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Learning to draw with the HIPP application

Rassmus-Gröhn, Kirsten; Szymczak, Delphine; Fahlström, Ingegerd; Björk, Karolina

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Preface

The sense of touch, together with gestures and sounds – in fact all the non-visual interaction channels - are as yet sadly undervalued and underused in most applications today. At the same time these modalities are becoming increasingly important for good mobile user experiences. In the mobile use situation one can no longer always focus on the screen; the use is embedded in a context where people and events in the environment may need your attention. More non-visual interaction designs will simply make applications and devices easier to user for everyone. HAID 2012, the Seventh International Workshop on Haptic and Audio Interaction Design brings together work in this challenging area. We look at how do we design effectively for mobile interaction? How we can design effective haptic, audio and multimodal interfaces? In what new application areas can we apply these techniques? Are there design methods that are useful? Or evaluation techniques that are particularly appropriate?

That sounds, gestures and touch are important in mobile settings is shown by the fact that HAID 2012 was organized in collaboration with the EU project HaptiMap. HaptiMap, Haptic, Audio and Visual Interfaces for Maps and Location Based Services, receives financial support from the European Commission in the Seventh Framework Programme, under the Cooperation Programme ICT – Information and Communication Technologies (Challenge 7 – Independent living and inclusion). More information about HaptiMap can be found at the project website: www.haptimap.org.

In these proceedings you find the short papers accompanying the poster and demo presentations at HAID 2012. Haptic interactive experience are usually quite personal (you need to touch things yourself to understand the experience) and the demos shown at HAID are a key ingredient of this workshop – take your time to test, interact and enjoy!

Lund, 17th of August 2012

Charlotte Magnusson

Content

CogWatch: Cognitive Rehabilitation for Apraxia and Action Disorganization Syndrome Patients

Christos Giachritsis*
BMT Group Ltd
Goodrich House
1 Waldegrave Road
Teddington, Middlesex
TW11 8LZ, UK
cgiachritsis@bmtmail.com

Gary Randall
BMT Group Ltd
Goodrich House
1 Waldegrave Road
Teddington, Middlesex
TW11 8LZ, UK
grandall@bmtmail.com

ABSTRACT
Neurological patients with symptoms of Apraxia and Action Disorganisation Syndrome commit cognitive errors during every-day goal-oriented tasks which premorbidly they used to perform automatically. CogWatch is a new cognitive rehabilitation system under development which uses instrumented objects, ambient and wearable sensors to monitor patients behavior and intervene with visual, auditory and haptic feedback to facilitate completion of Activities of Daily Living. Here, we present the CogWatch architecture and its technologies.

Categories and Subject Descriptors
J.3 [**Computer Applications**]: Life and Medical Sciences – *Health.*

General Terms
Measurement, Performance, Design, Experimentation, Human Factors.

Keywords
Stroke, Rehabilitation, Apraxia, Multi-modal.

1. INTRODUCTION
Following a *stroke* incident, a significant proportion of patients can suffer from *Apraxia* and/or *Action Disorganisation Syndrome* (AADS) which, among other symptoms, are demonstrated by the impairment of cognitive abilities to carry out *activities of daily living* (ADL). These impairments of naturalistic actions mean that AADS patients are handicapped in their daily life and frequently cannot live an independent life. This has socio-economic implications for the patients, their families and the regional and/or national healthcare system that supports them. Most common rehabilitation systems are focused on treating *physiological* aspects of stroke, such as limb movement, and are based on robot and/or virtual environment platforms which are expensive and impractical for home installations. Moreover, they are space dependent requiring the patient to function within their working

* Author for correspondence

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space rather than adapting to patient's natural environment. Current cognitive rehabilitation systems are also using similar platforms and therefore inherit similar limitations. CogWatch aims to advance knowledge of AADS and develop a rehabilitation system that is based on highly instrumented common objects, tools and landmarks that are part of patients' everyday environment and can be used to monitor behaviour and progress as well as re-train them to carry out ADL through persistent multimodal feedback.

2. THE COGWATCH SYSTEM
2.1 Problems Addressed
The CogWatch system tries to solve the problems that hinder current approaches to rehabilitation including patients, professional healthcare and rehabilitation technologies.

First, AADS patients may exhibit different types of cognitive errors when performing previously familiar tasks as part of ADL. These errors include [1] for example both *Omission* errors (failing to initiate essential action or sequence of actions to complete a task) and *Commission* errors (initiating an incorrect or inappropriate action). There is evidence that when the patient is provided with appropriate feedback he/she can correct his/her own action and complete the task. For example, if a therapist sits beside the patient and demonstrates the task the patient will frequently be able to perform the task [2]. Appropriate feedback includes visual markers on the objects involved in the task or schemata (i.e., verbal narration of task). In addition, if the patient grasps the correct object the probability increases that the action is performed correctly [3].

Second, healthcare professionals recognise that stroke care is typically short-term, hospital based and largely focused on physical rather than cognitive rehabilitation. There is fragmentation between services as the patient is often discharged on physical grounds regardless of their functional state on the basis that other aspects of therapy can continue at home. Yet current methods of treating AADS are hampered by a lack of recognition of the prevalence and impact of the condition amongst many practitioners, inadequate training for therapists, and limited evidence base for effective therapy. Many people with AADS after stroke are left with life-long disability and suffer unnecessary social exclusion and mental health problems because of inadequate rehabilitation. Cost-effective care for stroke requires the promotion of maximal independence in the stroke patient with minimal hospital admissions, through provision of home-based (community) services. To date this has involved relatively expensive care arrangements, with bolt-on therapy, that is often reactive in nature. Standard technologies have had little impact on

therapy, and are often threatening to patients, most rehabilitation is therefore still very 'low tech'. A more efficient system would put the patient and their family at the centre, utilise labour-saving technology, and provide sufficient data for healthcare professionals to monitor progress and intervene in proactive and timely fashion [4-6].

Third, most common stroke rehabilitation systems, such as robotic arms and virtual environments (VE) are focused on physiological impairments (i.e., hemiparesis) of stroke patients (e.g., MIMICS, REHAROB, ARMin, iPAM, Mitsubishi Pa10) and largely ignore the cognitive impairments of action comprising AADS. Even though, they seem to be effective in re-establishing arm movement ranges, they operate as station-platforms which the patient has to access and adapt. This results in fragmented rehabilitation activities which reduces the rehabilitation outcome of stroke patients. In addition, it detaches the patients from familiar activities of ADL that may have remained intact as memories (schemata). Moreover, they are often very expensive and/or too big for home installation. Even systems designed to address some cognitive rehabilitation needs suffer from the above practical and financial drawbacks [7]. Therefore, it is evident that a new PHS is needed to provide cognitive rehabilitation in familiar, everyday environments allowing the patient to carry out his/her ADL and rehabilitate at the same (continuous rehabilitation). Thus, the system has to be portable, wearable and ubiquitous. Moreover, it has to be adaptable and customisable to maximise effectiveness and reduce unnecessary costs.

To sum up, an effective and practical PHS that aims to rehabilitate AADS patients should have the following characteristics:

- Be **personalised** to suit the needs of individual patients
- Offer **long-term, continuous and persistent** cognitive rehabilitation to maximise treatment impact
- Be **affordable** and customisable to reduce unnecessary costs
- Be portable**,** wearable and ubiquitous to allow patients to rehabilitate in **familiar environments** performing **familiar tasks**.
- Be **practical** and **adaptable** for home installation

In the next section, we outline a new PHS for the rehabilitation of AADS patients based on instrumented objects and tools, wearable devices, ambient systems and virtual reality modules that addresses the needs of AADS patients that current stroke rehabilitation fails to meet.

2.2 Proposed Solution

The CogWatch system is a PHS that aims to deliver personalised, long-term and continuous cognitive rehabilitation for AADS patients at home using portable, wearable and ubiquitous interfaces and virtual reality modules. It is designed to be personalised to suit the needs of individual patients as well as practical and affordable for home installation so that rehabilitation takes place in familiar environments performing familiar tasks. In order to achieve this, CogWatch (Figure 1) will use sensors (e.g., pressure sensors, accelerometers, temperature sensors) embedded in everyday tools and objects (e.g., cutlery, plates, boxes, toaster, kettle) and wearable devices (e.g. textiles, motion trackers) to acquire multi-parametric behavioural (e.g. grip force, hand configuration, position and movement, body posture, position and

movement) and physiological (e.g., heart rate, blood pressure) data. The devices also incorporate RFID tags to identify their location. These data will be processed and analysed locally by a home-based processor which will apply action prediction algorithms to deliver multimodal feedback through speakers, vibrotactile actuators, visual displays which will also implement the *virtual task execution* (VTE) module. Feedback will:

- Guide patients' actions
- Make patients aware of cognitive errors when they occur
- Make patients aware of the actions that they need to take in order to correct the errors
- Alert patients if their safety is at risk when handling tools and objects inappropriately
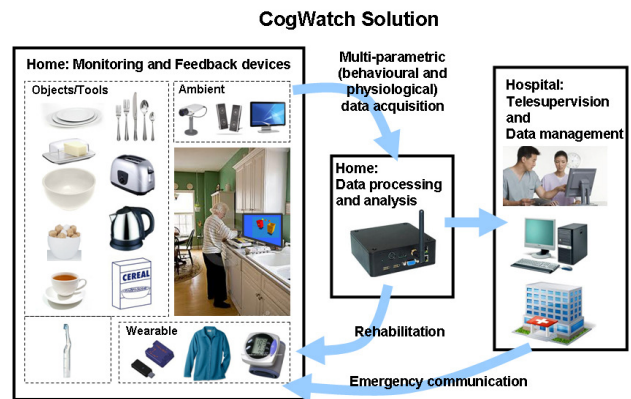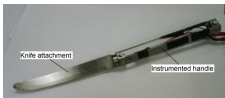
Figure 1. Schematic representation of the CogWatch system.

The behavioural and physiological data will be transmitted to a database at a healthcare centre or hospital where will be available for assessment and telesupervision by medical and healthcare professionals. The data will also be available to scientists and engineers who will use them to increase their understanding of AADS and improve the effectiveness of the system.

Below is a table with the key technologies that will be developed for cognitive rehabilitation and their functions.

Table 1. The three key technologies of the CogWatch system.

Devices	Function
	The cogwatch will be worn by the patient all day and will use multimodal feedback to guide action (via its visual display) and alert patients of errors and risks (via its vibration and/or sound modes). It will be developed by UPM.
	The instrumented objects will be used to complete familiar every day tasks and monitor object parameters (e.g., position, orientation, acceleration, temperature) and patient's

	sensorimotor behaviour (e.g., grip force, movement). They will be based one of the prototypes developed in [8]
	The virtual task execution (VTE) module will use visual displays installed on the walls of the kitchen countertop. It will be activated whenever CogWatch detects that the patient intends to carry out a task (e.g., making a cup of tea) on the countertop. It will use hands and object position information to guide patients through the actions. It will be based on the existing virtual environments module of MasterFinger2 simulating bimanual handling of virtual objects [9-11].

3. Ongoing Work

The development of CogWatch is ongoing and includes extensive experimentation with stroke patients in order to identify the exact cognitive deficits of individual patients and their responses to a particular type of feedback (e.g., visual, auditory and/or tactile). Based on this user requirements the system will be personalized to suit the needs of the individual patients.

4. ACKNOWLEDGMENTS

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Demo: Trails for Everyone

Charlotte Magnusson
Dept. of Design Sciences
Lund University
charlotte.magnusson@certec.lth.se

Kirsten Rassmus-Gröhn
Dept. of Design Sciences
Lund University
kirre@certec.lth.se

Delphine Szymczak
Dept. of Design Sciences
Lund University
delphine.szymczak@certec.lth.se

ABSTRACT

In this demo we present an inclusive tourist application that guides users along a forest/nature trail. The user points their phone in different directions and gets vibration feedback when the phone is pointed towards the target. In addition, the vibration feedback provides the user with information about the distance to the target. At a point of interest the user gets information through voice/speech and images. The application also implements accessible buttons that can be used both by sighted and visually impaired users.

Categories and Subject Descriptors

H.5.2 User Interfaces, Auditory (non-speech) feedback, Haptic I/O

General Terms

Design, Human Factors

Keywords

Navigation, multimodal, augmented reality, non-visual, inclusive.

1. INTRODUCTION

The introduction of compasses in more and more hand held devices has opened the way for applications making use of pointing gestures to provide information about objects or locations in the real world. With geo tagged information on a device which knows where it is (through GPS or other means) and also knows in which direction it is pointing (through a compass) it is possible to show the user information on important buildings, restaurants, future or past events etc etc in the direction the device is pointing (http://layar.com). Using non-speech sound or vibration in a handheld device to guide pedestrians in a wayfinding situation has been studied previously but not extensively. One group of proof-of-concept systems make use of spatial audio for navigation purposes and thus require headphones. AudioGPS by Holland et al. [1] displays the direction and the distance to a target uses stereo together with a repeated fixed pitch tone and a repeated varying pitch tone to give the user the directional information. A Geiger counter metaphor is used to convey distance from target (more frequent tone bursts the closer to the target the user is). In gpsTunes created by Strachan et al. [2] the user's preferred music was placed with spatial audio to provide bearing and distance information. As long as the user kept walking in the direction of the goal, the music was played at the desired volume. Stahl's The Roaring Navigator [3] guides visitors at a zoo by playing the sounds of the three nearest animals. The system also uses speech recognition for interaction and speech to display further information about the animals to the user. Jones et al. modify the volume of music stereo playback to guide users toward their destination in the ONTRACK system [4]. Their field trial also showed that visual distraction may interfere with audio guiding.

The AudioBubbles concept by McGookin et al. [5] is similar to AudioGPS, but does not require the use of headphones. The context is somewhat different in that is not specifically targeted to navigation, but to support tourists to be aware of and locate points of interest while wandering freely. The SoundCrumbs application described by Magnusson et al. in [6] enables the user to place virtual spheres of sound in a virtual georeferenced system and locating them again to support finding ones way back to a starting location, or to create virtual trails to share with others. It is possible to locate the next soundcrumb on the trail by pointing - when the magnetometer points in the direction of the next sound crumb, it will be played with adjusted volume, depending on whether the user points directly at the target or beside it.

Instead of using audio as a beacon at the target, tactile feedback such as vibration has also been used. Ahmaniemi & Lantz [8] similarly use vibratory feedback to investigate target finding speed in a laboratory set-up. The Social Gravity system described by Williamson et al. [9] intends to guide a group of people toward a common meeting point, called a "centroid" that adjusts its position according to the individual members of the group, using vibration feedback. In the SweepShake system presented by Robinson et al. [7] the user point in a direction and receives vibratory feedback when the device is pointing at the target. The targets are different in size depending on their information content (a larger target indicates more information content) and the use case described is primarily browsing and selecting geolocated information while standing still. The SweepShake was then evolved to support users' navigation as described in "I did it my way" [12]. The Tactile Wayfinder [13] explores the use of a vibrating belt to give directional information. PointNav [14] gives both orientation and navigation support through vibrations and speech feedback. For more exploratory navigation, different kinds of soundscapes have been created by communities or artists. The Urban Sound Garden [15] and the Tactical Sound Garden [16] are two examples.

As is shown by the "Lund Time Machine" application [17], non-visual augmented reality applications allow users to keep focus on the environment. In addition, the non-visual design approach makes these applications suitable also for persons with visual impairments. While the above mentioned work has been designed for urban environments (streets, open squares, parks etc), all designs that do not rely on routing/street-names could (at least potentially) work also in forest/hiking applications. Because of this we wanted to investigate how the design used in [17] could be used also in the forest/hiking type environment.

2. Application design

The guide application is based on the Lund Time Machine app (developed for Android 2.3). It uses GPS positioning and compass orientation to guide a tourist along a trail by tactile guiding (vibrations), and displays relevant information at the points of interest. When arriving within 15 meters of a point of interest, an information screen is displayed and a sound file with recorded speech plays automatically. An example of such an information text:

There is a legend about the "well-man". He was said to be a small, elf/goblin like figure who made sure there was fresh water in the well. He would get angry if the well was flooded, and could hit kids who got too close to the well. A boy born 1942 was warned about the well-man by his mother – and in addition the boy was told that if he swore he would grow horns and a tail. That boy pictured the well-man as a small devil. The well-man is now nearly extinct – he is almost forgotten!

The text is accompanied by a picture (Figure 1). To get to the next point the user either presses the "next point" button or shakes the phone. The application allows for multiple choice questions related to the place (results are given at the end of the trail).

Figure 1. Images from different parts of the trail. Geography, biology, history as well as fairy tale content is used.

By using the mobile phone as a scanner (pointing with it in different directions), the participant will get feedback in which direction to walk (Figure 2). When the phone is pointing in the direction of the next point of interest, within an angle of 60 degrees as recommended in [18], the phone vibrates with 3 short bursts. As the user gets closer to the target, the pulse trains of 3 bursts are repeated more often. The pattern of 3 bursts is always played until its end, to avoid getting borderline effects when exiting the 60 degree target angle. The pattern starts anew when the user goes outside the target angle and then re-enters it again. The calculations of the frequency of bursts is based on the actual distance to target, but also on a distance zone, so that the frequency increase in part becomes "stepwise" in the three zones *near, middle* and *far*. The vibration pattern design has been iteratively and systematically evaluated before the reported work [19]. The application allows the playing of ambient sounds at locations along the trail, something which can be used to enhance the environment with sounds from the past.
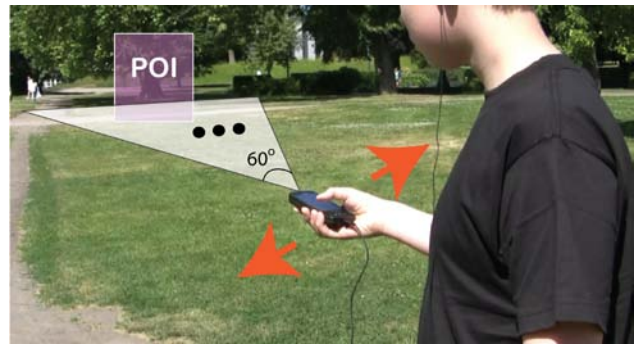
Figure 2. Pointing the phone in the right direction provides vibration feedback

The application also has an accessible button design which is designed for both sighted and visually impaired users (in contrast with the iPhone voice over). These buttons are described in the next section.

3. ACCESSIBLE BUTTONS

The application makes use of the HUI buttons available in the HaptiMap toolkit (http://www.haptimap.org/downloads.html). These buttons are based on the design used and tested already in the PointNav application [14]. In a screen with such buttons you slide your finger over the screen. When you pass over a button border you feel a vibration, and when you are on a button you will hear the name of it. Selection occurs when the finger loses the connection with the screen (select on release). This implementation works seamlessly for a sighted user – touching buttons the usual way selects them, but also allows a visually impaired user to use the interface.

4. CONCLUSION

This demo presents an inclusive guide app that takes a person along a hiking/nature trail. The basic design concepts have been tested in [14] in a park environment showing that it is possible for a blind person to use this type of design to locate goals and also to make use of the accessible buttons. The current trail will be tested during the summer of 2012 by groups of tourists visiting the trail area. Preliminary tests with children (5-6 years of age) showed that the application has attraction also for young kids, although they use it differently: they were not interested in the content, but used it in a treasure hunt fashion – as soon as they reached the point they considered this "mission accomplished" and shook the phone to go to the next point (not stopping to listen to the voice telling them about the place). Although the trails have not yet been tested by very many persons, the preliminary testing done indicates that these types of trail applications can be used to create inclusive trails that appeal to a wide variety of users.

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Audio and haptic feedback generated by a laterally moving touch screen

Christian Bolzmacher and Steven Strachan

CEA, LIST, Sensorial and Ambient Interfaces Laboratory
91191 – Gif-sur-Yvette CEDEX, FRANCE
christian.bolzmacher@cea.fr, steven.strachan@cea.fr

ABSTRACT

In this paper, we describe the audio and haptic feedback that can be generated by a laterally moving touch screen set in motion by a single amplified piezoelectric actuator. The large dynamic bandwidth of this type of actuator enables the delivery of rich tactile feedback to the user and covers at the same time the whole audio band for audio feedback and music rendering. We compare different signal forms in terms of vibrotactile feedback and audio generation.

Categories and Subject Descriptors

H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces

General Terms

Design, Experimentation, Performance, Human Factors.

Keywords

Tactile feedback, audio feedback, multimodal interface, piezoelectric actuator.

1. INTRODUCTION

Touch screen technology has become the reference for handheld devices such as mobile phones and tablets due to advances in user interaction, programming flexibility and cost factors. But the lack of physical buttons and its characteristic haptic and audio response change the manner of interaction with such touch screen-based devices. Currently, the haptic channel is primarily used for tactile input but can also be employed for tactile output. Several recent studies have shown that tactile feedback provided by vibration motors [1] or special actuator systems [2, 3, 4] to simulate physical buttons can be beneficial to the interaction [5].

