Tactile Composition: Configurations and communications for a musical haptic chair

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ABSTRACT

Musical experiences can be highly multisensory, from obvious auditory stimulation, to the visual elements of a live performance, and physical excitement of the body. In this paper, we propose a means of incorporating an additional somatic channel of communication into live performances and compositional practice to further augment the physical nature of live performance.

This work explores the integration of augmented vibratory, or haptic stimulation for audiences in live performance. The vibration interface is presented as an expressive and creative live performance-based tool for composers. Vibrations, or haptics, are implemented as an additional instrumental line, alongside auditory musical gestures, to expand the composer's palette of expressions through augmented somatic engagement.

The paper starts with the work's overall context, followed by related literature from exisitng projects that have informed this research. It also includes a discussion of the design and development of an array of vibrating motors, a composition produced for the system, and ongoing work.

1. INTRODUCTION

Sound propagates through space as a series of vibrations; the physical attributes of this motion excite and engage listeners on another level. For example, when standing close to a loudspeaker, you can feel the propagation of waveforms through the speaker cone; this is particularly prominent at low frequencies. Instrumentalists feel parallel, physical sensations as their instrument produces sound. Additional haptic and vibrotactile stimulation can provide a further sensory modality, or channel of communication through which musical information can be enhanced.

Frequently, live performances encompass integrated and interdependent multi-sensory experiences: stimulating audiences visually, auditorily and somatically intentionally or not. This occurs in traditional, staged performances, which have strong visual-performative elements from on and off-stage artefacts, the movements of individuals performing and within the audience, together with the architecture of the performance space [1].

Of interest to this project are the physical aspects of sound, particularly the physical sensation and somatic stimulation of sound imparted on listeners. The somatic nature of live musical experiences is inherent in the physicality of sound waves produced by instruments and loudspeakers. When considering the relationship between sound and touch, Glennie [2] states: "*Hearing is basically a specialised form of touch.*" Whilst the *tactility* of the ear facilitates the listener's perception of an ensemble's sound, the physical sensations of these waveforms are imparted on both the body as a whole, and objects in the performance environment.

Whether the multimedia nature of performance detracts or distracts from musical experience or not is debatable, however, the authors' pertain to a Deleuzian listening [3] approach that suggests *"art should lead the subject to an experience of multi-sensoriality."* For many composers, the advent of audio-visual technologies (real-time and fixed) has augmented their practice, allowing a greater control of multi-sensory listening experiences. No longer are composers limited to defining the auditory parameters of musical works.

Metaphorically, music can be said to communicate a visceral impression upon the body. Such emotional responses can be a key measurement of the impact of a composition and its performance in practice. This research explores how the composer can obtain greater control of physiological, visceral and metaphorical experiences in music through additional sensory stimulation.

Overall, the aim of this research is to communicate musical directions and expressions through vibrations, further extending the existing, limited discourse around audio-tactile languages for music. Explicitly, this element of project seeks to model the relationship between our perception of sonic, and somatic stimuli for use in the augmentation of musical expression through technology-enhanced compositions.

In this paper, we discuss *haptics* as an instrument and compositional tool, and demonstrate how haptic triggers can be integrated into a score. Specifically, the work is presented in the context of the first instrumental ensemble score composed for the system. Alluding to existing haptic works, whilst considering new techniques, this paper seeks to describe the design of a bespoke haptic hardware alongside its compositional potential, primarily as a processed *instrument*, with a view to it becoming an expressive tool.

This paper is structured as follows: Section 2 presents a background literature survey incorporating, an overview of the physiology and psychology of touch, haptic systems in accessibility and entertainment, and systems utilising related techniques. Section 3 presents the design and development of the individual system components, with composition being discussed in Section 4. The paper closes with a discussion of on-going work and conclusions.

2. BACKGROUND

Through a combination of an increased physiological understanding of touch, the accessibility of multimedia forms, and hardware advancements, research into haptic technology systems has made rapid progress in the past decade. Discussions include the psychophysical and perceptual applications of tactility, in fields such as medicine and health, accessibility, safety as well as media and entertainment.

This section discusses the basic mechanisms involved in *touching* alongside principles of its perception and integration with other sensory modalities. A discourse on both historic and current projects is given, encompassing a range of haptics in human-computer interactions (HCI) applications, with a particular focus on accessibility, entertainment and music performance.

2.1 The Sense of Touch

There are four different types of mechanoreceptors located within the skin and subcutaneous tissues [4]. Receptors, or nerve endings are located all over the body, covering most areas. Denser receptor clusters are often found in the skin, particularly around hair follicles, but also around joints, muscles, and blood vessels and within the ear. Stimulating different combinations of these receptor distributions affects the dimensions of our sensation. In that, a cutaneous sensation, that only affects skin receptors, is different to a more kinaesthetic movement, where receptors in the skin, muscle and joints can be excited.

