information and the value of adding haptic feedback to various types of content.

5. Develop and field test sample applications and content. Having examined the perceptual constraints of the UltraTV system, we will give an UltraTV capable device to a number of participants to use 'in the wild'. We will log their usage patterns and gather feedback on

the value of adding the ultrasonic haptic channel to mobile TV streams.

These issues are the focus of our continuing work in this area.

Conclusion

This paper has begun to investigate the design issues around mobile haptic TV devices. We first presented design considerations for such a device and then described UltraTV, a mid-air, multi-point ultrasonic haptic feedback system. We see UltraTV as a promising new method for providing the required haptic sensations to make mobile haptic TV a reality.

To validate the feasibility of our setup, we ran a user evaluation that showed participants could identify multiple specific feedback points with 87% accuracy and could identify the overall presence or absence of feedback with 100% accuracy.

References

[1] Cha, J., Ho, Y.-S., Kim, Y., Ryu, J., and Oakley, I., A Framework for Haptic Broadcasting. IEEE MultiMedia, 2009. **16**(3): p. 16–27.

[2] Cha, J., Ryu, J., Kim, S., Eom, S., and Ahn, B., Haptic Interaction in Realistic Multimedia Broadcasting, in *Advances in Multimedia Information Processing*. 2004, Springer Berlin / Heidelberg. p. 482–490.

[3] Fukumoto, M. and Sugimura, T. Active Click: Tactile Feedback for Touch Panels. in *CHI '01*. 2001. Seattle, Washington: ACM. p. 121–122

[4] Hall, M., Hoggan, E., and Brewster, S. T-Bars: Towards Tactile User Interfaces for Mobile Touchscreens. in *MobileHCI '10*. 2008. Amsterdam, The Netherlands: ACM. p. 411–414

[5] Hoggan, E., Anwar, S., and Brewster, S.A., Mobile Multi-actuator Tactile Displays in *HAID '07*. 2007, Springer Berlin / Heidelberg. p. 22–33.

[6] Hoshi, T., Iwamoto, T., and Shinoda, H. Non-contact Tactile Sensation Synthesized by Ultrasound Transducers. in *World Haptics*. 2009. p. 256-260

[7] Iwamoto, T., Tatezono, M., Hoshi, T., and Shinoda, H. Airborne Ultrasound Tactile Display. in *ACM SIGGRAPH 2008 New Tech Demos*. 2008. Los Angeles, California: ACM

[8] Iwamoto, T., Tatezono, M., and Shinoda, H., Non-contact Method for Producing Tactile Sensation Using Airborne Ultrasound, in *Haptics: Perception, Devices and Scenarios*. 2008, Springer Berlin / Heidelberg. p. 504–513.

[9] Kim, S.-Y., Yoon, S.-U., and Ho, Y.-S., Realistic Broadcasting Using Multi-Modal Immersive Media, in *Advances in Mulitmedia Information Processing*. 2005, Springer Berlin / Heidelberg. p. 164–175.

[10] Massie, T.H. and Salisbury., J.K. The PHANTOM Haptic Interface: A Device for Probing Virtual Objects. in *Haptic Interfaces for Virtual Environment and Teleoperator Systems*. 1994. Chicago, IL, USA

[11] O'Modhrain, S. and Oakley, I. Touch TV: Adding Feeling to Broadcast Media. in *European Conference on Interactive Television*. 2003

[12] Vaillant, L., High-Frequency Ultrasound of the Skin, in *Measuring the Skin: Non-invasive Investigations, Physiology, Normal Constants*, P. Agache and P. Humbert, Editors. 2004, Springer.

[13] Verrillo, R.T., Vibration Sensation in Humans. Music Perception, 1992. **9**(3): p. 281–302.

[14] Weinstein, S., Intensive and Extensive Aspects of Tactile Sensitivity as a Function of Body-part, Sex and Laterality, in *The Skin Senses*, D.R. Kenshalo, Editor. 1968. p. 195–218.

[15] Yatani, K. and Truong, K.N. SemFeel: A User Interface with Semantic Tactile Feedback for Mobile Touch-Screen Devices. in *UIST '09*. 2009. Victoria, BC, Canada: ACM. p. 111–120