The positive effect of a piezoelectrically actuated touch screen on a NOKIA 770 internet tablet has been shown by Laitinen *et al.* [3]. In the work presented here, we investigate the systems' behavior on lateral input motion on larger surfaces which are likely to behave differently as the surface area and mass increases. The main aim of this work is to provide rich haptic and/or audio feedback on large surfaces that is not only restricted to feedback for the confirmation of an action but also to the rendering of various surface roughnesses when the finger slides over the touch screen (e.g. the finger passing over button).

2. HARDWARE

The experiments were conducted on a modified ARNOVA 10 G2 tablet [6]. The basic device includes a 10.1" Multitouch capacitive display and provides an Android 2.3.1 user interface. It does not supply haptic feedback actuators. This tablet is an ideal candidate for this kind of research due to its relatively low cost and ease

with which it can be disassembled. In a first step, the capacitive touch screen was separated from the display and integrated into a compliant frame that allows displacement in one degree of freedom. An amplified piezoelectric actuator (Cedrat APA400MML, [7]) was then fixed between the housing and the mobile part. Second, the display and the electronics were placed into a new housing that enables the integration of the compliant frame (see Figure 1). The new housing was designed in a way that the touch screen is just one millimeter above the display to reduce visual discrepancies when the user does not interact perpendicularly with the device.

P. Stroppa/CEA

Figure 1. Touch screen integrated into a compliant structure powered by an amplified piezoelectric actuator.

P. Stroppa/CEA

Figure 2. Modified ARNOVA 10 G2 tablet with a housing including the compliant frame and the piezoelectric actuator.

Finally, the device is closed by a cover in order to protect the actuation part and the electrical wires. An application was designed with various 'pushbutton'-type controls which play prerecorded mp3-files when the buttons are clicked (see Figure 2). The actuator was connected via an amplifier to the headphone jack in order to render the selected signal.

3. AUDIO RENDERING

It is generally difficult to reproduce the entire range of audible frequencies at good quality using a single loudspeaker. But, amplified piezoelectric actuators are able to restitute frequency signals with good linearity over a wide frequency range. A limiting factor is however the electrical power needed to drive the actuators in order to obtain high displacements especially at higher frequencies. Nevertheless, the large screen area may sufficiently amplify the piezoelectrically induced motion to produce high audio output levels. The stiffness of the compliant frame plays a significant role, which acts on the one hand as a guide and on the other hand as a mechanical damper. Harmonic distortion effects may be reduced or amplified depending on its stiffness.

Useful insight into loudspeaker performance is provided by its frequency response. Two signal forms can be applied to characterize the loudspeaker – white noise and a stepped sine sweep. Here, a stepped sine sweep from 20 Hz to 20 kHz was applied to the actuator in 1 s intervals. This signal form is less prone to acoustic noise from other sources in the measurement environment [8]. The response was measured with a laser vibrometer. One can clearly see the first resonance mode of the touch screen near 100 Hz (Figure 3). Nevertheless, the audio quality is very good despite no signal processing having been applied.
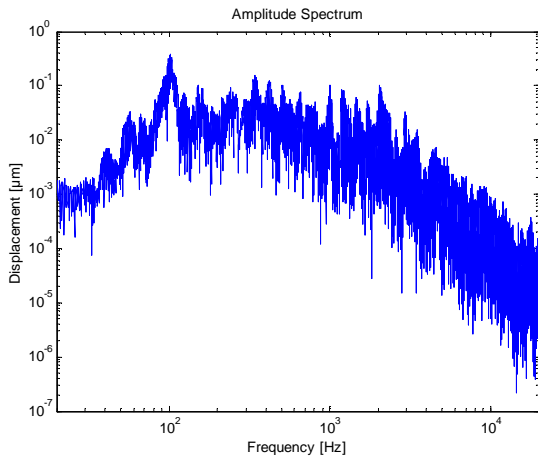
Figure 3. Audio performance of the surface actuated tablet.

4. AUDIO/VIBROTACTILE FEEDBACK

In the next step, the vibrotactile feedback performance was evaluated. Here, the improved reactivity of piezoelectric actuators compared to vibration motors becomes more obvious as shown in Figure 4. The vibration motor (Precision Microdrives C10-100) needs about 130 ms to reach 90% of its final displacement whereas the piezoelectric actuator (under load) needs less than 1 ms for the same amount of deformation. This suggests that piezoelectric actuation delivers richer tactile information and may be more appropriate for applications where very fast feedback is necessary. The applied square signal excites Eigenmodes of the touch screen display in the case of the piezoelectric actuator which are attenuated within 100 ms. Very sharp signal forms such as pulses or fast sweep signals can be generated with a certain localization. The vibration motor almost requires 500 ms to stop its motion. This type of tactile feedback is well-suited for longer

stimuli but should be limited to smaller devices than the tablet presented in this work because of the important mass which has to be displaced.
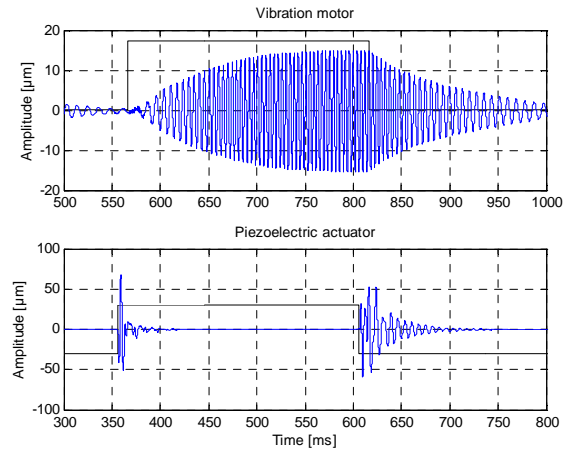
Figure 4. Response time of a vibration motor and a piezoelectric actuator to a square input.

In the next step, three tactile stimuli types have been tested, exemplarily:

- Sinusoidal signals
- Square signals
- Ramp signals

Each signal was applied to the piezoelectric actuator with frequencies from 10 Hz to 50 Hz at 30 V leading to a maximum displacement of 5 µm (see Figure 5). One can see that the sinusoidal signal follows the input signal while the ramp and square signals excite resonance modes of the surface. The sharp rise time of the piezoelectric actuator acts on the surface like an impulse signal for the square input and to some extent for the ramp signal (transition point). This behaviour does not change for input signal frequencies beside the surfaces' resonant frequencies).
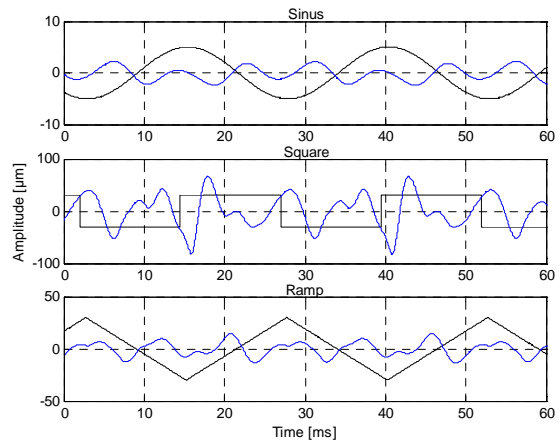
Figure 5. Sample signals (black lines) applied to the surface and the corresponding displacement response (blue lines).

The perception of those signals is very different, while sinusoidal waveforms provide a very smooth feedback with relatively high recognition threshold at very low frequencies, ramp signals and

especially square signals can be detected even when single pulses are applied.

Depending on the frequency range used for the tactile stimuli, the signal can be audible [5, 9]. This has to be taken into account when developing tactile patterns for various applications. Pure signals without any higher harmonic modes are less perceptible than signals that excite Eigenmodes of the structure. In the case of sinusoidal signals very smooth audio feedback is provided starting from about 40 Hz (for 5 µm lateral input motion) while the square signal provides a typical strong click-sound of high intensity already at 10 Hz. Sound levels have been measured for the three signal types exemplarily for 10 Hz and 50 Hz, respectively:

Sinusoidal:	56 dB and 65 dB,
Square:	84 dB and 91 dB,
Ramp:	62 dB and 79 dB.

5. DISCUSSION

This paper describes first performance results on audio and haptic feedback provided by a relatively large laterally moving surface. The capacitive touch screen of a 10.1" tablet device was integrated into a flexible frame with one degree of freedom and displaced by an amplified piezoelectric actuator. This kind of actuator provides theoretical displacements of several hundreds of micrometers over a large dynamic band at high forces allowing the displacement of surfaces with considerable mass. First, the loudspeaker performance was investigated. It was shown that the music rendering is of good quality even at low frequencies. It covers to some extent the complete audio frequency range applying only one single actuator. Here, we did not implement any type of signal processing because the flexible frame acts as a kind of passive filter. For stiffer frames harmonic distortion effects are reduced but also the displacement amplitudes, and thus, the maximum audio output power. Low stiffness frames enable better rendering of low frequencies because the force to be applied by the piezoelectric actuator to the flexible frame is reduced, which leads to higher displacement amplitudes. An important result was discovered during audio rendering experiments. Even when touching the moving surface the audio performance did not degrade. The user can feel the surface moving but the emitted sound is not affected.

Secondly, we investigated the tactile feedback performance of such a device. Due to the actuator's fast response time of less than 1 ms almost any signal form can be applied to the surface. Signals of sinusoidal form couple very smoothly into the surface and give a sensation to the user quite similar to vibration motors starting from about 40 Hz for the reference signal amplitude. In contrast to sinusoidal signals, square signals excite the surface' Eigenmodes directly which lead to very high output displacements. The user receives very strong tactile feedback of the click-type. Ramp signals can be placed in between the two other signals providing good tactile feedback due to relatively high displacements but a little smoother than the square signal. Both, square and ramp signals can be detected for reference input amplitudes over the whole tactile frequency spectrum. The audio feedback generated is about the same, sinusoidal signals remain soundless at very low frequencies up to 40 Hz. From 40 Hz to about 100 Hz only little background noise can be identified while the tactile feedback becomes quite clear. Ramp and square signals can be recognized as click and sharp click audio feedback, respectively. Our findings largely agree with previous studies [10, 11]. In the very low frequency range, users were primarily sensitive to stimuli with fast accelerations as is the case for square signals with a very fast initial rise time and ramp signals at its transition point. At higher frequencies, sinusoidal signals were appreciated by users due to the smoother coupling.

6. CONCLUSION

In conclusion, a compromise has to be found between music rendering and tactile feedback performance. This can partially be obtained with the flexible frame and in a later design phase by signal conditioning. It was found that the intrinsic natural audio feedback is very strong for tactile feedback signals which might be either of benefit for some applications, i.e. in noisy environments, or a drawback when silent exertion is demanded. Nevertheless, the proposed approach provides rich interaction possibilities for large surface devices and requires little space as the surface is displaced laterally. Next steps include further characterization of the device with various compliant frames, the design of appropriate patterns for different applications and its validation with user studies.

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ViPong: Probabilistic Haptic Gaming for the Visually Impaired

Steven Strachan, Harald Zophoniasson, Margarita Anastassova
CEA, LIST
Sensorial and Ambient Interfaces Laboratory
91191 – Gif-sur-Yvette CEDEX, FRANCE
firstname.lastname@cea.fr

ABSTRACT

In this paper we present the use of probabilistic inference as a mechanism for introducing uncertainty into haptic gaming for the visually impaired, with the aim of producing dynamically changing game conditions, via simple parameter changes, that enable a more adaptable, accessible and enjoyable gaming environment. The ViPong demonstration uses an instrumented mouse that enables a person to compete in a game of pong using only haptic feedback linked to the position of the ball. We find, after an initial informal study, that there is some positive effect of the feedback uncertainty level on the user's game play and experience with the game.

Categories and Subject Descriptors

H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces

General Terms

Ergonomics, Experimentation, Human Factors.

Keywords

Haptic, games, visually impaired, particle

1. INTRODUCTION

Haptic interaction is one way of enhancing game accessibility for gamers with visual impairments. However, to design easy-to-use, attractive and accessible haptic and tactile games for people with visual impairments, a number of problems must be overcome. First, some basic game characteristics such as 2D or 3D graphics are still difficult to represent in touch [1, 2, 6]. Second, it is difficult to provide an accurate haptic representation of objects, events and abstract features in a virtual world. It is even harder to do it for the multiple objects and events that need to be perceived during game play [5]. Third, the selection of what game features to represent as haptic, how to do it and when to do it is not straightforward [7].

This last problem resulted in two main approaches to the design of computer games for people with visual impairments [5]. The first approach is sensory substitution. In this case, the cues that would normally come from the visual channel are replaced by haptic or audio stimuli. This allows the design of new games as well as the adaptation of already existing games designed for users without

visual impairments. Blind Hero [11] is a typical example of a game where sensory substitution has been applied to a very well-known video game, i.e. Guitar Hero from Red Octane. Guitar Hero is a rhythm action game that is played by using a guitar shaped input device with colored buttons. The buttons must be pressed after the appearance of visual cues on the screen. In Blind Hero, the visual cues were replaced by haptic cues coming from a motor-based glove device. The user tests showed that players with visual impairments were able to play the game successfully and enjoy it. VI-Tennis and VI-Bowling are other examples of games based on sensory substitution [4]. In this case the haptic interface is based on a motion sensing controller enhanced with vibrotactile and audio cues. This device allows the players to detect key events (e.g. ball bouncing) in the game play.

The second approach is to design games that are inherently non-visual. The interaction with such games is exclusively based on audio and/or haptic cues. An example of such a game is Haptic Sudoku [3]. In this game, players can feel the Sudoku board and scan the numbers using a haptic display. Audio cues inform gamers about the outcome of their actions.

Building on the idea of inherently non-visual games, we describe an approach to designing games that enable visually impaired players to play using a probabilistic approach to the generation of haptic feedback. Williamson and Murray-Smith [10] describe a method of improving user audio feedback through the display of time varying probabilistic information via the use of granular synthesis. Using a similar approach to the provision of tactile feedback, we inject a natural sense of uncertainty into the game with the aim of enhancing the overall enjoyability and adaptability of gameplay to a variety of user needs.

Figure 1: The ViTouch mouse with integrated vibrator.

2. HARDWARE

This research was developed using a custom built mouse instrumented with a lateral vibrator built in to the left mouse button, as shown in figure 1. This vibrator, designed to aid the reproduction of surface texture sensations, when driven by a white noise signal enables the perception of very subtle tactile cues [8].

3. ViPONG

The ViPong application, based on the classic console game, uses a particle filter simulation to predict future positions of the game ball dictated by a fusion of all the external influences on the ball. The only influence in this case is the rather simple physics involved, meaning that it is relatively easy to predict the future position of the ball. Our particle filter predictions of the possible future ball positions are thus only influenced by the randomness injected to the initial angle or direction of travel (between +/- 45 degrees) and velocity of the ball before the simulation begins. Figures 2 and 3 show predictions of a pong ball's possible future positions, with larger circles indicating predictions further into the future, given the initial uncertainty levels (figure 2, high initial uncertainty and figure 3, low initial uncertainty). It is hypothesized these initial conditions will have an effect on the feedback detected and hence on the overall gameplay experience.
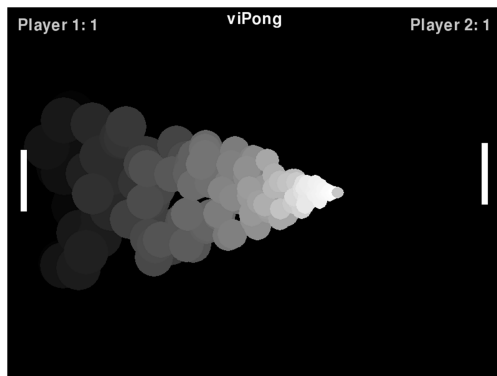

Figure 2: Pong ball future position simulation with high uncertainty. The ball moves from right to left. Circles representing predictions further in to the future are given a larger radius.
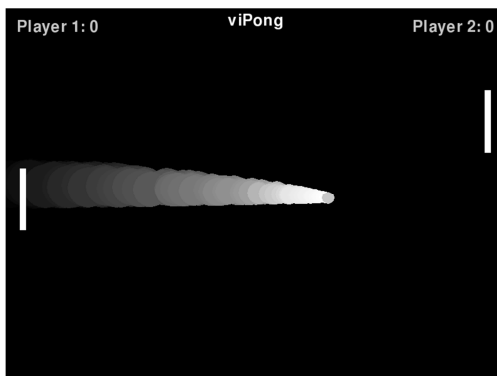

Figure 3: Pong ball future position simulation with low uncertainty with the ball moving from right to left.

The reason for choosing such a simple dynamic simulation in this case is that for this first demonstration we would like to be able to accurately quantify the effect of the varying uncertainty injected into the simulation on the user's perception of and performance during the game play without external influences affecting the measurements. Future iterations will include games with more complex dynamics and this is where the real power of the particle filter approach will prove to be useful.

3.1 Feedback

Haptic feedback is generated directly from the particle simulation in a way similar to that described in [9]. As each of the particles virtually interact or 'impact' with the user's paddle, illustrated in figures 2 and 3, they increase the overall energy imparted to the paddle, which is correlated to the amplitude of a white noise signal, used to drive the vibrator. The particles further along the simulation in time, i.e. the larger particles in figures 2 and 3, contain less energy and hence provide less vibration to the user. The user effectively feels the vibration increase as the ball gets closer to the paddle and the certainty of the paddle being in the correct location increases. The user also hears the typical pong audio sounds to confirm that the ball was successfully hit.

4. INITIAL TESTING

As an initial indicator of both how this feedback performs in general and how the level of uncertainty or randomness affects the game play, 3 sighted users were asked to take part in an informal user study. They were required to first play the game in a normal sighted situation for 40 seconds, in order to gain a feel for the game and the feedback. They were then asked to play two times for 40 seconds blindfolded with both high and low uncertainty feedback (as in figures 2 and 3). Traces of the users' paddle position and feedback amplitude were recorded with the results for one user show in figures 4-6.
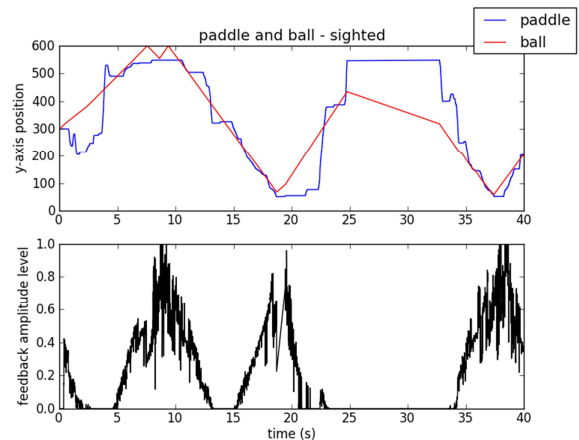
Figure 4: Paddle trace and feedback for a sighted user.

These initial results indicate first that it is actually possible to partake in an eyes-free game of pong using only tactile feedback and second, that the level of uncertainty injected into the future predictions of the ball's position do have some positive effect on the game play and accessibility, with all 3 participants able to return at least one ball using haptic feedback alone. Figure 6 (low uncertainty) shows that while the user's paddle movement is much more variable than in the sighted case (figure 4), as the user continuously searches the space for feedback, it is slightly less variable than the higher uncertainty case (figure 5), indicating that there is some effect of feedback on gameplay.

Similarly, the feedback generated in the low uncertainty case is clearly more focused than in the higher uncertainty case. It is also clear from this result that in the unsighted case the task is reduced

to a basic tracking task as the user is essentially trying to follow the path of the feedback until their paddle makes contact with the ball.
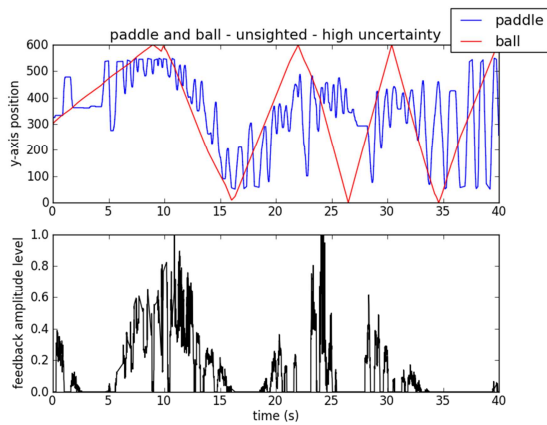
Figure 5: Paddle trace for blindfolded user with high uncertainty added to game play (top). Level of feedback delivered (bottom).
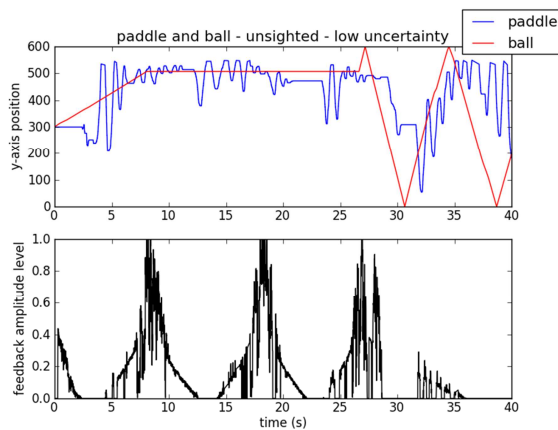
Figure 6: Paddle trace for a blindfolded user with low uncertainty added to the game play (top). Level of feedback delivered (bottom).

Although these results come at an early stage in development they do provide some encouraging indications about what to expect in later experiments, where we aim to quantify the effect of this variation in uncertainty on the user interaction, enjoyment and accessibility.

5. FUTURE DEVELOPMENT

Thus far we have shown the early potential for this mechanism to provide haptic feedback to users of games for the visually impaired. A number of controlled experiments need to be conducted in order to verify the hypothesized effects but this system also provides a simple platform to examine the limits of the interaction and exactly how 'uncertain' we can make the feedback before its utility is lost. While this research is still in an early stage there are encouraging signs that this versatile mechanism for providing haptic feedback can be refined and applied to more complex gaming experiences. The results

concerning accessibility features based on tactile feedback are also encouraging.

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Learning to draw with the HIPP application

Kirsten Rassmus-Gröhn
Dept. of Design Sciences
Lund University
kirre@certec.lth.se

Delphine Szymczak
Dept. of Design Sciences
Lund University
delphine.szymczak@certec.lth.se

Ingegerd Fahlström
GotIT resource center
Municipality of Gotland
ingegerd.fahlstrom@gotland.se

Karolina Björk
Anpassningsbyrån
anpassningbyran@telia.com

ABSTRACT

In this paper, we describe an audio-haptic drawing application prototype that has recently been tested by five pupils who are 8-13 years. The application has been used by pupils, assistants and teachers to access graphics and create graphics that are accessible for pupils with severe visual impairment or blindness. We have observed a spread in the actual use of the system that seems to depend, for example, on the special pedagogical knowledge of teachers and assistants, their learning focus, and the age of the pupil when they start using the system.

Categories and Subject Descriptors

H.5.2 Information interfaces and Presentation: User interfaces: *Input devices and strategies, haptic output, voice output* **K.4.2 Computers and Society:** Social issues*: Assistive technologies for persons with disabilities* **K.3.2 Computers and Education:** Computer Uses in Education: *Computer assisted instruction*

General Terms

Design, Human Factors

Keywords

Haptic, audio, multimodal, non-visual, blind

1. INTRODUCTION

Persons who have visual impairments are excluded from accessing certain types of information that are accessible to the general public. Today, screen reading software and Braille displays or text-to-speech systems are used for enabling access to text. For accessing graphics, and especially digital graphics, no standardized technology is in widespread use. In education, preprinted material is often used, which forces teachers to plan well ahead of time to be able to produce or borrow the material they need. This makes the learning situation less dynamic, and it is hard to produce tactile material on-the-fly. Because of this, pupils with severe visual impairments also get less trained in the reading and understanding of graphical material which will exclude them from certain information in their grown-up lives.

The emergence of haptic hardware and the possibility to create interfaces for non-visual audio-haptic interaction has opened a door to the access of digital graphics and 3D models. Still, the relatively high price of high-precision haptic devices is a hindrance, as well as the lack of useworthy applications.

2. METHOD AND SYSTEM DESIGN

We have used a participatory design process in a school context to develop an audio-haptic non-visual image editor and explorer, which may also be used collaboratively [1][2]. The system, called HIPP (Haptics In Pedagogical Practice) and the methods around it, while undergoing continuous improvement, are evaluated in four schools by five pupils with severe visual impairment or blindness, their teachers and assistants. The different pupils and teachers have chosen to use the system in different ways, according to their own needs and wishes.

The drawing application is written C++ and Python on top of the H3D API [3], and Cairo graphics [6], and is available as open source code [4]. It uses a combination of haptic and sound feedback to display information to the visually impaired user. The haptic feedback is displayed via the PHANToM OMNI device. A sighted user can simultaneously use the mouse to interact with the application.

The virtual environment consists of a virtual sheet of paper. The PHANToM user draws on the paper by pressing the front switch when in contact with the paper. The mouse user draws while pressing the left mouse button. The users can choose to draw the line in either positive or negative relief. A combination of positive and negative relief can be used to display different features in a drawing. The PHANToM user can feel the lines while drawing. Each line is tagged with a number and text string which is spoken by the application each time a user selects an object by touching it with the PHANToM pen or hovering over it with the mouse cursor, or, it can be tagged with a sound effect.
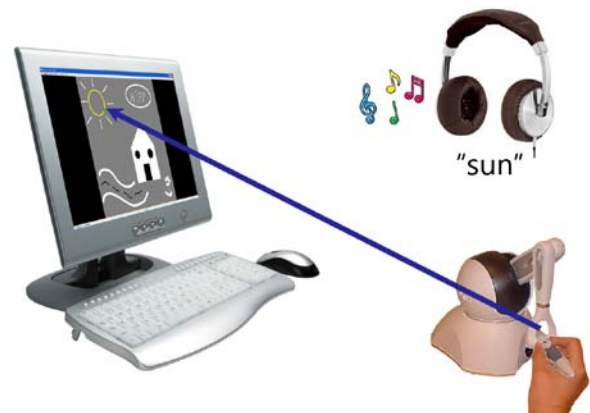

Figure 1. HIPP concept picture. The pen for haptic feedback, the earphones for spoken feedback or sound effects.

Objects can be manipulated in different ways; moving, resizing, copying, pasting and deleting. Additionally, text tags for the shapes can be changed, sound files can be associated with shapes and shapes can be transformed into straight lines, rectangles or circles. The manipulation tools are fitted with auditory icons, which are feedback sounds designed to resemble a real world manipulation of similar nature [5]. E.g. the copy function sound effect is a camera click.

3. RESULTS

The extent and mode of use of the HIPP system has varied for the different pupils. It has been used both for the own creation of drawings (made by the pupils) and exploring of school material, such as diagrams, maps or other illustrations. The preconception of the teachers' was such that they were very focused on teaching: *transferring* knowledge in pictures *to* the pupils, and would start talking about maps and mathematics figures as being the biggest problem in school (for pupils with visual impairment). This seemed to get more prominent the older the pupils got, and the playful experimentation with the digital material (in the form of the HIPP system) was not pursued as much. For the younger pupils, an approach of playing with sounds, drawing and simultaneous use of normal tactile drawings on paper seemed to come more natural.

However, asking pupils with severe visual impairment or blindness to draw is not without its problems. How do you go about teaching drawing to someone who does not see and cannot as yet interpret tactile drawings very well? It was also seen that while some pupils have a wish to draw as their sighted peer do, others are reluctant to try. When one of the pupils (with blindness) was asked to draw something, the pupil answered: *"I have to say thank you, but I'd rather not"*. It is also important to note that blind pupils (as a rule) have as yet tried very little to do drawings at all. The available aids for non-visual drawing are limited and non-dynamic and they also do not help the pupils do nice drawings (as computer-aided drawing applications do).

The approach that showed to be fruitful for the reluctant pupil in the end was to let the pupil do doodle-drawings with the HIPP system, much as younger sighted children do when learning to hold a pen at 1-3 years of age. These doodles were then interpreted by an assistant who would say things like: *"Oh, what you are drawing there looks like a rose, would you care to bring it home to give to your Mom?"*. And then they would print the drawing on swell paper (which raises the black lines on the paper) and explore it as well. When the pupil later took the initiative to draw something, visual interpretation and communication around 2D drawing conventions were discussed.
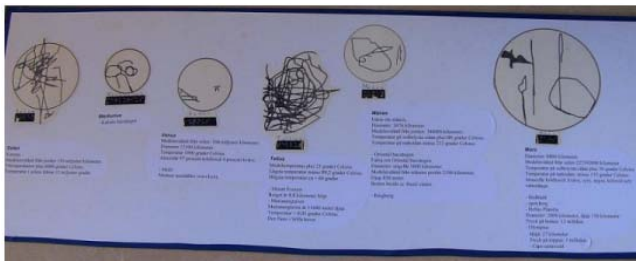
Figure 2 Solar system printed on swell paper.

For example, the pupil would like to draw a planet from the solar system. Therefore, the pupil started to ask question like: "*How do you draw a planet? And how do you know that at planet you draw*

as a circle, is in fact a sphere? And how do you draw the craters on the moon? How about the mountains?" From the pupil's initiative, a whole wealth of discussion topics around 2D drawings, scaling and perspective came naturally from working with the system in a real activity. Also, the fact that the drawings were not kept in the digital format, but also printed on swell paper and examined, probably helped to convey the meaning and importance of graphical images.

The examples above cover the personal learning for the pupil, learning to draw and understand drawings. In the particular case, this learning took place in a special session with specialists that had deep knowledge of both the HIPP system and of visual interpretation and tactile material use. This is not always the case, since specialists are hard to come by in a school that maybe has one single pupil with visual impairments in maybe a 20-year period.

Another issue with pupils who are visually impaired is that they sometimes have problems collaborating with their sighted peers in class (in Sweden, most pupils with visual impairment are integrated in a regular class). Since they have different learning material (the tactile material and the visual material differ) it is hard to collaborate in certain tasks. It is also difficult to take part in the creation and exchange of graphics, which is important as a learning tool especially for the younger children. In one school, the assistant and the pupil used the HIPP system to create such material, which was going to be used in a visual exhibition in the classroom. This was done on their initiative, and since it was for an exchange with peers, the usefulness of HIPP was clear to everyone involved. However, there is still the problem of the communication of the sighted pupil's graphics to the pupil with visual impairment.

Figure 3 A part of an ocean collage in the classroom. The shell and the bird above it are created with the HIPP application.

4. DISCUSSION & CONCLUSIONS

As can be seen from the examples above, and also inferred by similar examples from other schools, the HIPP application, which is in many ways still quite simple (we sometimes refer to it as a non-visual "Paint" application), has sufficient functionalities to be of use in the classroom. It puts some demand on the pedagogical personnel surrounding the child, however, and we have seen how the computer skill and the knowledge of special pedagogy have a big impact on how often the tool is used and in what situations. However, this is the case, we believe, also with other material and pedagogical situations. We hope to solve some of this problem by

creating good introductory material and example graphics to start with, as well as making the program more standard.

Learning to draw, and also being inspired to draw is indeed possible with the help of HIPP, and by printing swell paper copies of the drawn pictures, sometimes in several stages before the picture is finished, helps making the build-up of pictures clearer to the pupil. We have also seen how the task of drawing something triggers questions about 3D-2D projections, and about certain conventions in drawing, for example how you usually draw a car from the side, and not from the top.

With the younger children, a playful and child-driven approach has been more pronounced. The children themselves draw freely, and they are the ones driving the activity. Their own inner pictures are the beginning material. We guess that this is one reason why that has worked better with them, because they are more engaged in the drawing activity, which originates from their own motivations. The root cause for the playful approach can be the pedagogy for smaller children as such, but it may also have to do with the escalating demands on the pupils' as they grow older. They simply have no time to learn a new tool in a playful manner. This indicates that learning a new tool like HIPP should be scheduled in the lower classes; however, we have also experienced clashes with other new tools being learned such as Braille displays or new keyboards.

We infer that the use of HIPP as only a transmitter or conveyor of school material such as maps, drawings and diagrams, will not work well. In the classes where the conveying of material has been the focus, it seems the HIPP application has been used less. Partly, we believe, because without the knowledge of what a picture is and how you create it, the decoding and understanding of pictures is harder – thus emphasizing the importance of the child-driven drawing activity. But it may also be because this then puts a greater demand on the assistants or teachers actually creating the material, and spending preparation time working with HIPP. The time needed to spend on a new tool,

even if it is seen as useful, is hard to add on top of the other work that is already done in school.

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A Magnetorheological Haptic Device for In-Vehicle Use: An Exploratory User Evaluation

Margarita Anastassova, Mia Ajanki, René Polizzi, Floran Periquet, José Lozada, Samuel Roselier, Moustapha Hafez
CEA, LIST, Sensory and Ambient Interfaces Laboratory,
91191 – Gif-sur-Yvette CEDEX, France
{margarita.anastassova, rene.polizzi, florian.periquet, jose.lozada, moustapha.hafez@cea.fr}

Peter Bengtsson
Lulea University of Technology
University Campus
Pörson, SE 971 87 Lulea, Sweden
peter.bengtsson@ltu.se

ABSTRACT

This paper presents an innovative rotary haptic interface based on magnetorheological fluids, as well as its exploratory user evaluation. The interface is able to emulate a large variety of tactile stimulations and allows the rendering of multiple haptic patterns. It is used for the control of In-Vehicle Information System (IVIS) functions. The user study described in this paper aimed at exploring user preferences for haptic patterns, the differentiation of the latter and their association with a few IVIS functions. The preliminary results show that users are able to differentiate the presented haptic patterns. However, the association with the tested IVIS functions, though possible, is not always straightforward. We discuss these results and present a number of perspectives.

Categories and Subject Descriptors

H5.2. [User interfaces]: Haptic I/O, Evaluation/methodology, User-Centered Design.

General Terms

Human Factors, Design

Keywords

Haptic device, haptic patterns, in-vehicle interface, magnetorheological fluids, user evaluation

1. INTRODUCTION

In-Vehicle Information Systems (IVIS) such as GPS, emergency help systems, MP3 music catalogues, cell phones and email proliferate in today's cars pushed by an expected $15–100 billion market [9]. However, most of these technologies are based on visual feedback and require attention- and time-sharing with the safety critical driving task. A way of reducing the generated workload and to improve safety is to present information using *well-designed* auditory or tactile/haptic feedback [10]. According to [8], the major potential advantages of using non-visual channels are 1) a greater alertness to non-visual stimuli and a more rapid user response; 2) a reduction of the visual overload; 3) a relative independence of the effectiveness of these signals on the current direction of a driver's gaze. In this paper we will focus on haptic feedback. We propose a device based on

Magnetorheological (MR) fluids, which could possibly alleviate driver's visual overload by communicating non-driving-related information using a variety of haptic patterns.

Haptics is still rarely used in vehicles, though some researchers suggest that it may be a realistic approach to safer in-vehicle displays [10, 11]. The design of easily understandable and efficient haptic messages or patterns is crucial in such a context. Considerable work has been in this field [3, 4, 7, 8]. However, past work has been mainly focused on motor-actuated haptic interfaces. Compared with semi-active MR fluids-actuated systems, motor-actuated systems show less stable manipulation and relatively restrained mechanical bandwidth. MR fluids are suspensions of micron-sized ferromagnetic particles that can align to form chains when a magnetic field is applied. These chains, whose mechanical resistance is a function of the magnetic field intensity, can be used to generate a torque opposing the motion generated by the user [1, 2]. Thus, when subjected to a magnetic field, the fluid greatly increases its apparent viscosity. Furthermore, MR fluids are able to provide a stable response with a short response time (~ 5 ms) [1, 2]. Because of these characteristics MR fluids allow the rapid alternation of different degrees of viscosity and, as a result, the creation of a variety of haptic stimulations, ranging from a very smooth force-feedback to a sensation of considerable stiffness. The intensity of the stiffness sensation is inversely proportional to the force applied by the user. Users' perception of these particular types of haptic stimulation has rarely been evaluated up to now. The work presented in this paper is a contribution in this direction.

The paper is structured as follows: we first present the tested haptic device and an example of an in-vehicle use scenario. Then, the user study is presented. We conclude by a discussion of the results of the study and some suggestions for future work..

2. THE MR HAPTIC INTERFACE: DESIGN, POTENTIAL APPLICATIONS

The haptic device tested in our user study is called MR-Drive [12]. It consists of a knob whose force feedback can be controlled by MR fluids (Fig1, left). The knob can be turned clockwise and anti-clockwise as well as translated in the horizontal plane in order to control the visual interface. Fig. 1 (right) shows a CAD view of the MR-Drive. The system is composed of two magnetic poles facing each other (1), a coil around the central pole (2), a neodymium permanent magnet (3), all these parts are fixed to a

frame (5). A thin cylinder (4) and a cap (6) are connected with the shaft (8) and guided by two bearings. A nitrile joint is used to prevent fluid leakage. The rotation angle is measured by an optical encoder (7). The thin cylinder rotates in the gap between the magnetic poles.
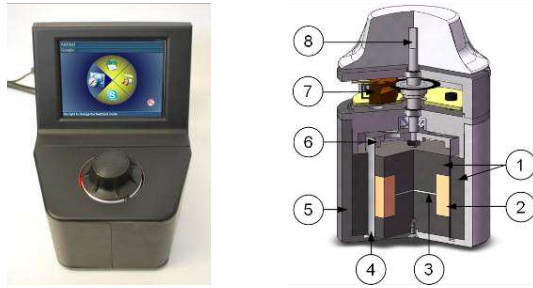
Figure 1. MR-Drive, a 1 DOF rotary haptic device with an example of visual interface left and a CAD view of the magneto-rheological fluid based knob right

This gap is filled with MR fluid. Applying a current into the coil generates a magnetic field that can either increase or decrease the permanent magnet's magnetic field. The MR fluid shearing stress can then be controlled by controlling the coil current. The presented rotary knob can produce a maximum controllable torque of 5.25Nm.

The preliminary user evaluation described in this paper concerns only unimodal haptic stimulations generated by the MR-Drive. In the future, the MR-Drive will be used as a control device allowing the navigation in graphical user interfaces and the control of different in-vehicle functions. As mentioned before, the objective of introducing haptic feedback via the MR-Drive is to leverage the driver's visual workload. Thus, if the MR-Drive is used to control an in-vehicle e-mail application, the general user interaction scenario will be the following. Using the knob, the user browses the list of e-mails he has received. He/she perceives different types of force-feedback depending on the properties of e-mails (e.g. newly received mail, very important mail, mail coming from a particular person, etc.). When the user decides to "read" an e-mail depending on the perceived force-feedback, he/she could get acquainted with its content using an in-built speech output function. Therefore, user interactions will demand little visual attention.

3. USER STUDY
Several haptic patterns were developed. Based on previous work [5, 6], we produced patterns that are easy to discriminate. User experience with these haptic patterns was tested during an exploratory user study. We wanted to investigate the following points: 1) the differentiation of haptic patterns rendered by the MR-Drive; 2) test participants' preference (acceptance, pleasantness) related to signal's wave shape or torque; 3) the matching of certain haptic patterns with abstract concepts such as the ones used to represent in-vehicle functions controlled by the MR-Drive (i.e. telephone, car-navigator, radio and e-mail).

A total of 10 subjects (7M, 3F), all right-handed, aged from 22 to 28 years, participated in the study. All of them were employees or students doing an internship in the institution developing the haptic device. The test participants were sitting on a chair with the

MR-Drive located on their right, while the experimenter was on the other side of the desk, controlling the pattern presentation. After having heard the experimental instructions, the participants tested 3 pre-test patterns in order to get familiarized with them. No data was recorded at this point. Then, 10 test patterns were introduced and the participants were asked to compare two pairs of patterns with similar characteristics (i.e. torque and wave shape). For each pair they were asked to sketch the perceived pattern, to express their preference and their judgement on the level of similarity and to verbally associate the haptic pattern with one of the 4 in-vehicle functions, which were presented (again verbally) during the tests. These 4 functions were telephone, car-navigator, radio and e-mail. The participants were allowed to switch multiple times between the two compared patterns. Every pattern participated in 3 pairs, which resulted in a total of 15 cases of paired comparison. These pairs were presented to the subjects in a random order. Our 10 haptic patterns contained 5 different types of wave shapes (i.e. sinus, triangular, arc, line, and square).

4. MAIN RESULTS
The results presented below are based on descriptive statistics only. No comparison of means was done because of the exploratory nature of the study. Hence, we were mainly interested in basic tendencies in users' behaviour, which can orient future stricter experimental studies. The majority of the participants (8/10) stated that they recognised and remembered the patterns they had interacted with. Furthermore, participants found the interaction with the MR-Drive pleasant and natural. The presented pairs of haptic patterns were well-differentiated by the participants. There were only 4 cases (3%), in which haptic patterns in pairs had not been differentiated correctly. Users preferred the haptic patterns based on the lowest level of torque. The wave shape did not seem to influence individual preferences, since 4 of the 5 possible wave shapes were represented in users' choices.

In order to describe the associations between haptic patterns and the abstract concepts presented during the study (i.e. the in-vehicle functions), Relative Deviations (RDs) were calculated. RDs measure the association between two nominal variables. They are calculated on the basis of a comparison between observed and expected frequencies (i.e. those that would have been obtained if there was no association between the two variables). There is attraction when the RD is positive, and repulsion – when it is negative. Thus, participants tend to associate the GPS concept with pattern A (RD_{gps-a}=0.43) and pattern J (RD_{gps-j}=0.43). The concept of the telephone is predominantly associated with the pattern C (RD_{tel-c}=0.53), and the concept of radio is mostly associated with the pattern F (RD_{rad-f}=0.42). As for the concept of e-mail, it is mainly associated with the pattern L (RD_{mail-l}=0.63). Although these associations seem strong (Cramer's V=0.17), the majority of the subjects expressed difficulty in associating a pattern with the concepts of e-mail and GPS. On the contrary, it seemed easier for them to associate patterns with telephone and radio.

5. DISCUSSION AND CONCLUSION
Our exploratory study demonstrates that it is possible to render differentiable and easily acceptable haptic patterns with the MR-Drive. This result shows that drivers may be able to perceive, differentiate and treat basic information encoded in haptic patterns rendered by MR-based devices. Differentiation seems possible even when the patterns are presented sequentially or in groups.

Users also seem to enjoy the interaction with the device and the haptic patterns. However, the study presented in the paper is an exploratory one. In this sense, there was not strict control of the experimental variables and their characteristics. That is why, no conclusions on the relations between patterns physical characteristics and user preferences can be drawn.

The study also shows that users tend to favour patterns with a low level of torque. This point could be used as a basis for future design guidelines. As for the matching of haptic patterns with abstract concepts, our results show that this is not always a straightforward activity. Though some associations are possible, no clear underlying rule can be derived to explain participants' choices. A possible solution to this problem, before further developments and theoretical conceptualisations, is to pre-assign meanings to haptic messages. Such pairs of haptic stimulations and abstract concepts could be then learned by future users.

6. LIMITATIONS OF THE STUDY AND FUTURE WORK

In our preliminary study, there was no strict control of patterns physical characteristics and the associated human psychophysical responses. Furthermore, the user sample was very small and not representative of future users. In the future, it would be interesting to better identify and control the physical parameters of the haptic stimulation (e.g. torque, wave shape) in order to get a clearer idea of the user's reaction from a psychophysical point of view. To have valid results, such studies could be done with larger and representative samples. On the basis of the results, one could propose guidelines for the design of usable, easily differentiable and acceptable patterns. In this context, the concepts of perceived comfort, pattern "aesthetics", and user acceptance should be of major importance. Also, in order to further explore user preference of interaction based on MR-fluids, ca study comparing this interaction with the interaction with motor-based devices must be performed.

Another direction which is worth exploring in the future is the user perception and performance in a real driving situation. Though the use of the device may eventually leverage driver's visual attention, a cognitive overload may be induced by the necessity to process, remember and recall haptic patterns. Hence, a controlled study exploring visual and cognitive load when using the MR-Drive in simulated driving situation must be done.

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Guitar Simulator: An Audio-Haptic Instrument for Android Smartphones.

Ben Cahill and Stefania Serafin
Aalborg University Copenhagen
A.C. Meyers Vænge 15, 2450
Copenhagen
Denmark

Bcahil09@student.aau.dk,
sts@create.aau.dk

ABSTRACT

The haptic capabilities of a smartphone are used in a model of plucked strings. The current implementation is simple yet shows promise for this type of interaction on the Android platform.

Keywords

Haptics, musical instrument, smartphone, guitar

1. INTRODUCTION

The smartphone platform offers a unique test bed for music-based experiments; high quality graphics, sound and haptic capabilities are built into most modern examples.

Haptic feedback has been shown to enhance a virtual musical experience [1][2] by increasing the realism of the experience via multisensory stimulation. Even relatively low fidelity stimulation across multiple sensory channels is capable of providing a convincing impression of an event.

The Android interface encourages tapping and stroking and many instrument simulations have been developed that exploit these actions [3][4]. A limitation in these simulations is the latency due to audio drivers that are not optimised for real-time performance (unlike Apples iOS audio system). This makes percussion simulations in particular unconvincing and difficult to use with any degree of accuracy.

Very few virtual instruments use active haptic feedback, although some use haptics as navigational cues in menus. The smartphone actuators are usually small eccentric motors that have a low maximum amplitude but have short rise and fall times.

These capabilities are employed in a simulation that works in three modalities; the visual, audio and haptic.

2. DESIGN

2.1 Platform

The hardware platform is comprised of a Samsung Galaxy S2 Smartphone and a Dell Studio XPS laptop PC. The user interaction, graphics and haptics are programmed in Processing, a Java-like high level IDE, and compiled for Android; the audio is programmed in PureData and runs on the Windows PC. The Smartphone is running the Processing sketch and sending OSC data to the PureData patch over a local network.

2.2 Guitar Simulator

The Guitar Simulator (GS) is an interactive application that provides visual, audio and haptic feedback in a virtual acoustic guitar. The user can pluck or strum the strings and adjust the string dampening and the plucking mass. A metronome triggers a change to a random diatonic chord at a given subdivision.
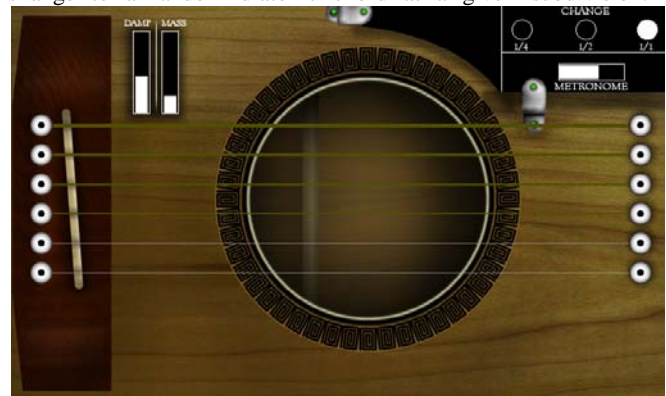
Figure 1. Guitar Simulator GUI

The user plays the strings by stoking across them. Additional GUI features are operated by tapping and dragging.

The strings are modelled graphically using a mass-spring-dampener model (MSD). The user's striking speed is sampled, the acceleration derived and multiplied by the mass to get the input force to the model. The centre mass is displaced at that initial time according to the MSD formula and decay over time accordingly. The string is drawn by interpolating between offset MSD models. The frame rate is set to 60fps.

The audio data is generated using a Karplus-Strong algorithm [5] in PureData. A short noise burst is fed into a filtered, attenuated delay line and this emulates the decay characteristic of the string. Changing the delay time changes the pitch of the tone. The input force is mapped to both the amplitude of the sound and to the filter in the delay line. This provides a duller, quieter tone at soft plucking levels and a louder, brighter tone at harder plucking levels.

Each string is tuned to its real world equivalent in standard tuning (E,A,D,G,B,E) and the corresponding MIDI note is sent to the string simulation.Each of the 7 diatonic chords is represented by an array of offsets per string which renders the chord voicing. The chords are based on the I chord having the same form as a first-position E major chord. When the metronome sends the change

message, a new chord from the diatonic array is selected. The key can be changed by adding an overall offset (-5 to +6 for all 12 keys) to the MIDI note number. Implementing rules to define key changes in this system would be relatively and allow the possibility of semi-automated composition.
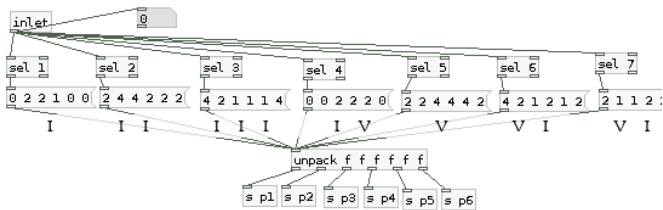
Figure 2. Chord selection Pd subpatch

The Android SDK allows the Smartphone vibrator to be turned on or off once per millisecond, giving a maximum vibration frequency of 500Hz. The vibration is relatively light but the position of the vibrators on the back of the phone provides a good haptic sensation to the fingertips. The amplitude of the vibration is fixed but can be manipulated using primitive Pulse Width Modulation. The primitive nature of the PWM is that its resolution is frequency dependant. For example, at 500HZ, no PWM is possible; at 250Hz only 3 PWM variations are possible.

The haptic feedback is therefore quite simple; a 10ms "on" signal is sent to the vibrator at the event of a string pluck. As the GUI and the input and haptic systems are all running on the Smartphone, there is no noticeable latency in the visual-haptic domain.

2.3 Conclusion

The Guitar Simulator has a lot of potential as a haptic instrument. Although not formally evaluated yet, informal tests with several Android users showed that even the simple level of haptic interaction in the current iteration provides an enjoyable sensation, congruent with the visual and audio aspects.

A possible venue for formal experimentation could be to assess the role of haptic feedback in enhancing realism and quality of the simulation.

The current system can serve as a platform for both exploring haptic feedback in hand-held musical instrument simulations and for computer assisted composition.

The next iteration of this work is to rewrite the audio code for an Android compatible system and integrate it into the application. Using the Karplus-Strong algorithm also facilitates the ability to render more detailed feedback. The interaction between the finger and an already vibrating string would add to the realism of the simulation and allow the user to dampen strings and play more expressively. The random chord change is not musically useful. A system to create dynamic chord progressions would also add interest for the player and the GUI could be updated to show the last 4 chords so a player may remember a favoured progression.

One interesting avenue of research could be to add decaying vibrations to the string, summing these then using PWM to create the composite decay in the haptic domain. As it stands, the limitations of the data permitted to be sent to the vibrators provide so simple way to execute composite events.

The current multi-touch implementation in Processing for Android is at the beta stage and somewhat unreliable. Allowing multi-touch interactions would provide a more complex and interesting user experience, as well as a closer analogue to the real-world input method.

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Supraliminal Vibrotactile Stimulation does not Facilitate Visual Vection

George H. Van Doorn
Monash University
Northways Road, Churchill
Victoria, 3842, Australia
+61 (03) 5122 6746
george.vandoorn@monash.edu

Takeharu Seno
Kyushu University
4-9-1 Shiobaru Minami-ku
Fukuoka 815-8540
+81 (80) 3538 8374
seno@design.kyushu-u.ac.jp

Mark Symmons
Monash University
Northways Road, Churchill
Victoria, 3842, Australia
+61 (03) 5122 6747
mark.symmons@monash.edu

ABSTRACT

The effect of supraliminal vibrotactile stimuli on the strength of vection (i.e., illusory self-motion) was assessed. An experiment showed that forward vection was weaker than backward vection, but vibrotactile stimuli (i.e., horizontal bar patterns simulating radial motion towards or away from the body) had no influence on vection. Others have examined illusory self-motion and vibrotactile stimuli, but not in a manner that pairs supraliminal vibrotactile stimuli with visual vection stimuli.

Categories and Subject Descriptors

A.0 [**General Literature**]: General – *conference proceedings.*

General Terms

Performance, Experimentation, Human Factors.

Keywords

Vection, Vision, Haptics, Sensory Integration.

1. INTRODUCTION

When viewing a field of dots continuously radiating from a central point, the dots seem to travel towards the observer. If the screen accounts for most, or all, of the observer's visual field an illusory sensation of moving forward is often experienced. The reverse is also true – when the dots converge from the periphery to a central point the observer may feel as though they are moving backwards. This effect is called vection [1]. The visual vection effect can be enhanced with the addition of consistently acting stimuli in other sensory modalities [2]. Seno, Ogawa, Ito and Sunaga [3] reported that blowing air into a stationary observer's face enhanced 'forward' visual vection. Väljamäe, Larsson, Västfjäll and Kleiner [4] and Riecke, Feuereissen and Rieser [5] have demonstrated that vibratory stimulation enhanced auditorily-induced illusory self-motion.

The aim here was to investigate whether visual vection is modulated by vibrotactile stimuli applied to the fingertip. Consistent with Seno et al's [3] findings, we hypothesis that the illusory sensation of movement will be enhanced when the vibrotactile stimulus is consistent with the visual stimulus: an expanding field of visible dots paired with a vibration "travelling" distal to proximal on the prone fingerpad, and converging field of visible dots paired with proximal to distal vibration, rather than the alternative, inconsistent combinations.

Interestingly, moving one's arm from a distal to proximal position in front of oneself has become equated to gravitational-vertical movements from high-to-low, with both signaling "down" [6]. As such, it may be that vibrotactile stimuli simulating movement towards (away from) the body correspond with downward (upward) moving visual stimuli. As a supplementary hypothesis, we propose that the illusory sensation of movement will be enhanced when a downward moving grating is paired with a vibration "travelling" distal to proximal on the prone fingerpad, and an upward moving grating is paired with proximal to distal vibration, rather than the alternative, inconsistent combinations.

2. METHOD

2.1 Participants

Thirteen volunteers aged 20 to 56 years (M = 32.5 years, SD = 10.1 years) with no reported visual or vestibular abnormalities participated. The experiment had Monash University Human Research Ethics Committee approval.

2.2 Stimuli

The up/down visual stimulus was a white vertical sinusoidal grating whose luminance was horizontally modulated. Motion displays subtended a visual area of 72° (horizontal) x 57° (vertical) when viewed from 57cm in front of a 50-inch plasma television screen (Sony; pixel resolution, 1068 x 768; refresh rate, 60 Hz). Upwards or downwards vection was induced by moving the grating stimulus (spatial frequency: 0.3 cycle/deg; mean luminance: 18 cd/m^2; Michelson contrast: 80%) down or up respectively (i.e., the perceived vection-induced movement is in the opposite direction to the movement of the grating), at a speed of ~20 deg/sec. The grating moved in only one direction for the duration of each trial, which was fixed at 30 sec for all conditions. The stimuli were presented in a darkened room.

Participants were also presented with a separate set of visual stimuli. These stimuli were radially expanding and converging optic flow patterns that generated forward and backward vection. The mean luminance of the background and the dots were 0.0 cd/m^2 and 40.4 cd/m^2, respectively. These motion displays were created by positioning 16,000 dots at random inside a simulated cube (length 20 m) and adjusting the observer's viewpoint to simulate self-motion of 16 m/s. As dots disappeared off the edge (or into the middle) of the screen they were replaced at the far (or near) depth plane, creating an endless visual motion display. Approximately 1,240 dots were presented in each frame, and each dot subtended a visual angle of 0.03-0.05^{o}.

Vibrotactile stimuli (i.e., horizontal bar patterns) were presented via an OPtical to TActile CONverter (Optacon; see Figure 1a) and appeared to move either towards or away from the body. The speed of simulated vibrotactile motion was fixed at ~2 cm per sec. The time interval between vibrotactile bars was standardized at 1 sec.
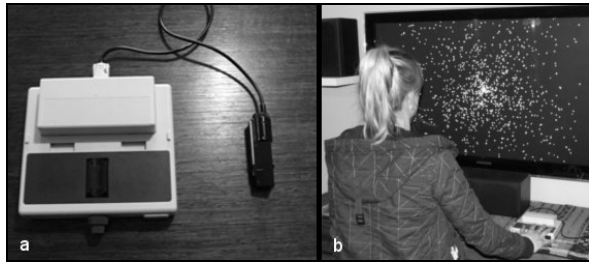

Figure 1. (a) The Optacon. (b) The experimental set-up including the expanding stimuli and Optacon (bottom-right).

2.3 Procedure

Each participant's right index finger rested on the vibrator pad of an Optacon, which was situated on top of a table in front of each participant (see Figure 1b). When a visual stimulus was presented with a vibrotactile stimulus the latter was swept across the fingerpad via the Optacon for ~5 sec before the field of dots was presented. In the no-tactile conditions participants observed the visual stimuli while their finger rested on the "silent" Optacon. All combinations of stimuli were employed (see Table 1) and the presentation order of trials was randomized. A 30 sec rest period was inserted between trials, which could be extended as necessary to avoid motion sickness.

Table 1. The stimulus pairs produced by combining three types of vibrotactile stimulation and four types of visual stimuli

| | | Vibrotactile | | |
		Moving towards body	Moving away from body	None
	Upward moving grating	X	X	X
Visual	Downward moving grating	X	X	X
	Expanding dots	X	X	X
	Converging dots	X	X	X

Participants were instructed to press a button when they perceived vection and again if vection ceased, or became ambiguous. The duration and latency of vection were recorded as dependent variables. Latency was defined as the time interval between the onset of the stimulus presentation and the time at which the subject first pressed the button, which indicated that they were experiencing illusory self-motion. Duration was calculated as the total time between the first and second button presses. After the presentation of each visual stimulus or visual-vibrotactile stimulus combination, participants rated the strength of illusory movement on a scale from 0 (no vection) to 100 (very strong vection).

3. RESULTS

The data from one participant were removed prior to the analysis because this person did not experience an illusion in any condition. A 3 (vibrotactile stimulation: moving towards the body vs. moving away from the body vs. none) x 4 (visual stimulus: upward moving vs. downward moving vs. expanding vs. converging) repeated-measures ANOVA on subjective ratings of vection strength was conducted (see Table 2). As the assumption of sphericity was not met for either the vibrotactile stimulation (Mauchley's $w = 0.51$, $p = .02$, $df = 2$) or vection type variables (Mauchley's $w = 0.24$, $p = .01$, $df = 5$), Greenhouse-Geisser corrections were used. Bonferroni-corrected post-hocs revealed a significant difference between the expanding and converging conditions ($p < .05$). No other comparisons were significant.

Table 2. ANOVA for the estimated strength of vection

Variables	df	F	η^2	p
Vection	1.74 (20.93)	5.32	.31	.02
Vibrotactile	1.34 (16.10)	.14	.01	.79
Interaction	6 (72)	1.39	.10	.23

A second 3 (vibrotactile stimulation) x 4 (visual stimulus) repeated-measures ANOVA on the onset times of vection was conducted (see Table 3). As the assumption of sphericity was not met for the interaction (Mauchley's $w = 0.02$, $p = .01$, $df = 20$), Greenhouse-Geisser corrections were used. Post-hocs revealed a significant difference between the expanding and converging dot conditions ($p < 0.05$) with the onset of vection being significantly shorter in the converging condition than in the expanding condition. No other post-hocs achieved significance.

Table 3. ANOVA results for the onset time of vection

Variables	df	F	η^2	p
Vection	3 (36)	4.44	.27	.01
Vibrotactile	2 (24)	.75	.06	.48
Interaction	2.75 (32.95)	.97	.08	.41

A third 3 (vibrotactile stimulation) x 4 (visual stimulus) repeated-measures ANOVA on the duration of vection was conducted (see Table 4). As the assumption of sphericity was not met for the vection type (Mauchley's $w = 0.25$, $p = .01$, $df = 5$) or vibrotactile stimulation factors (Mauchley's $w = 0.49$, $p = 0.2$, $df = 2$), or the interaction between these factors (Mauchley's $w = 0.04$, $p = .04$, $df = 20$), Greenhouse-Geisser corrections were used. Post-hocs revealed a significant difference between the expanding and converging dot conditions ($p < 0.05$), with the duration of vection being significantly shorter in the expanding, relative to the converging, condition. No other post-hocs achieved significance.

Table 4. ANOVA results for the duration of vection

Variables	df	F	η²	p
Vection	1.66 (19.96)	4.73	.28	.03
Vibrotactile	1.33 (15.93)	1.26	.10	.29
Interaction	3.24 (38.86)	.69	.05	.57

4. DISCUSSION

The fact that the interactions failed to reach significance is at odds with our hypothesis. For example, an expanding visual stimulus (i.e., dots appearing to move towards the participant) paired with vibrotactile stimuli simulating radial motion towards the body did not generate stronger forward vection than an inconsistent pair. As such, we propose that vibrotactile stimuli presented on the fingertip and simulating motion towards (or away from) the body have no influence on the perceived strength of forward (or backward) vection. Consistent with previous research [7], vection was perceived as being stronger in the converging than the expanding condition; this is a reasonably standard finding.

It is possible for information from other senses to generate dramatic changes in perceived vection [3], but findings are not always unequivocal. For example, Kim and Palmisano [8] found that vection was enhanced when head movements were incorporated into visual displays. But there was little difference between consistent and inconsistent conditions. Our findings are somewhat similar to the Kim and Palmisano's [8] general findings, i.e., vection was observed but was not systematically modulated by consistent or inconsistent input from another modality. The interplay between sensory inputs is complex and further studies are required.

Although vection was not modulated by vibrotactile stimuli simulating movement in a direction consistent with that of the visual stimuli, some of the results are consistent with those found in Seno's previous work (i.e., the average vection latency, duration, and magnitude were 12.25 sec, 21.98 sec, and 38.74 sec, respectively), which helps to confirm the validity of the vection measures. It is possible that our design was not sensitive enough to capture the effect, if one exists. Although speculative, the findings may be related to the work of Riecke et al. [5] who showed that the possibility of actual self-motion facilitates vection; in their experiment auditory circular vection was enhanced by suspending participants above the ground. In our experiment, participants' feet touched solid ground and they rested their hand on a table. Perhaps these actions served as information indicating stationarity and, consequently, decreased the influence of vibrotactile stimuli simulating motion (see [5] for a similar argument).

The absence of significant effects here is not meant to imply that supraliminal vibrotactile information will not facilitate vection under different circumstances. For example, Väljamäe et al. [4] showed that vibrotactile stimuli intensified auditorily-induced vection.

In conclusion, we have shown that visual vection is not modulated by supraliminal vibrotactile stimuli simulating motion (across a fingertip) in a direction consistent with that of the visual stimuli. Although vection was observed, the tactile stimuli used here did not enhance illusory self-motion.

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The Inability of Supraliminal Tactile Stimuli to Influence Illusory Self-Motion

George H. Van Doorn
Monash University
Northways Road, Churchill
Victoria, 3842, Australia
+61 (03) 5122 6746
george.vandoorn@monash.edu

Takeharu Seno
Kyushu University
4-9-1 Shiobaru Minami-ku
Fukuoka 815-8540
+81 (80) 3538 8374
seno@design.kyushu-u.ac.jp

Mark Symmons
Monash University
Northways Road, Churchill
Victoria, 3842, Australia
+61 (03) 5122 6747
mark.symmons@monash.edu

ABSTRACT
The effect of supraliminal tactile stimuli on illusory self-motion (i.e., vection) was assessed. An experiment showed that forward vection was weaker than upward, downward and backward vection. However, tactile stimuli (e.g., the tip of a rod moved up the body) had no influence on perceived vection.

Categories and Subject Descriptors
A.0 [**General Literature**]: General – *conference proceedings.*

General Terms
Performance, Experimentation, Human Factors.

Keywords
Vection, Vision, Haptics, Touch, Sensory Integration.

1. INTRODUCTION
Stationary observers often experience illusory self-motion (i.e., vection) when they are exposed to patterns of apparently moving objects in the visual field [1]. Vection can be enhanced by stimuli from one (or more) of the non-visual senses if that input is consistent with the visual stimuli [2]. For example, Ash, Palmisano and Kim [3] reported that head movements consistent with visual stimuli facilitated vection.

Research on the influence of haptic stimuli on illusory self-motion is limited. Seno, Ogawa, Ito and Sunaga [4] have shown that somatosensory stimulation (generated by adding air-flow to a stationary observer's face) enhanced the vection induced by optic flow, while Väljamäe, Larsson, Västfjäll and Kleiner [5] found that vibrotactile stimuli intensified auditorily-induced vection. Riecke, Feuereissen and Rieser [6] had subjects sit in a hammock with their feet either touching the ground or suspended above it. During these conditions participants heard two sounds rotating synchronously around them; the vection-inducing stimuli. On half of the trials barely noticeable vibrations were also applied. Reicke et al. [6] demonstrated that the vibrations enhanced vection.

Our aim was to investigate whether visual vection is modulated by supraliminal tactile stimuli. We hypothesised that when the direction of movement of the tactile stimulus was consistent with the paired visual stimulus the effect of vection would be stronger than when the movement was in the opposite direction.

2. METHOD
2.1 Participants
Eleven volunteers aged 20 to 56 years ($M = 31.5$ years, $SD = 8.8$ years) with no reported visual or vestibular abnormalities participated. The experiment had Ethics Committee approval.

2.2 Stimuli
The up/down vection stimulus was a white vertical sinusoidal grating whose luminance was horizontally modulated. Motion displays subtended a visual area of 72° (horizontal) x 57° (vertical) when viewed from 57cm in front of a 50-inch plasma television screen (Sony; pixel resolution, 1068 x 768; refresh rate, 60 Hz). Upwards or downwards vection was induced by moving the grating stimulus (spatial frequency: 0.3 cycle/deg; mean luminance: 18 cd/m^2; Michelson contrast: 80%) down or up respectively (i.e., the perceived vection-induced movement is in the opposite direction to the movement of the grating), at a speed of ~20 deg/sec. The gratings moved in only one direction for the duration of each trial, which was fixed at 30 sec for all conditions. The stimuli were presented in a darkened room.

Participants were also presented with a separate set of visual stimuli. These stimuli were radially expanding and converging optic flow patterns to generate forward and backward vection. The mean luminance of the background and the dots were 0.0 cd/m^2 and 40.4 cd/m^2, respectively. These motion displays were created by positioning 16,000 dots at random inside a simulated cube (length 20 m), and adjusting the observer's viewpoint to simulate self-motion of 16 m/s. As dots disappeared off the edge (or into the middle) of the screen they were replaced at the far (or near) depth plane, creating an endless visual motion display. Approximately 1,240 dots were presented in each frame, and each dot subtended a visual angle of 0.03-0.05°.

We used a short rod to present the tactile stimuli, which were repetitive strokes along the sagittal plane from either the lower back to the shoulders or vice versa. Participants wore a t-shirt in all conditions and the same experimenter ran each participant through the experiment. The time interval between strokes was standardized at 1 sec.

2.3 Procedure
A visual stimulus was presented with or without a tactile stimulus. In the with-tactile conditions, the experimenter slid a rod along each participant's back from high-to-low or low-to-high. Each person received one full stroke in a manner consistent with the condition they were about to experience prior to being presented with the vection stimuli (e.g., in the upward vection/upward

tactile condition they received a tactile stimulus moving up their back prior to the presentation of visual stimuli). We carefully matched the total number (i.e., 18), length (i.e., 40 cm) and speed of the strokes. The speed of the strokes was approximately equal to the speed of the vection stimulus. In the no-tactile conditions participants observed the visual stimuli without any tactile stimulation. Each participant kept their hands by their sides (see Figure 1).

Figure 1. The experimental set-up showing grating stimulus and rod touching the participant's back.

There were three tactile stimulation conditions (i.e., stimulus moving up the back, stimulus moving down the back, and a no tactile stimulation condition) and four types of visual stimuli (i.e., upward moving grating, downward moving grating, expanding dots, and converging dots). All combinations of stimuli were employed and the presentation order of trials was randomized. There was a 30 sec rest period between trials, which could be extended as necessary to avoid motion sickness.

Subjects were instructed to press a hand-held button when they perceived vection to be present and again if vection ceased, or became ambiguous. Duration and latency of vection were recorded as dependent variables. Latency was defined as the time interval between the onset of the stimulus presentation and the time at which the button was first pressed, which indicated that the participant was experiencing illusory self-motion. Duration was calculated as the total time between the first and second button presses. After the presentation of each visual stimulus or visual-tactile stimulus combination, observers rated the strength of vection on a scale from 0 (no vection) to 100 (very strong vection).

3. RESULTS

The data from two participants were removed prior to the analysis because they did not experience an illusion in any condition. A 3 (tactile stimulation: up the body vs. down the body vs. none) x 4 (visual stimulus: upward moving vs. downward moving vs. expanding vs. converging) repeated-measures ANOVA on subjective ratings of vection strength revealed a non-significant main effect of tactile stimulation [$F(2,20) = 1.43$, $p = .26$]. The main effect of the visual stimulus factor was significant [$F(3,30) = 3.99$, $p = .02$], with a small effect size ($\eta^2 = .29$). Post-hoc tests revealed that vection was rated as significantly weaker in the expanding dots condition relative to the other three conditions (p

$< .05$). No other comparisons were significant (see Figure 2). The interaction was not significant [$F(6,60) = .65$, $p = .69$].
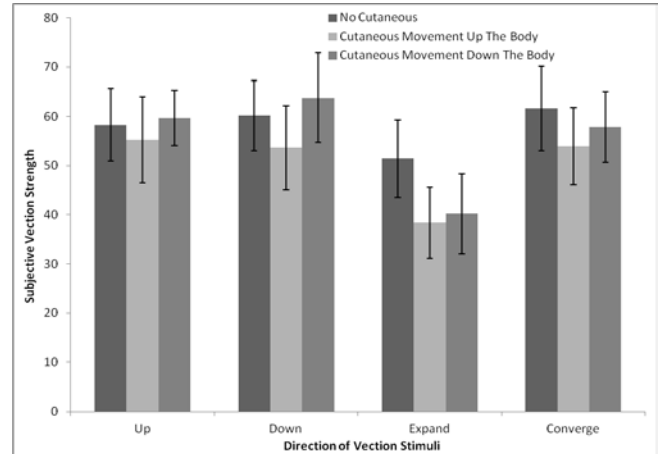
Figure 2. Estimated strength of vection across conditions. Error bars ($\pm$ 1 SE) are shown.

A second 3 (tactile stimulation) x 4 (visual stimulus) repeated-measures ANOVA on the onset times of illusory self-motion was conducted. As the assumption of sphericity was not met for the tactile stimulation (Mauchley's $w = .50$, $p = .04$, $df = 2$) or the visual stimulus factors (Mauchley's $w = .22$, $p = .02$, $df = 5$), Greenhouse-Geisser corrections were used. The ANOVA revealed a significant main effect of visual stimulus [$F(1.63,16.27) = 5.44$, $p = .02$], with a moderate effect size ($\eta^2 = .35$). Post-hocs revealed a significant difference between the expanding and converging conditions ($p < .05$), and the expanding dots condition and the downward grating condition ($p < 0.05$). The onset of illusory self-motion was significantly shorter in the converging and downward conditions than in the expanding condition (see Figure 3). No other post-hocs achieved significance. Neither the main effect of tactile stimulation [$F(1.33,13.29) = .69$, $p = .46$] nor the interaction achieved significance [$F(6,60) = .30$, $p = .94$].
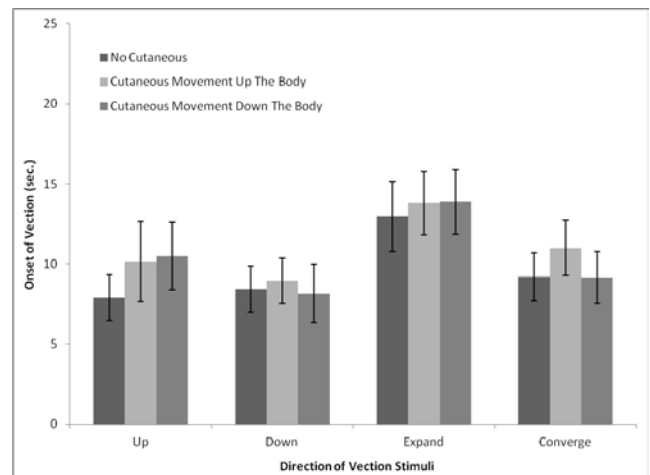

Figure 3. Onset time of illusory self-motion across conditions. Error bars ($\pm$ 1 SE) are shown.

A third 3 (tactile stimulation) x 4 (visual stimulus) repeated-measures ANOVA on the duration of illusory self-motion was conducted. As the assumption of sphericity was not met for the tactile stimulation factor (Mauchley's $w = .49$, $p = .04$, $df = 2$),

Greenhouse-Geisser corrections were used. The ANOVA revealed a significant main effect of visual stimulus [$F(3,306) = 10.61$, $p < .001$], with a moderate effect size ($\eta^2 = .52$). Bonferonni-corrected post-hocs revealed a significant difference between the expanding and upward conditions ($p < .05$), and the expanding and downward conditions ($p < .05$). The duration of vection was significantly shorter in the expanding condition relative to the others (see Figure 4). The main effect of tactile stimulation [$F(1.33,13.28) = .73$, $p = .45$] and the interaction failed to reach significance [$F(6,60) = .39$, $p = .88$].
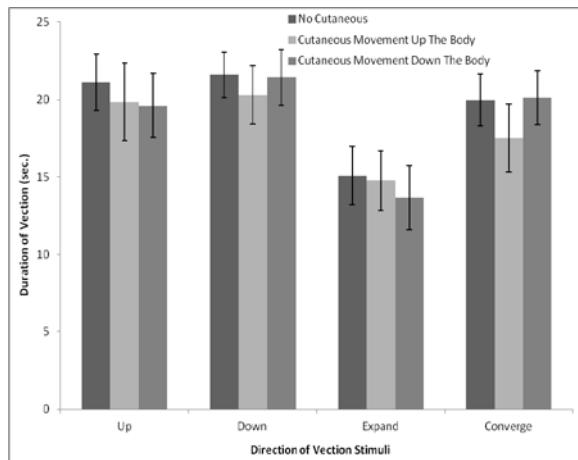
Figure 4. Duration of vection across conditions. Error bars ($\pm$ 1 SE) are shown.

4. DISCUSSION

The interactions failed to reach significance. For example, an upward-moving visual stimulus paired with tactile stimuli simulating upward motion did not generate stronger downward vection than an inconsistent pair. This is at odds with our hypothesis and, as such, we propose that supraliminal tactile stimuli simulating motion across a participant's back do not modulate vection. Consistent with previous research [7], vection was perceived as being stronger in the converging than the expanding condition.

We know that information from other senses can generate dramatic changes to perceived vection [4], but findings are not always unequivocal. For example, Kim and Palmisano [8,9] found that consistent stimuli did not enhance vection. Specifically, they found that the perceived strength and speed of vection was greater when viewpoint jitter was introduced, regardless of whether this jitter was generated actively (i.e., via head oscillation) or passively. Kim and Palmisano [9] found that the strength and onset of vection were greater when head movements were incorporated into visual displays. However, there was little difference between minimal and high sensory conflict conditions. Our findings are somewhat similar to the general outcomes of these experiments, i.e., vection was observed but was not systematically modulated by consistent or inconsistent input from another modality.

Although speculative, it is possible that cutaneous and visual stimuli were presented asynchronously. As such, they may not have been coordinated into a single cue (i.e., the *assumption of unity* was violated); when this occurs the more likely it is that one stimulus will be attended over the other. This may help explain the inability of the tactile stimuli used here to influence visual vection.

The absence of significant effects is not meant to imply that all supraliminal tactile information will fail to facilitate vection. Earlier, we cited Seno et al. [4] who showed that air blown onto the face of a participant enhanced vection. This is also 'supraliminal' tactile information, and there are good reasons as to why it contributes to vection. Not only is airflow more ecological (i.e., it is often experienced during self-motion) but it is more global than the stimulation used in the present experiment; the tip of a rod activates relatively few tactile receptors.

In conclusion, the experiment failed to support the idea that vection is modulated by supraliminal tactile stimuli simulating movement in a direction consistent with that of the visual stimuli. Although vection was observed, the tactile stimuli used here did not enhance illusory self-motion.

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Development of Tactile Navigational Patterns

Christos Giachritsis
BMT Group Ltd
Goodrich House
1 Waldegrave Road
Teddington, Middlesex
TW11 8LZ, UK
cgiachritsis@bmtmail.com

Gary Randall
BMT Group Ltd
Goodrich House
1 Waldegrave Road
Teddington, Middlesex
TW11 8LZ, UK
grandall@bmtmail.com

Samuel Roselier
CEA, LIST
18 Route du Panorama
92265 Fontenay-aux-Roses CEDEX
France
samuel.roselier@gmail.com

ABSTRACT

In this paper, we describe a method for developing intuitive navigation patterns representing basic *directions*, *landmarks* and *actions*. A group of users familiarize themselves with the ViFlex device. Then half of them were asked to use the device to create navigational patterns and the other half to identify them. Simple *directions* were easier to identify than *landmarks* or *actions*. The identification of *landmarks* or *actions* improved when information about their meaning was available.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: user Interfaces – *Evaluation/Methodology, Haptic I/O.*

General Terms

Measurement, Performance, Design, Experimentation, Human Factors.

Keywords

Navigation, Vibrotactile, Mobile.

1. INTRODUCTION

Recent research in tactile navigation has investigated the use of vibrotactile signals on smart phones (directly or through another device), wearable devices and steering wheels [1-5]. Most of the designs use navigational patterns defined by the developer and require the user to learn these patterns before being able to use them. Here, we report a method of developing intuitive navigational patterns representing basic *directions*, *landmarks* and *actions*. We asked a group of users familiar with the device to define the patterns using the device. The patterns were edited for clarity and arranged in series representing navigation from a starting point to a destination point. Then they were presented for identification to another group of users also familiar with the device. These users were asked to identify the patterns with and without any information about their meaning.

2. THE STUDY

2.1 The ViFlex Device

The ViFlex device uses an electromagnetic actuator to rotate a mobile platform with an octagon shape and area of 45x45 mm^2. The platform can rotate around its two cardinal XY axes and their intermediate axes by magnitude of ±10° (Figure 1, left). Thus, through rotation the platform could signal eight different directions/positions. The device is capable of fast rotations up to 200°s^{-1} and can achieve a torque of 20 Nmm. More detailed description of the technical characteristics of ViFlex can be found in [6].

Figure 1. The Viflex device with its octagonal platform (left). The device with its battery extension handle can be used with one (middle) or two (right) fingers.

The ViFlex device can be used with one (index) or two (index and middle) fingers (Figure 1, middle and right). By employing only one finger the device will primarily engage the cutaneous system to deliver vibrotactile signals at different locations of the finger pad. When the user employs two fingers positioned at the edges of the X-axis, the device will primarily engage the proprioceptive system at the metacarpal-phalangeal joints when rotating about the Y-axis and the cutaneous system when rotating about the X-axis.

2.2 Developing Intuitive Navigational Patterns

The purpose of the experiment was to find out if it is possible to generate intuitive navigational patterns based on patterns defined by users experience with the functionalities of a device. Seven female and four male (average age of 30) with no sensory impairment took part in the study. Eight of them had previously taken part in the previous study to establish the spatiotemporal thresholds. The rest of the participants familiarized themselves with the functionality of ViFlex before asked to carry out the required navigational tasks.
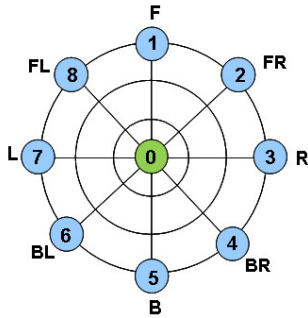
2.2.1 Types of Navigational Patterns

Three types of navigational patterns were used: directions, landmarks, and actions. Table 1 shows the navigational patterns used with their abbreviations.

Table 1. The three types of navigational patterns used in the study.

Directions	Landmarks	Actions
Forward (F)	Roundabout (RA)	GO
Backward (B)	Crossroad (CR)	STOP
Right (R)	T-Junction (TJ)	Destination Reached (DR)
Left (L)	Y-Junction (YJ)	
Forward-Right (FR)	Uphill (UH)	
Forward-Left (FL)	Downhill (DH)	
Backward-Right (BR)	Stairs-Up (SU)	
Backward-Left (BL)	Stairs-Down (SD)	
Clockwise 180° (CW180)	Obstacle (O)	
Anti-Clockwise 180° (ACW180)		

Similar patterns are commonly used in navigational tasks [7-9] and some of them were previously used in a preliminary ViFlex study [10]. The study included two stages. In the first stage, five users were asked to *create* patterns and in the second stage, the remaining six users were asked to *identify* the patterns created based on the description in the first stage.

Figure 2. The circular grid used to record users responses when they were asked to indicate how the platform should move to represent a particular pattern.

2.3.1 Creating Navigational Patterns

Directional and landmarks patterns were created by the users as follows. The users were presented with the ViFlex device and a pattern, which was verbally communicated by the experimenter. Then, they were asked to move the platform in any direction that they thought it could be used to represent the specific pattern. Their responses (i.e., movement of the platform) were recorded on a circular grid representing the eight different directions/positions of the platform (Figure 2).

2.3.1.1 Results

Table 2 shows the position sequences that users indicated to represent *directional* patterns. Simple directions in the cardinal and intermediate axes were unanimously indicated. *Directional* patterns with multiple positions such as CW180 and ACW180 were indicated as semi-circular patterns by four out of five users.

Table 2. *Directional* patterns indicated by the users. A final pattern was created to be identified in the next stage.

User	F	B	L	R	FR	FL	BR	BL	CW180	ACW180
1	01	05	07	03	02	08	04	06	056781	054321
2	01	05	07	03	02	08	04	06	056781	054321
3	01	05	07	03	02	08	04	06	056781	054321
4	01	05	07	03	02	08	04	06	012345	018765
5	01	05	07	03	02	08	04	06	0812	0218
Final	010	050	070	030	020	080	040	060	0567810	0543210

Table 3 shows the position sequences that users indicated to represent *landmarks*. In general, users agreed as to the structure of the pattern but the position sequences they used were more variable.

Table 3. *Landmarks* patterns indicated by the users and the final pattern that was created to be identified in the next stage.

User	RA	CR	TJ	YJ	UH
1	0567812345	015037	07305	080205	0555
2	0187654321	015037	05073	050802	0111
3	0543218765	015037	03705	050208	0555
4	0543218765	051073	03705	02070	0555
5	0567812345	026084	07305	050802	0555
Final	0567812340	0150370	037050	0508020	05550

User	DH	SU	SD	O
1	0111	055005500550	011001100110	0151515
2	0555	011001100110	055005500550	05555
3	0111	011001100110	055005500550	05555
4	0111	05050	01010	0515151
5	0111	055005500550	011001100110	05050
Final	01110	055005500550	011001100110	03737370

The final patterns that would be used for identification in the next stage were created on the basis of the most dominant positions indicated by the users. The exception is the final pattern for O. Since positions 0, 1 and 5 were used to represent UH, DH, SU and SD, we decided to use positions 3 and 7 to avoid mapping too many navigational patterns to the same platform positions. *Directions* and *landmarks* were implemented by rotating the

platform by 10° (users could reliably perceive this magnitude) towards the corresponding position. The *action* patterns were pre-defined by the experimenter as follows: GO=01010 [normal speed rotations of 9°], STOP=050505050 [fast rotations of 9°], DR=0370150 [fast rotations of 3°]. The navigational patterns were developed using >3° rotations and shorter than 1250ms transition times. Users were also instructed to use their index finger to perceive the navigational patterns.

2.3.2 Identifying Navigational Patterns

Six users were asked to navigate from a starting point to a destination using two series of 45 patterns. Series A was provided without pattern information while Series B was accompanied with information about the meaning of the patterns. Both series started with GO and ended with DR and included exactly the same navigational patterns with the same presentation frequency but, different presentation order. For example, Series A was GO-F-L-R…CW-L-DR and Series B was GO-L-F-STOP…L-R-DR. The patterns in both sequences were presented to the users one at a time and the users were asked to identify the current pattern before the next pattern was presented. There was no visual representation of the patterns. When users were uncertain about the meaning of a pattern the pattern was repeated as many times as it was necessary to obtain an interpretation. If an interpretation or identification was not possible then a 'Do not know' response was recorded.

All users were right handed and used the index of their right hand to perceive the navigational patterns. Also, they navigated through series A and B only once while the order of presentation was always A-B so that all users experienced exactly the same sequence of patterns in the same order.

2.3.2.1 Results

In the 'no information' condition, users found it easier to identify and interpret *directional* patterns rather than *landmarks* and *actions*. Single point *directional patterns* (e.g., F, R, L, FL, FR) were easier to identify than multipoint *directional* patterns. *Landmarks* and *actions* resulted in more variable interpretations. This may be because they involved more complex spatiotemporal signals and, sometimes, similar positions/directions. Performance with both series was measured in terms of overall proportion correct and proportion correct per pattern.
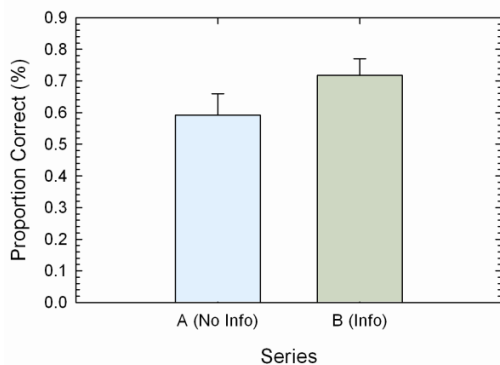
Figure 3. Overall performance with Series A and B. Error bars represent constant errors.

Overall performance was improved from 59% without any information about the meaning of the patterns (Series A), to 72% with information available (Series B) (Figure 3). However, a T-

test showed that this improvement was not statistically significant. Single-point *directional* patterns (i.e., F, L, FR, FL) resulted in highly accurate interpretation in Series A and identification with Series B. Multipoint *directional* patterns (i.e., CW180 and ACW180) resulted in less accurate interpretations with Sequence A but, with Sequence B, resulted in over 80% identification accuracy. *Landmarks* resulted in less accurate interpretation than *directions* in Series A. In principle, it seemed easier to interpret *landmarks* involving different points, such as CR and TJ, rather than *landmarks* involving similar points and movements, such as UH, DH, SU, SD and O. Identification of *landmarks* improved in Series B. In particular, all junction-*landmarks* (i.e., CR, TJ and YJ) were identified with an accuracy of > 80%. The identification of the rest of the *landmarks* also improved. *Actions* were the patterns that resulted in the least noticeable changes of interpretation and identification accuracy between Series A and B. While there was some improvement with the patterns GO and STOP, the accuracy with the DR pattern did not change (Figure 4). However, it should be noted that the GO and STOP patterns were the most frequently occurred patterns in both sequences with 10 and 9 appearances, respectively, while the DR pattern appeared only once, in the end.
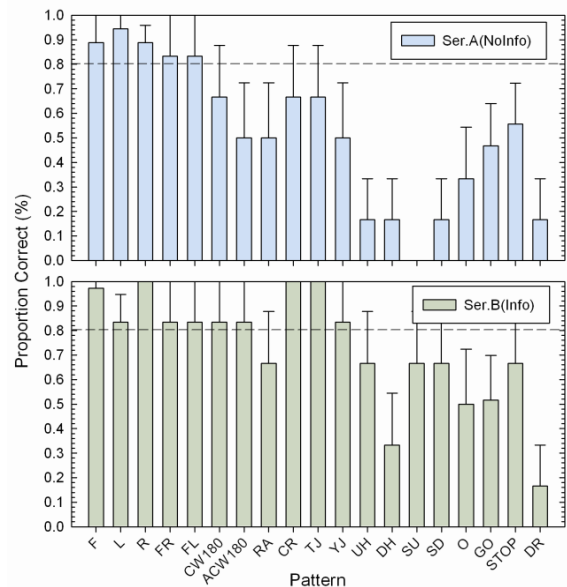
Figure 3. Percentage correct per pattern in Series A and B. Error bars represent constant errors.

3. DISCUSSION

The study showed that users easily interpreted and identified simple, single-point *directional* patterns. Multipoint directional patterns such as CW180 and ACW180 were more difficult to interpret in the absence of any information about the patterns. However, when information was available participants identify them with high accuracy (>80%). One of reason for this result may be that the CW180 and ACW180 could be confused with the *landmark* RA which involved similar pattern of movement of the ViFlex platform. While semicircular (CW180 and ACW180) and circular (RA) movements of the platform could be resolved at a sensory level and therefore perceived accurately by the participants (since they were developed using signals well above threshold), the attributed meaning varied.

In conclusion, the present study has shown that it is possible to develop vibrotactile navigation signals based on users' experience of the functionality of a device. In addition, simple spatiotemporal signals can be interpreted and identified easier than more complex ones. Further research is needed which includes a diverse user group (e.g., pedestrians, drivers, visually-impaired) that can provide insight about how visuo-motor-audio experience during real life navigation can be mapped onto spatiotemporal tactile signals at specific body locations.

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The CORDIS Audio Haptic Real Time Platform
for Musical Creation with Instrumental Interaction

James Leonard
ICA, Grenoble INP,
France
leonard@imag.fr

Nicolas Castagné
ICA, Grenoble INP,
France
castagne@imag.fr

Jean-Loup Florens
ACROE
France
florens@imag.fr

Claude Cadoz
ACROE & ICA
Grenoble INP, France
cadoz@imag.fr

ABSTRACT
In this paper, we describe recent work conducted at ACROE and the ICA laboratory of Grenoble INP on real time audio-haptic interaction with physical models for musical creation. These new developments enable the user to create complex mass-interaction physical models in a high level and user intuitive graphical environment. These models can then be simulated in real time, connected to a high fidelity haptic device, for rich audio-haptic musical interaction with ergotic coupling.

Keywords
Force Feedback, Physical Modeling and Simulation, Mass-Interaction Models, Modeler and Real Time Simulator, Instrumental Multisensory Interaction, Ergotic Interaction, Virtual Musical Instruments.

1. CONTEXT AND OBJECTIVES
Integrating haptic feedback into digital music instruments has become an increasingly popular activity in recent years. One of the main arguments is that haptic feedback can enhance the musician's performance [1] and allows for a more intimate control over the sound produced. Moreover, the energetic exchange, or ergotic function of instrumental interaction, conveys meaning and is a key factor for expressiveness in the sound of a musical instrument [2]. The acoustic outcome of the physical interaction between a musician and an instrument is the result of a continuous and intimate exchange of energy between the two parties.

Haptic devices offer a unique platform for embodied cognition though the dynamic coupling of the user and a virtual entity [3]. Applied within the context of Computer Music, this brings forward a new perspective for interaction with virtual musical instruments [4].

A number of applications augment digital instruments with haptic mechanical models [5] to enhance playing "feel". In some cases the haptic model also produces the sound, whereas in others it is correlated in a less direct form. When the haptic interaction is closely related to the production of sound, instruments such as the bowed string, which are usually difficult to play expressively via standard musical protocols such as MIDI, yield a convincing resemblance to their acoustic counterparts [6]. Indeed, the development of joined haptic / acoustical models in digital musical instruments can restore the ergotic function in an instrumental situation [7] [8].

This paper aims to present a modeling environment for mass-interaction audio / haptic models, and a simulation environment where the user can play these models in an instrumental fashion,

using a haptic device fit for conveying the energetic coherence of the musical gesture's ergotic nature.

This work builds upon two technological components that are presented in sections 2 and 3. Section 4 presents the work achieved for the CORDIS Audio Haptic Real Time Platform.

2. GENESIS MODELING ENVIRONMENT
GENESIS [9] is a physical modeling environment in which users can build elaborate mass-interaction models for musical creation (Fig. 1). The physical models are based on the CORDIS ANIMA [10] formalism. A small number of elementary modules, of two sorts, masses and interactions, can be assembled to form complex models. Being rooted at its lowest level on physical consistency, hence offering dynamics and subtle variations in the generated phenomena, GENESIS is an alternative to signal based top/down control, which is currently dominant in Computer Music.
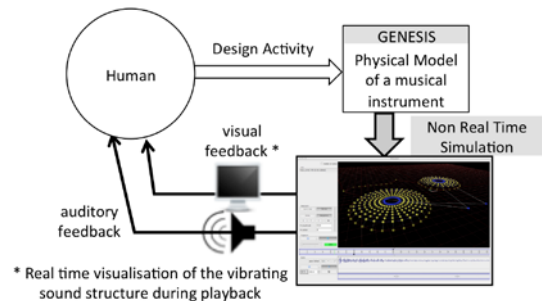
Figure 1. GENESIS design activity and off-line simulation

GENESIS allows for microscopic sound construction as well as macroscopic physical structures for sound control, musical gesture metaphors, and compositional principles. Hence, GENESIS proposes the physical modeling paradigm not only as a tool for sound synthesis, but also as a full support for innovative musical creative processes, including musical composition. A single physical model can encompass, stand for, and generate an entire musical piece such as performed by Claude Cadoz in the artworks pico..TERA [11] and Gaea, composed of tens of thousands of physical interacting components. Figure 2 shows the simulation of such a large GENESIS model.
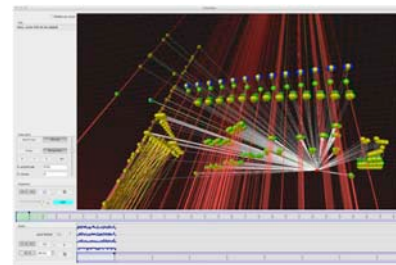
Unfortunately, neither the modeling capabilities of GENESIS or its simulating capabilities are real-time and gesture interaction oriented. From the point of view of GENESIS, the work presented here goes toward the enlargement of its functionalities by integrating real time gestural interactions at the both modeling and the simulation stages.

3. HAPTIC REAL TIME WORKSTATION

The TGR (*transducteur gestuel rétroactif*) haptic device and the ERGON_X [12] simulation platform from ERGOS Technologies[1] developed by ACROE form a high quality haptic simulation workstation. It combines very low latencies in terms of force feedback interaction with high morphological versatility in terms of number of degrees of freedom and end-effectors organizations. The modular slice-based construction of the TGR allows for many degrees of freedom (one to sixteen) and can receive a number of mechanical end effectors, such as one-dimensional keys, 2D or 3D joysticks, 3D pliers, or string bows, allowing adapting to the versatile morphology of instrumental gestures. Figure 4 shows, as an example, the 12 key setup used in the present work.

The ERGON_X platform features the TGR and its electronics, and a "haptic board" [13] connected into a hosting computer. The haptic board function is implemented on a TORO DSP board from Innovative Integration, which hosts ADC/DAC converters and can calculate real time floating point operations. The real time physical simulation runs fully on the haptic board, within a single-sample, synchronous, high frequency computational loop.

Both the haptic feedback and sound are produced from a single physical model based on the CORDIS-ANIMA formalism, computed on the DSP, at a high enough sample rate for audio restitution, typically 44,1kHz, in a single fully synchronous loop.

A wide number of physical real time simulations with haptic interactions [12] have been implemented on this platform, used in physics educative applications as well as in research on audio-haptic interactions and in virtual reality applications. Unfortunately, such a workstation does not yet benefit of modeling capabilities such as those developed in the GENESIS software. Hence, models were developed so far with a one-shot approach by researchers.

4. CORDIS AUDIO-HAPTIC REAL TIME PLATFORM

Bringing the GENESIS environment and the real time haptic simulation environment together proves challenging as their initial standpoints are quite opposed. Three main operations have been undertaken for the development of the first CORDIS Audio Haptic Real Time Platform.

4.1 A modular simulator

The GENESIS environment is primarily focused on physical modeling, with a modular system that gives the user the freedom to build any physical model he wishes. Simulation of the model is then calculated off-line. On the other hand, the real time applications are aimed at obtaining maximum efficiency for the simulation: they are programmed directly in C++ for the DSP, making use of algorithmic and code optimizations for each specific implemented model.

A new, modular, real time CORDIS-ANIMA physical simulation engine has been constructed for DSP applications. Thanks to data structure optimization, and tailoring of CORDIS-ANIMA algorithms for the specificities of the DSP architecture, it is model-independent while retaining similar performance results to model-specific, handwritten C++ code. The user is guaranteed full modeling freedom in GENESIS as well as optimal simulation efficiency in a real time situation.

4.2 Control of the correspondences between real and simulated worlds

We propose a number of processes in order to maintain the physical coherence of the whole interaction / simulation chain, and to provide the user with full and comprehensive control over the different quantitative elements that have to be considered, during the modeling process, in regards to the interaction between the simulation process and the real physical word across the haptic interface device.

The quality of the TGR's dynamics, the synchronous temporal skeleton of the simulation and the complete control of the haptic device/simulation bidirectional chain make it possible to confer precisely known quantitative properties to this interactive simulation system. In particular, this concerns the various relationships between the parameters and physical quantities the user has to consider along the modeling process. This is particularly useful, not only for designing/playing virtual instruments or sound synthesis processes, but also for using the system as an experimental tool for audio or psycho-physic measurements.

Our process includes three steps:

- First, a calibration process allows maintaining the best possible precision for the position and force feedback data at each step of the device/simulation chain.

- Secondly, the user configures the relation between the set of parameters and variable quantities used in the GENESIS model, and those considered in the standard real world, evaluated with standard unit systems.

- The user can then fine tune the interaction with the simulated model in the real world, by adjusting the specific parameters of the haptic interface and simulation system:
  - The position/speed real/simulation conversion gain.
  - The force simulation/real conversion gain.
  - The sampling / simulation time step, usually set at a frequency of 44,1 kHz.

With these 3 steps, the user is able to map GENESIS physical models into the gestural world, and reciprocally - that is to adapt space and impedance [14] independently between gestural and simulated worlds for each TGR key, while guaranteeing quality energetic flow, which is crucial for the instrumental interaction.

### 4.3 The user-friendly software environment

We finally introduce a dedicated friendly graphical Human-Computer Interface for real time simulation of GENESIS models.

First, this environment mediates the concept of relations between the mechanical world and the simulation to the user, who can choose the convenient representation scales and set the parameters

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[1] http://acroe.imag.fr/ergos-technologies

that define the physical interaction between the simulated model and the mechanical world.

Secondly, it lets the user manage the various steps needed to go from the GENESIS model to the actual simulation. In this environment, any model created in GENESIS can be imported directly into the real time environment, where the TGR/Simulation interaction points and mechanical/simulation correspondences can be configured. The model is then interpreted and compiled into a real time DSP application. This offers an extensive modeling environment for creating haptic musical instruments (Fig. 3 and 4).
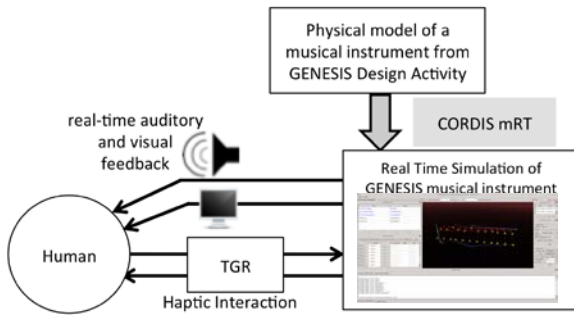
Fig 3. Steps from offline design of physical models in GENESIS to real time simulation with haptic interaction.

5. CONCLUSIONS

This paper presents recent work on audio-haptic interaction with physical models built in the GENESIS environment. The association of high performance haptic devices and an extensive modeling framework allows for complete dynamic coupling between the musician and his virtual instrument. This offers a unique tool for further exploring the influence of the ergotic function in musical gestures, and the relevance of full instrumental audio-haptic interaction in musical creation processes with a digital and/or virtual music instrument. Through this work, we believe to have achieved a prototype of the first modeler/simulator for audio-haptic ergotic interaction designed for musical creation (Fig.4).

Fig 4. The CORDIS Audio Haptic Real Time Platform in use

Examples of musical models created within our new modeler-simulator system include: vibrating strings, which can be struck or plucked, dampened and changed in pitch as with a "fretting hand"; piano-like models, with adjustable key weight/stiffness, with up to 12 keys each connected to hammers that strike vibrating structures tuned to different pitches. More generally, the modeling features of GENESIS and its coupling to the simulator enable easy exploring of a very large range of possibilities. We are able to demonstrate a number of instrumental simulations with models built in GENESIS, to the public, scientists or artists, as well as "on the fly" instrument modeling and real time simulation of the created models.

Future perspectives include support for larger models, by increasing the computational power by means of multi-processor calculation. Another exciting challenge to address is implementing physical data exchanges between several CORDIS Audio Haptic Real Time platform processors at the vibrating structure's simulation rate.

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Tactile feedback in real life sports: a pilot study from cross-country skiing

Stina Nylander & Jakob
Tholander
MobileLife@SICS
Box 1263, 16429 Kista, Sweden
stny@sics.se,
jakobth@dsv.su.se

ABSTRACT

We describe the research challenges of bringing HCI into the domain of sports, and what research in this domain can add to the general questions multi-modality and sensor-based interaction. To illustrate this, we present results from a pilot study on providing tactile feedback to cross-country skiers. Our results show how real-time feedback can be provided for a variety of purposes without disrupting or disturbing the actual sporting experience

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Keywords

Multi-modality, sports interaction, tactile feedback, skiing.

1. INTRODUCTION

At her keynote speech at CHI 2010, Genevieve Bell pointed to sports as one of the domains that have been largely forgotten in Human-Computer Interaction (HCI) research, even though work is starting to emerge. We argue that HCI research in sports could contribute to the general problems involved in how to develop interaction models for a range of complex and variable settings where traditional hand-eye interaction is not sufficient., as well as to current concerns in exploring ways of designing for various kinds of bodily experiences [5,10,11] Sports and physical activity provide challenging examples of such settings, and design principles and interaction techniques are potentially transferrable to other mobile domains, such as social and leisure activities in nature.

Most readily available sports technologies, such as sports watches and GPS-devices, rely on the use of physical and physiological data as indications of measures of *individual performance* and not so much for other dimensions such *personal or social experiences*. We argue that a research on HCI in sports should align with current strands of experientially oriented research [6] by addressing performance in concert with aspects such as flow, rhythm, joy, sociality, and context. This involves a strive to gather and portray physiological and biomechanical measures in a way that opens up the possibilities for interaction by incorporating *user interpretation,* rather than attempting to exactly model people's performances and communicate objective information about the activity. This will allow users to connect performance measures to the particular social and physical context and to the individual's subjective perception of the whole activity.

We claim that an interpretative approach allows us to design interactive technology that users perceive as more robust and trustworthy in the fast paced and dynamically changing situations that sports usually involves. Thereby it reduces the risk of breakdowns in the interaction due to limitations in underlying computational models and provides resources for users to construct a subjective experience that allows them to improve their athletic performance.

To achieve this we need to address three important research areas:

- *multi-modal forms of interface representation* that augments the performance and experience of sports and physical exercise. Critical elements is to allow for interpretative representations, account for combinations of modalities, and how they map to the temporal, spatial, bodily, perceptual, and social aspects of the activity.

- *multi-modal interaction mechanisms* that allow users to interact with technology while still being fully engaged in the experience of the activity in real-life settings, thus leveraging on the sporting activity as an integral part of the interaction, taking advantage of the possibilities offered by light-weight sensors, actuators and mobile devices.

- *data modeling techniques* of physical and physiological data, exploring how data sets from individuals can be meaningfully analyzed in order to be integrated with interaction mechanisms and representations, as well as shared and used in social and collaborative activity.

Here, we will relate this research agenda to the existing literature, and describe preliminary work on interaction mechanisms for sports activities illustrated by results from a pilot study on vibration feedback for cross country skiers. This is the first step for in exploring design for movement and physical activity in sports, as well as how to design for dimensions of optimale performance and personal user experience in concert.

2. RELATED WORK

2.1 Sports Technology

Interactive technology has been used for a long time to enhance athletes' performances in sports. Success in sports at the highest level is a matter of millimeters and milliseconds. Until recently this development has focused on how to optimize performances in sports, while we now start to see approaches that bring in social and leisure oriented perspectives on body metrics and other forms of physical and bodily data. We argue that there is a need to further widen this towards experiential perspectives in the design of light-weight technologies for sports and physical exercise, since these activities involve more than giving feedback to people based on physical and physiological measures. There is a range of different technologies that have successfully taken advantage of the possibilities offered by novel sensor, actuator, and recording technologies. These have contributed to pushing athletes' performance to higher levels as well deeper understandings of how to design for such settings. These technologies range from video analysis tools and advanced motion capture systems for experimental studies of athletes' movement pattern, to pulse-bands (Garmin, etc), mobile applications (Runkeeper), and light-weight sensors worn in shoes or clothing (Nike+) available on the commercial market. Research has developed technologies to support detailed aspects of sports techniques such as running mechanics [2], and balance and weight-transfer in snowboarding [6]. However, most of these have focused on how to improve specific details of the performance and many have been designed for testing and experimentation in laboratory settings. There is still a limited set of technologies that can easily be used in the field. To further expand on this research there is need to design technologies that embrace a larger perspective on performances in sports and physical activity. This is in line with some previous studies of recreational athletes [8,10] that show that the experiential (social, intellectual, emotional, and bodily) side of the performance is a key aspect as to people's engagement in the activity. These are also aspects that are emphasized in sports psychology [4] and flow-theory [1] regarding what creates optimal performance. The notion of flow has also been one of the fundamental dimensions explored in experience oriented design approaches. In most sports technology research performance and flow have been separated, even though athletes and coaches often emphasize exactly this connection [4]. Central research challenges thus include how to design technology that combines performance measures, emphasized in sports technology, with experiential aspects, emphasized in sports psychology.

2.2 Interaction

With the development of inexpensive and accessible sensor-technology we have seen a growing interest in designing interaction based on users' movement. Interaction along this line of research range from gesture-based interaction around stationary devices, multi-touch interaction for mobile screen based interaction, to more open-ended forms of interaction for dance and music making [5,3]. Furthermore, numerous explorations of technology illustrate novel multi-modal approaches for interaction, such as the eMoto pen [9] for bodily emotional expression, or BodyBeats [12] for dance-based music creation. A critical aspect in designing for body and movement is to expand the modalities used for input and output. To design working interaction for people engaged in physical activities such as walking, running, or swimming, we cannot rely on visual or screen based forms of interaction, but need modalities that also engage non-visual senses such as haptics, tactility and audio. Research along these lines have for instance investigated how to provide audio-based feedback to people in movement [2], and the use of tactile feedback in sports and recreational activities such as tactical guidance for soccer players, body posture feedback for speed skaters and cyclists [11], and performance of specific movements in snowboarding [7]. However, much research along these lines has focused on how to design for interaction based on one specific modality such as sound or tactility. To expand this line of work, we need to address challenges on how different modalities could be combined in terms of the temporal, spatial, bodily, perceptual, and social aspects of the activity. Critical aspects that need to be explored include where the feedback should be presented, how to present it, in which modality, and at what time. The combination of these is crucial for the unfolding of the interaction and for the integration in an activity as a whole.

3. PILOT STUDY

As a starting point for exploring how to design interaction for sports activity we conducted a pilot study on vibration feedback with cross country skiers. The aim of this work is to design technology that gives skiers real-time feedback on their skiing technique out in the field.

3.1 Study Setup

The study was carried out at the Swedish Winter Sports Research Centre in Östersund, Sweden. Four Swedish elite skiers participated, recruited by test leaders at the research centre.

The purpose was to explore how vibrational feedback is perceived *during* a sport activity, to what extent it integrates with or disrupt the experience, and how the perception of vibrations are affected by physical activity, and vice versa.

The skiers were equipped with a cell phone strapped around the chest, and skied on a treadmill using different skating techniques at various speeds and inclinations for approximately 30 minutes each.

Different vibration signals were remotely triggered in the phone attached to the skiers' chest. Signals varied in length and repetition. They were all were of the same strength (internal to the phone). Skiers were instructed to acknowledge and comment on the vibrations when they felt them. A post interview was carried out after the skiing session. The whole session was video and audio recorded.

3.2 Preliminary Results

Overall, the skiers were very positive to the idea of vibrational feedback on their skiing technique. They all said they clearly perceived the vibration, and did not describe the experience as intrusive or distracting. Several of them would have preferred a stronger more distinct vibration to make it easier to perceive while focusing on the skiing at higher level of fatigue.

As stated above, the vibration strength did not vary during the session, but the skiers expressed that they had experienced variations in strength. Possible reasons for this could be variations in tension in the upper body as well as variations in focus and concentration in different speeds and techniques, and different levels of fatigue. For instance, one of them said that *you need to be really focused to ski fast, so you block out a lot of stuff.* This suggest that the strength should possibly be increased as skiing intensity increases, but also, that the feedback should not attempt

to involve to much information as it may disturb the focus of the skier, thus, potentially being contra-productive.

The skiers believed that vibration feedback on their skiing technique would be helpful during training sessions. In particular, they foresaw using it during high-intensity sessions where they would be especially focused on maintaining a correct technique despite a high-level of fatigue. Moreover, they reported that the skiing technique in general is more in focus at higher workloads since that is when loss of technique is most costly. Consequently, it would be in these situations that skier would benefit mostly from interactive training support. During slower skiing, the technique is usually less critical so feedback would not be as valuable.

Examples in which they mostly themselves saw the usefulness of real-time feedback were technical details such as the transferring of weight from side to side, keeping the appropriate angles in hips or knees, to help keep specific technique training details in mind, and to be reminded of thinking about technical improvements that they could be working on.

The skiers also saw connections to video analysis, motion capture and other interactive tools that they use to analyze skiing technique. Such tools could be used to reveal important details that need improvement. Combined with real-time feedback mechanisms in the field, these could then be used to prompt skiers to think about those details and keep them constantly in mind during training sessions.

4. FINAL REMARKS

We have presented initial results from a pilot study on the design of real time vibrational feedback in sport activities. Overall, this works targets design of services for movement based and bodily engaging settings in the wild. Our overall conclusion is that well designed real-time feedback can be provided for a variety of purposes without disrupting or disturbing the actual sporting experience. Moreover, even though the feedback we provided were relatively basic, the athletes saw usages that went beyond what we had foreseen when designing the study. This points to the possibility of using simple, easy to use devices when designing for a complex settings and activities.

We are currently expanding this work by designing a series of prototypes in domains with various characteristics (cross-country skiing, golf, horseback riding). This work will entail explorations of real-time feedback based on data modeling and analysis techniques for sports and physical activities, by drawing on sensor-based data as well as data generated from social media and data sharing techniques. This will allow us to build more complex services while relying on the computational and interactive possibilities of smart phones and cloud computing.

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Out of Touch

Danielle Arets
Ass Reader Strategic Creativity
Design Academy Eindhoven
+31 (0) 6 41 87 98 00
danielle.arets@designacademy.nl

ABSTRACT
This paper discusses the concept of haptic architecture and how blind, visual impaired and in fact every sensible human being can benefit from this type of architecture. Tactile experiences are of crucial importance to navigate and feel safe and comfortable in buildings, especially for persons with vision problems who are highly dependent on tactile experiences. We think it is crucial that architects and designers focus more on haptic experiences, and we provide and discuss guidelines and solutions.

General Terms
Design

Keywords
Design for all, inclusive design, tactile experiences, haptic architecture, research through design

1. INTRODUCTION
Last year, Bartimeus, the institute for blind and visual impaired, and Zilvergrijs, a Dutch foundation for sensible architecture, worked on a research project that aims for a more sensible architecture. Together with journalists, scientist, architects, blind and visual impaired we researched how we can design more comfortable buildings by focusing on a more sensible approach on architecture? To answer this question we studied literature about the senses related to design and architecture as well as research through design. By interviewing people, using experiences from architects, designers, blind and visual impaired and using insights of environmental psychologist we tried to get a better understanding of sensible architecture. The outcomes will be published in a publication (launched in November) and is accompanied with an audio documentary in which journalist interviewed 10 blind and visual impaired people in public buildings about their experiences in the building.

It seems rather obvious that an environment with a lot of attention for haptic elements is easier to navigate for blind and visual impaired people. If an environment has strong haptic cues, it helps them to easy distinguish rooms and recognise specific areas. But blind or visual impaired don't want buildings that – with specific 'adaptations' confirm their 'handicapped' position. In our research we find many interesting ways to build an environment with a strong focus on haptic experiences that is comfortable for all users. This *Design for all* or inclusive design approach was a leading principle in our research.

In this paper we will present some insights on haptic architecture based on this literature research as well as the interviews and design research process (research through design).

In the first paragraph we will roughly sketch why we think we are getting out of touch and why this is a 'problem' when it comes to our built environment. The second paragraph deals with how we experience and interpret tactile stimuli. In the third paragraph we outline our research through design approach and sum up some haptic design approaches and solutions that will create a more comfortable environment for not only blind and visual impaired but all habitants. In the final paragraph we mention a haptic design strategy for architects.

2. SEEING WITH THE SKIN
In our adult life touch seems to play a rather marginal role. A lot of hand-work nowadays is replaced by machines and computers. Even designers, artists and architects tend to start their research and sketching process behind the computer. The sociologist Richard Sennett fears we are getting out of touch. In his beautiful book *The Craftsman* he pleas for more 'hand' craft. The sociologist, who is also a merit musician, thinks that this digital and mechanical age is destroying craftsmanship and with that a specific kind of knowledge. An opinion that is shared with the finish architect Juhani Pallasmaa. He even thinks that we can think with our hands and see with our skin which are also the titles of two of his books on this topic (*The Thinking Hand* and *Eyes of the Skin*). Because all our senses are eventually extensions of our sense of touch, we should, according to Pallasmaa, focus primarily on our tactical experiences. In his opinion this means that making models by hand or manually sketch the outlines for a building are crucial activities in order to build meaningful and habitable buildings. Before we explore the importance of the tactile experiences and its role in the built environment we first introduce some tactile strategies with which we can distinguish material experiences, navigate and orientate and which might create more confortable environments.

3. TACTICAL SENSE & SENSE OF TACTICS
At the age of four, children are able to distinguish the physical differences between materials (smoothness, flexibility), feel differences in temperature (thermoception) and pain (nociception). Al these experiences we call cutaneous tactile experiences.
Except from these we have a sort of inner sensor that knows when we stand on a slope, or when we are walking upward, how hard to shake a hand and with how much 'pressure' we can handle a raw egg. This tactile sensing, with which we can perceive the spatial position of our body and dose our muscular strengths is called proprioception. For architects this is a very 'useful' aspect to take into account, for instance by creating an upwards entrance (paragraph 3) .

3.1 Tactile strategies

We usually need to scan an object on many ways (moving it up, down, lifting, pressing, stroking) to perceive all crucial information especially when it concerns large objects that we can't encapsulate at once. With our visual sense we can immediately perceive an overview of the environment, but with our tactile sense we sequential perceive the environment. This appeals for a lot of memory capacity as well as concentration. Therefore it is crucial that architects create buildings with 'easily perceived' tactile elements (see paragraph 3).

3.2 Active, passive, dynamical

Except from this active way of scanning, the Belgian scientist Herssens and Heylighen also distinguish passively and dynamically touch (Herssens & Heylighen[1]). Most of us perfectly notice (passively) changes and movements in our environment such as temperature variations or changes in altitude. Also we easily recognize subtle changes in foundation; we immediately feel if we more from the carpet to the wooden floor. We even feel these changes 'through' objects, for instance while riding a bike or drive a car. Blind of visual impaired can feel these differences through their stick. This experience through objects is what Herssens and Heylighen call the dynamical touch.

In general the active way of scanning gives information about orientations and passive about the atmosphere in an environment, whereas dynamical scanning is the 'in between' experience. According to Herssens and Heylighen architects should focus on these three aspects by working in different planes (paragraph 4).

In the built environment we use tactile experiences for orientation as well as for our 'sense of comfort and well being' in a room. Our tactile sense is the only sense organ with which we can change our environment, since we can replace, move or reform objects. Because of this strong interaction, Herssens and Heylighen are of the opinion that our tactile experiences are crucial in our daily environments. [2]

4. HAPTIC DESIGN SOLUTIONS

Especially for blind and visual impaired people the feet or hands can 'organize' the world for them. By recognizing tactile marks such as differences between clay, asphalt, pavement or carpet they get easily information about rooms. It helps of course if architects (both exterior and interior) support this by making strong marks, f.e. discriminating various rooms with different materials. This not only provides tactile cues but also creates acoustic variation (paragraph 4).

Blind and visual impaired prefer doormats. The different materials have a different language for them. A smooth floor

[1] *Blind Body Language: Haptics in the homes of Congenetally Blind.* J. Herssens en A. Heylighen, in: In Clarkson, P., Langdon, P., Robinson, P. (Eds.), *Proceedings of the 5th Cambridge Workshop on Universal Access and Assistive Technology.* (pp. 109-118). Cambridge (UK): University of Cambridge, 2010.

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'tells' them that this is a free space, whereas a rough, bumpy floor communicates that the user can expect some obstacles. Instead of the material itself, also the thickness and altitude communicate. By means of our proprioceptic perception we feel when a path goes upwards. Architects can 'use' this by making an upwards entrance of a building; blind and visual impaired will get the 'message' that they will walk towards something.

The same is true for stairs. Often stairs are perceived as obstacles in buildings. But blind people can perfectly walk stairs as long as they have a 'good rhythm' and if the first and final step are clearly marked (for instance with a carpet).

Marks could also enhance the orientation; think of noticeable buttons in an elevator, braille on the stair rails. With big public buildings a miniature relief model of the building could give crucial information about the routing.

Because of the mentioned tactile strategies we need to touch an object or environment in multiple ways. Big rooms are hard to 'perceive tactically'. In long isles a shelf on a wall could give support. A nicely decorated shelf [image 1] could even give extra tactile pleasure. As George Kabel, a blind philosopher and sculptor in our interview mentioned " it would be great if architects would focus more on tactile pleasures. Normally if people need to wait they start looking around; for blind or visual impaired it would be great if they could 'feel around' while waiting; why haven't architects or designers focused yet on creating nice carvings in the counter desks?" The Dutch architect Marco Matic designed atactic licence plates with a 3d image, that both for blind, visual impaired and people with normal vision gives aesthetic pleasure [image 2].

Image 1:carved shelf

Image 2: tactic licence plate with 3d image

4.1 Atmosphere

Of course materials have a strong impact on our feelings. Soft and natural materials are often perceived as more friendly. According to the Finnish architect Pallasmaa using non natural materials can have devastating mental influences. Since these mechanically produced materials are not aging. The timeless perfection of these materials is according to

Pallasmaa not in line with our mental need to see things aging. [3]

The tactile expert Marieke Sonneveld (University of Delft) thinks there are a lot of clichés in this perspective. Nowadays products with soft touch are popular, but we can't only enjoy soft and caressing materials. We need contrasting experiences. The Belgian scientist Herssens en Herssens emphasize from their research that blind and visual impaired prefer firm objects with a clear and fixed structure. [4]

Petra Blaise shows in her book Inside Outside the impact of fabric in environments. Fabric not only can 'exclude' the night but also distinguish rooms, feel comfortable and enhance acoustic qualities.

4.2 Design language

A lot of our daily objects are restyled frequently. There are for instance numerous design solutions for taps; some ones you have to push, others you need to swing or lift to get water our and there are even ones you have to use your feet or infrared sensors. The same is true for flushing the toilet or light switches. These variations make it hard, not to say impossible, for blind to visit public bathrooms. As the blind American architect Downey puts it: "I frequently have to search for the towel, I don't know how to open the tap and if I get cold or hot water, and search long for the dustbin. Knowing that public toilets are far from clean, I don't feel comfortable touching extensively. So if possible I avoid public toilets." Of course we would not like to plea for a universal form language, but for public environments it would be recommendable to have some basic design rules for public buildings.

5. HAPTIC ARCHITECTURE

Regarding the abovementioned aspects we think it is crucial that architects and designers focus more on haptic experiences. The Belgian scientists Herssens en Heylighen plea for a more haptic architecture. [5] In their opinion architects should divide their design in planes instead of volumes. They distinguish guiding, moving and rest planes. Every plane has one or more functions that determine the choice of materials and decoration.

Designing for the moving plane means that architects focus on elements that stimulate orientation and movements in an environment. This can be done with tactile accents like a doormat in a transition room, curtains to divide spaces with a different functionality and materials that correspond with the function of a room.

[3] Pallasmaa, The Eyes of the skin, p 30

[4] Zie bv. (Herssens & Heylighen 2009) A lens into the haptic world. J. Herssens en A. Heylighen, in: *Proceedings of Include 2009*. London: Royal College of Art, Helen Hamlyn Centre, 2009.

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Challenging Architects to Include Haptics in Design: Sensory Paradox between Content and Representation, J. Herssens en A. Heylighen, in: Leclercq P., Martin G., Heylighen A. (Eds.), *Designing Together*. Liège:. Editions de l'Université de Liège, 2011 (in print).

If the atmosphere in a room is more important than the movement or orientation, most information is perceived passively (meaning temperature or air pressure changes). In that case architects should focus primarily on the rest plane meaning creating enough spaces to relax, sleep or relax. Designing for the guiding plane, means taking into account the active (conscious touching and moving) and dynamical touch (by means of a device, object or stick). In this case architects should focus on the structure of an environment and use elements that support the routing, for instance a shelf on a wall, clear (material) distinctions between roams and no unnecessary obstacles. In this way architects are 'forced' to think of more haptic design solutions within the constructing process.

6. DESIGN FOR ALL

Although architects have a strong voice in framing the built environment, we have to notice that they work in a widespread field in which many actors and stakeholders (housing companies, project investors, municipalities and so on) are involved. Not the least to mention the users (habitants) themselves. To create a more haptic approach on architecture all the actors in the field should be involved. Since the architectural field is 'dominated' by an ocular-centric perspective, this is not an easy task. It helps though, that tactical design solutions are not highly complicated. The abovementioned guidelines are not costly and most 'solutions' are rather obvious. Moreover with a more haptic approach we might even save budget, because we might avoid stigmatised adaptations.

The starting point in this process is the user himself. He needs to have a crucial voice in the process. We discovered that by talking to blind and visual impaired - experience the built environment through their eyes- that we can easily alter the environment with cheap, obvious design solutions so that it is easier to navigate and more comfortable for all users.

7. SUMMARY

Tactile experiences are of crucial importance to navigate and feel safe and comfortable in buildings. We active, passive and dynamically touch our environment. Since we perceive so many information by tactile experiences and because we can alter our environments by touch, the tactile sense is crucial to take into account in our daily environments. Especially for. blind and visual impaired who are highly dependent on tactile experiences.

Architects could focus on haptic architecture by dividing a building in rest, guiding and moving planes (Herssens & Heylighen). Each plane needs corresponding haptic design solution concerning structure, material and design language. Some think that the use of natural, aging materials is preferable (Pallasmaa). Blind and visual impaired prefer vast materials (Herssens & Heyligen), and in general we like contrasting materials (Sonneveld). For public environments like rest rooms, it is strongly recommendable to look out for a clear 'universal' design when it comes to placing of dustbin, toilets and sinks (as well as taps, light switches and son on).

Because tactile architecture is highly dependent on the users involved in the building (personal preferences, working conditions, requirements and so on) it is impossible to give uniform guidelines regarding tactile architecture. By using design research experiences of the users themselves we get a better understanding that helps us to create, in the words of Pallasmaa, meaningful tactile buildings for all!

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Developing Visual Editors for High-Resolution Haptic Patterns

Cuartielles, D., Göransson, A., Olsson, T.
K3 – Malmö University
SE – 20506 MALMÖ, Sweden

david.cuartielles@mah.se
andreas.goransson@mah.se
tony.olsson@mah.se

Stenslie, S.
Aalborg University
Aalborg, Denmark

stenslie@hum.aau.dk

ABSTRACT

In this article we give an overview of our iterative work in developing visual editors for creating high resolution haptic patterns to be used in wearable, haptic feedback devices.

During the past four years we have found the need to address the question of how to represent, construct and edit high resolution haptic patterns so that they translate naturally to the user's haptic experience. To solve this question we have developed and tested several visual editors

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *graphical user interfaces (GUI), natural language, prototyping.*

General Terms

Design, Languages.

Keywords

Haptic language, haptic editors.

1. INTRODUCTION

A haptic vocabulary is a 'toolbox' containing different ways and methods for touching users. The earlier Erotogod installation (2003) [6] used a two-way bodysuit that both sensed users through input and touched them through vibrotactile stimulators. Here three kinds of touch patterns formed its haptic vocabulary. These were i) the ground, basic patterns used in every part of the installations dramaturgy, ii) the designed and specific patterns scripted as specific parts or sequences of the dramaturgy and iii) the random patterns that were generated as response to user's touch. Patterns were made without a visual editor. To aid the making of specific touches the patterns were first laid out as drawings marking positions and movement before coded directly into the software.

Much like a textual language, a haptic language consists of a hierarchical structure where the lowest layer defines the most basic components of the language, for example the characters of a text. This most basic component is then defined in more complex structures that produce yet another level of understanding; in our textual example this would be words. Multiple second tier constructs are then combined into the communicated message.

In our visual editors we have tried to facilitate both for exact control of single vibrator outputs -analogue to characters- as well as the formation of combinations of multiple outputs that form higher level and meaningful haptic expressions analogue to 'words'. Haptic languages can be subdivided into the alphabetic using tactile clues to form actual words (Braille, telegraph) and the conceptual, symbolic and non-verbal attempting to form meaning through emotions and embodied sensations (hand gestures and body language) [2]. In this project we focus on the symbolic expression of haptic language. Although less exact it is much faster and experienced more direct for most users.

2. RELATED WORK

In 1998 Fogg et. al. developed the haptical entertainment device called HandJive [4]. While developing HandJive the authors also realized the need of a novel haptic language for their device which they named "Tactilese". Composed of three hierarchal units – Positions, Patterns, and Routines – Tactilese lets the user create haptic messages of varying complexity which are then passed on to another player holding a similar device.

The basic units of Tactilese, Position and Pattern, were simple for users to grasp quickly. However, the more complex Routines had a much steeper learning curve and consequently users had difficulty grasping them, but given enough time they had no problem learning and performing them.

Many other works within the field of haptic interactions consider haptic languages as something immediate, a synchronous communication between two, or more users through devices equipped with haptic actuators [1-3,9,10]. The immediate communication is often initiated by an input device and received, and acted upon, by an output device. An example of this is the InTouch project by The Tangible Media Group at MIT Media Lab. Two identical roller devices in separate locations both record and exchange their movements, thus enabling their users to directly sense each other's actions.

Similarly, haptic feedback patterns can describe the environment in novel ways [5], actively helping the user to make decisions based on the information acquired by the haptic pattern.

Through this previous research we find that haptic patterns can be recorded, and/or played, in two modalities.

i. Through direct touch on the haptic input device which then interprets that interaction and controls a haptic output device, synchronously or asynchronously. In this construction the haptic input device can be the same as the haptic output device; as in the example of HandJive, TapTap, and Huggy Pyjama.

ii. Through an indirect definition or recording of a haptic pattern which is synchronously, or asynchronously, initiated by the haptic device based on events; originating either from the device status or its context. In the example of Soundcrumbs the device had a statically stored low resolution haptic pattern which was activated by the user in a specific context as navigational aid.

The biggest difference between the two modalities is the freedom to define the haptic language, in i) the user is free to define the vocabulary and its meaning herself, in ii) the meaning is already defined for her.

3. HAPTIC PATTERN RESOLUTION

A user defined haptic language is highly dependent on the number of haptic actuators implemented in the system. Ideally the amount of haptic actuators should exceed 90 to achieve a deep enough immersion into, and correct interpretation of, the high resolution haptic pattern [6].

In our project we define the difference between low-resolution haptic patterns and high-resolution haptic patterns as the combination of the number of haptic channels and each haptic channel's inherent data-resolution.

The garments developed in this project each had a varying number of haptic channels, ranging from 6 (Sweet) and 64 channels (Blind Theatre). Each channel had a data resolution of up to 128bit allowing us to precisely adjust the strength of the vibratory output of each channel.

4. THE PROTOTYPES

In this section we discuss the three latest iterations of the visual editor for high resolution haptic patterns. We also introduce our next version of the editor, currently in development.

4.1 First Generation Editors

The Blind Theatre editor (2009) was heavily influenced by the DMX GUI's used by technicians at the theatre. Featuring a total of 64 haptic actuators, and with little to no natural interactions planned in the user interface this editor had a very high threshold for beginners. While the interface was very complex, it also offered a high degree of control for each haptic actuator, and therefore an overall control of the entire suit.

Figure 1 Blind Theatre Editor

4.2 Sweet Editor

Sweet marked the beginning of the second generation editors. Here we made a conscious move towards a much lower resolution haptic pattern compared to what was used in previous iterations, we settled with 6 channels because our aim in this project was not to explore haptic interactions but rather develop the concept of a haptic toolkit for designers.

The environment developed in Sweet should follow the basic design principles of user interfaces; among others it should be clear, non-intimidating, and intriguing for the designer. Another important principle for Sweet was the one defined by Bret Victor in which he defines that creators need an immediate connection to their creations [8].

Therefore the visual environment of the Sweet Editor should:

i.   Resemble the outcome of the wearable device on which the high-resolution haptic pattern would be applied.

We envisioned that the Sweet Editor would allow the designer to insert a drawing or a photo of the garment giving the designer an immediate, and visual, connection between the garment and the haptic pattern. The Sweet environment should also:

ii.   Offer immediate connection to the outcome of the created haptic pattern.

Through the interface of the Sweet Editor the designer would be able of instantly installing, and testing, the pattern which is currently being edited. Another important concept of the Sweet Editor was also to move towards a more natural way of haptic interaction inside the programming environment – through touch.

iii.   The editor should be based on a touch-enabled platform allowing for a more natural interaction when creating the haptic pattern.

As there were no suitable touch-enabled platforms to sport the interface at the time of creation we tested functionality by mimicking touch-interactions through a standard WIMP interface. This enabled us to test basic functionality, but also caused confusion for test subjects.

Figure 2 The Sweet Editor

4.3 Sense Memory Editor

As cloud computing and streaming media is becoming the norm for accessing applications on mobile interfaces, we decided to move our tools and data online. This removed the need to actively install new geo-located high resolution audio-haptic patters on the mobile device and instead issue a pull command to a web database when needed.

Also notable is that we decided to temporarily abandon the touch-based editing paradigm implemented in Sweet as that caused some confusion when applied to a WIMP style interface. The detailed time-line editor offered sufficient control for initial test, but represents a time consuming activity demanding several iterations of haptic pattern testing and re-editing.
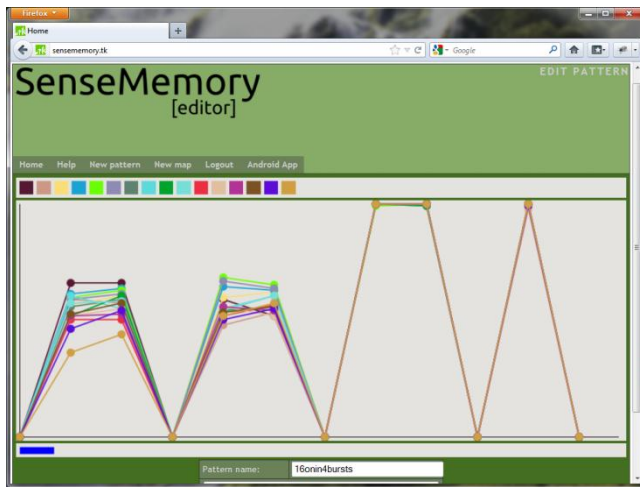
Figure 3 Sense Memory Editor

4.4 Next Generation Editor

All our editors gain detailed control over the haptic channels in combination with an interactive timeline graph. However, as haptic stimulus must be edited one after the other, this represents both a slow and non-transparent approach. In realizing this we decided that our next generation editor should lessen detailed control over the haptic pattern through a timeline, and design towards a more natural touch interaction paradigm. Our new editor creates haptic patterns by touching iconographic representations of the body on a touch screen interface.
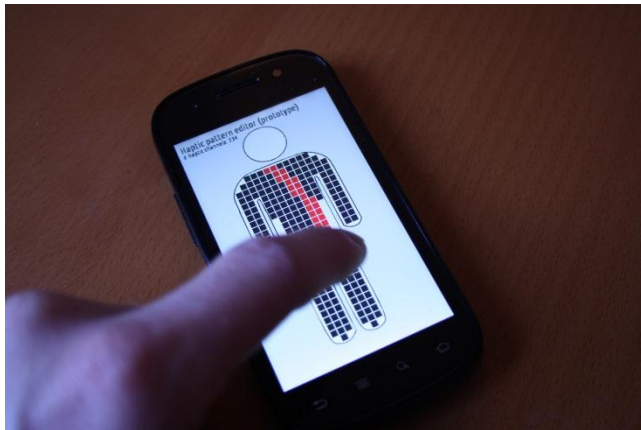

Figure 4 Next Generation Prototype

5. EDITOR ANALYSIS

The graphical editor iterations have been tested in several projects. Project group discussions and interviews have constructed the base for our iterations throughout the project, and from them we've gathered the following guiding principles for our next generation editor.

i. The editor should support both modalities of creation and consumption of haptic patterns, and support this through both through asynchronous and synchronous communication.

ii. Provide a direct feedback connection for designers working with the haptic pattern.

iii. Direct feedback to haptic pattern generation on the small smartphone screens can be enhanced both through sound and vibration

iv. Visual editors of full body haptic patterns should include iconography representing the whole body, both in front and rear view.

6. CONCLUSIONS AND FUTURE WORK

Developing visual editor software for high resolution haptic patterns and multimodal audio-haptic sculptures is a complex and difficult task. Possible solutions should focus on natural, touch based input to form and edit haptic patterns. Our intentions are to continue this project; developing visual editors for high resolution haptic patterns which are easy to use, portable between multiple systems and provide high-resolution haptic patterns in the three most common textual data formats – XML, JSON, and CSV.

7. ACKNOWLEDGMENTS

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Enhancing Multisensory Environments with Design Artifacts for Tangible Interaction

Héctor A. Caltenco
Certec, Dept. of Design Sciences, LTH
Sölvegatan 26
223 62 Lund, Sweden
+46 46 222 08 77
hector.caltenco@certec.lth.se

Henrik Svarrer Larsen
Certec, Dept. of Design Sciences, LTH
Sölvegatan 26
223 62 Lund, Sweden
+46 46 222 40 38
henrik.svarrer.larsen@certec.lth.se

Per-Olof Hedvall
Certec, Dept. of Design Sciences, LTH
Sölvegatan 26
223 62 Lund, Sweden
+46 46 222 40 94
per-olof.hedvall@certec.lth.se

ABSTRACT

Even though multisensory environments (MSE) incorporate artifacts and technology to provide sensory stimuli, most of these artifacts are non-interactive. Twenty-four children with profound developmental disabilities from three MSE institutions have been involved in a research study. A handful of interactive design artifacts, which have been developed as a tool for ideation and to enhance the use of MSE by promoting children's engagement are presented. With these artifacts the children have shown us a vast topology of interaction and bodily engagement, showing a potential for haptic and audio interactive design fields to contribute to a more participatory MSE practice.

Keywords

Tangible interaction, disability, children, MSE, artifacts, interfaces, physical computing, arduino, capsense, Kinect

1. INTRODUCTION

The pedagogical Snoezelen practice, or multisensory environment (MSE), has been described as another world [5]. It does not rely on verbal communication, but instead incorporates sensory artifacts and environments to blend sensory stimuli, such as sights, sounds, textures, aromas and motion, with the purpose of enabling a child or adult with developmental disability to find the calmness or impetus needed to engage in the world. These artifacts are used to build an environment that initiates changes in arousal by affecting the relaxation process, reducing anxiety and/or pain (both physical and emotional). Currently, the artifacts found in MSE rooms are reactive, if at all, via push buttons and switches. Many of them only produce non-interactive dynamic stimuli. Very few of these artifacts are interactive by computational means, and the ones that are do not seem to have tight and co-located coupling and lack more elaborated behavior.

The purpose of this paper is to open up for dialogue and ideation with our colleagues in the haptics and audio interaction design fields to contribute to a more interactive and participatory MSE practice. A demo of the design artifacts is to be presented at the conference. This paper is based on a paper by Larsen and Hedvall [4], and on the ongoing work in the SID project

(http://sid.desiign.org), in which twenty-four children with profound developmental disabilities and pedagogical staffs from three MSE institutions participate. The project tries to dive into exploring ways that continuous coupling interaction can involve tactile and proprioceptive senses of such children, therefore promoting and enhancing the children's engagement in the MSE. This is done by using interactive tangible computing artifacts to enhance the children's interactive experience. The project's design process has three foci [4]:

a) The use of proximal senses, tactile pressure, vibration, balance, etc. rather than solely the prevailing audio-visuals.

b) The use of co-located continuous (and gradual) coupling interaction, instead of the current binary (on/off) interaction found in the common MSE practice.

c) The use of an aesthetic perspective perceiving artifacts as entities with rudimentary agency, which is both predictable and yet never the same.

The three foci bring sensitivities and curiosities to the fieldwork. But they also bring delimitations derived from the need of a more narrow scope, leaving out fields such as scent, gaze tracking, wearable computing and speech recognition. However, the foci relate very closely to the field of haptics, there is a natural relationship between physicality and touch [1]. The inclusion of haptic and sound feedback as part of the MSE artifacts could provide a strong pillar for collaboration between haptic research and the MSE practice.

The current paper describes the design artifacts used as an integral part of the research process. These basic yet interactive design artifacts are not products to be introduced to the MSE practice, but tools for ideation, sketches that are continuously being reshaped and reinserted into the collaboration with the MSE institutions.

2. DESIGN ARTIFACTS

The design artifacts in the project are explorative interactive sketches aimed to enhance the children's interactive experience and participation. Mock-ups had to be ruled out, as participants in the project cannot take part in interplays that require pretending or abstract thinking and dialogues. Wizard-of-Oz prototypes [2] were also ruled out for the most part, as the children indeed paid attention to "*the man behind the curtain*", instead of to the actual interaction. Therefore the design artifacts have to be interactive yet should also be manifold and easy to alter as we learn from the children's actions. Some of the design artifacts are presented

below. All of them explore various couplings of light to touch, push, grab and hug. Some of them provide vibration or movement feedback to the interaction. However, in some of them, audible response will also be added.

2.1 LivelyButton

The thought behind the LivelyButton is to explore spatial co-locatedness. It is a simple construct of a capacitive sensor controlling two RG LED-strips connected to an Arduino (www.aurdino.cc) board, and a stepper motor connected to another Arduino board via an motor shield. The motor spins two metal spirals below the surface of a semi-transparent fabric on the top-side of a wooden black box.

A sliding potentiometer can be used to set the sensitivity of the capacitive sensor so the LivelyButton reacts just before and at touch. When activated, the Arduino master board sends a cyclic pattern of PWM signals to the LED-strips, backlighting the soft surface in interplay of light and spiraling shadows. At the same time, the master board communicates to the motor board via serial port, and the motor spins the metal spirals under the soft surface accompanied by vibrations and the sound of the motor (Figure 1).

The LivelyButton has promoted relevant discussions and inspiration regarding co-location. A modified version is being developed, which considers different visual and tactile feedback behaviors depending on the type, degree and length of the touch-interaction.

2.2 LivelyForm

This design points beyond the existing MSE practice by introducing a moving object. The thought behind it is investigating if the interaction with such a moving object can promote the child's own movement. The construct is a worm-like elongated form that can bend (curl) and stretch. A 24V DC-motor pulling a curled plastic sheet which acts as a spring is connected to an Arduino master board. A capacitive sensor connected to an Arduino slave board detects if the LivelyForm is being touched. Another slave board drives an array of LEDs. The boards communicate via I^{2}C protocol. If touched, it stretches and light patterns run along its inner side depending on its current "openness" and the time elapsed since the touch started. If not touched, the LivelyForm returns to a curled position. (Figure 2).

It was observed that the children tend to continuously grab the LivelyForm rather than alternating between touch and look, a single sensor did not make sense. A modified version is being developed, which lets the LivelyForm react to being moved rather than being touched, and responds with different movement and light behaviors depending on the degree of manipulation.

Figure 1. Left: Open LivelyButton showing metal spirals, LED-strips and motor components. Right: child interacting with the LivelyButton.

Figure 2. Left: Internal structure of the LivelyForm. Right: Child interacting with the LivelyForm, showing a capacitive sensing outer side with a semi-transparent lit inner side.
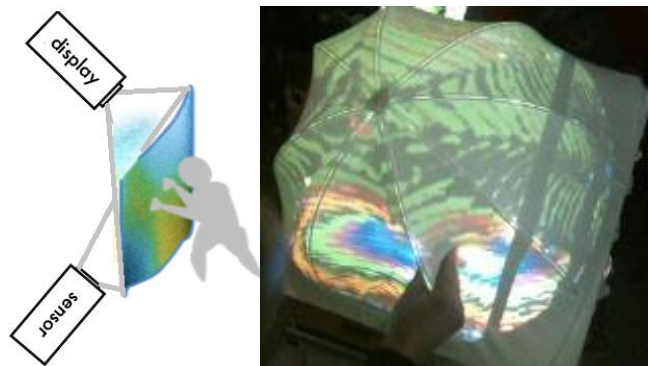
2.3 ActiveCurtain / ActiveSphere

The thought behind the ActiveCourtain was to relate the feel of one's body touching the material to color change where the child presses. The physical design artifact is basically a backlit projection of colored surface into a soft screen. A Microsoft® Kinect sensor is located behind the soft screen, detecting the location and depth of the "press".

On the first version of the ActiveCourtain, a colored and thresholded depth image of the Kinect is projected back to the screen. Therefore, pressing the surface of the screen changes the color of the indented area by an amount of thresholded steps, depending on the depth of the touch (Figure 3).

Based on the observed interactions and the deliberations with the staff, ways to make the design more inviting for interplays around simultaneous interaction are under investigation. A spherical version is being developed (Figure 4), which considers more elaborate temporal and spatial behaviors. It uses multipoint detection to send TUIO [3] messages to any TUIO clients, which project different animations (and sounds) to the ActiveSphere surface, depending on the type and degree of multi-touch interaction.

Figure 3. The first version of ActiveCourtain, using various ways of bodily engagement

Figure 4. Left: ActiveCurtain/ActiveSphere components. Right: Example interaction with the ActiveSphere.

**Figure 5. Child interacting with MalleablePillow, which responds with co-located gradual light-effects**

2.4 MalleablePillow

The basic thought behind the MalleablePillow is to explore continuous and co-located coupling of actions and effects that are tightly connected to the child when using his or her body. The construct is a semi-transparent white fabric casing groups of LEDs distributed along three clusters of glass marbles, each with a microphone picking up the kneading sounds from the marbles. The signal from the microphones is filtered and pre-amplified and then used as an input to an Arduino board. The board controls the LED groups using PWM signals. More kneading gives more light intensity on cluster closer to where the kneading takes place (Figure 5).

The MalleablePillow has recently come out to the MSE institutions, and there have not been enough observations and learning yet. Another sensor setup using accelerometers is planned, which would make the artifact lighter and easier to carry. Moreover, it will give way to reacting to different ways of "malleability", bending and manipulation. Sounds will be added as part of the interaction's feedback.

2.5 HugBag

The thought behind HugBag was to make use of the child's strong and gross motor based actions, while exploring continuous and co-located coupling of action and effect tightly connected to the child's gross motor activity. HugBag is still currently under development. The construct is made of a semi-inflated ball resting on a semi-circular plate base. An accelerometer mounted on the base detects the tilt direction and angle while a Microsoft® Kinect sensor, also mounted on the base, detects the location and degree of deformation while being hugged, pushed or punched. These sensors control evolving light patterns and sounds as a response to interaction (Figure 6).
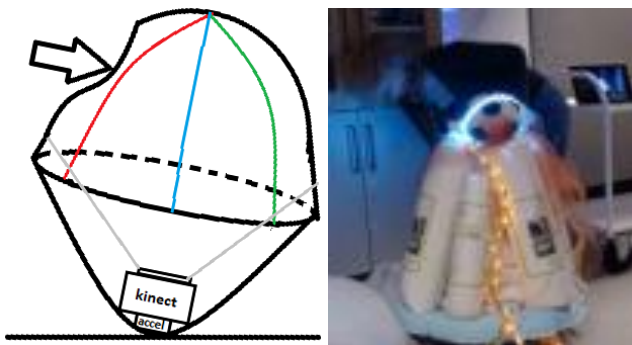
Figure 6. Left: Iustration of the HugBag with the Kinect and accelerometer on the base and LED-strips on the semi-inflated ball. Right: Early sketches of HugBag prior to the one currently under development

3. DISCUSSION AND CONCLUSIONS

A handful of interactive design artifacts, whose interaction is gradual and co-located, have been presented. These artifacts are used as a tool for ideation and to expand the MSE practice by promoting and enhancing the children's engagement in MSE. To achieve this, the artifacts should not only be evocative, but also fairly simple to build and alter [4].

The artifacts have evolved as they travel between the three MSE institutions. The evolution takes place based on the observations from the children's interaction and interpretations from the institution's pedagogical staff.

The project is explorative in a manner of letting the children affect ideation in the design process. The artifacts enable us to ask "questions" so the children give generative feedback. With these artifacts the children have shown us a vast topology of interaction and bodily engagement: from putting the cheek on the LivelyButton to full upper body immersion into the ActiveCourtain, and even a finer motoric interaction when grabbing the MalleablePillow.

This exploration has opened up for novel ways of engagement inside the MSE practice. Yet, this is only the beginning of a change in the use of tangible computing technology for the already existing MSE practice. With this paper we hope to open up for dialogue with our colleagues in the haptics and audio interaction design fields to contribute to a more interactive and participatory Snoezelen practice.

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