This project is interested in the relationship between events stimulating both the haptic and auditory systems. The abovementioned nerves within the ear, specifically the cochlea (the receptive structure of the ear), are essentially sound, or vibrations information pathway to the brain [5]. To be more precise, the ear provides us with a more attuned, or focused representation of sound's vibrations that are *felt* by our body in its entirety. Despite the clear similarities and relationship between them, there is limited discourse on the integration of the haptic and auditory.

2.2 Haptic Illusions

There are a range of known haptic illusions, that influence how we perceive touch. Haptic and tactile illusions can fall into two main categories, those effecting an individual's perception of the physical attributes of an object, and haptic spatial perception. Illusions can be induced through *active touch*, or 'touching', where the environment and surrounding objects are decoded through exploratory feel, and *passive touch*, or 'being touched', which presents a tactile communication channel for information to be unwittingly relayed through stimulation of the skin [6].

Our perception of the spatial location and distance between vibrations can be influenced by actuator location and onset. Of particular interest to this project is vibrotactile apparent motion (VAM), described by Niwa *et al.* [7], "*When activating two or more tactors sequentially with a certain timing, the stimulation point is perceived as if it is moving continuously from one position to another, although the physical stimulating points are discrete.*" In this project, VAM techniques are employed alongside another technique known as sensory funnelling. A further discussion and analysis of these phenomena can be found in Lederman and Jones [8].

2.3 Haptic Systems and Applications

Haptic technology systems focus on relaying information to users via stimulation of the skin. These technologies are commonly found in both consumer and research environments. In consumer electronics, products such as mobile phones and games controllers often incorporate some element of haptic feedback.

2.3.1 Haptic Chairs

The integration of tactile stimulation into a chair for entertainment purposes is not a novel concept. In 1959, director William Castle introduced the 'Percepto' seat alongside his film *The Tingler*. The seats were built from vibrators salvaged from World War II aircraft and activated at random by the projectionist during specific scenes in the movie [9]. A similar concept has endured through smaller scale productions in amusements parks, and some cinemas.

Haptic technology systems have been designed, with a focus on enhancing the listening experience for the hearing-impaired. For example, Nanayakkara's [10] haptic chair explored the relationship between auditory, visual and the somatic sensory modalities. Speakers are integrated into the chair to physically recreate the vibrations of the audio. Vibrotactile feedback, together with synchronised visuals, is designed to augment the music listening experience for the hearing-impaired.

Similarities can be drawn between this work and the development of existing auditory-vibrotactile chairs. However, Nanayakkara's work focuses on congruent, analogous reconstructions of sound, enhancing aspects of it that are already apparent. The work described in this paper has a clear distinction; overall it seeks to engage listeners in sonic experiences without necessary reference to an existing audio waveform. It seeks to flexibly facilitate somatic excitation in more abstracted paradigms, for example, as part of a stochastic process, or to highlight unapparent aspects of sound and even to work incongruently with musical gestures.

More recently, Israr and Poupyrev [11] designed a 'Surround Haptics' algorithm, for use in a gaming chair, that uses some of the haptic illusions alluded to previously. Application of such techniques allows a lower resolution display (4 x 3 actuators) reducing device cost and intrusiveness. The vibrations produce a smooth haptic motion through 'virtual actuators' that can occur between any two physical actuators on the grid.

2.3.2 Haptics, Music and Research

Research has been conducted into the application of haptics in musical performance systems. Hayes and Michalakos [12] propose a system to aid improvised performance through the use of networked vibrating motors. Berdahl *et al.* [13] design a system, which uses a thimble to indicate correct fingering position through haptic feedback. There are numerous other implementations of haptics in musical performance, including new interfaces for musical expression and communication of tempo [14].

3. HAPTIC SYSTEM DESIGN

A haptic system comprising of hardware and software components has been designed for composers and integrated into concert halls for performance. It incorporates various hardware and software modules, for synchronisation, trans-domain mapping and media rendering. The main hardware component is the haptic seat cover that can be placed over chairs. Alongside the modular and flexible hardware design, similarly adaptable software is implemented to allow multiple application scenarios in instrumental and electronic, live and fixed media performances.

In this section the design and development of the system, with a particular focus on implementation and integration of haptic devices into the performance space, will be described. Specifications of the system are overviewed, alongside hardware and software development concepts and implementation.

3.1 System Overview

The design requirement of the overall system can be considered as four distinct modules: Media preparations, performance following and synchronisation, mapping, and reconstruction. In achieving this projects aim a method of incorporating additional haptic data into a score has been designed. Two methods of performance tracking including manual score following (with a sensor interface) and real-time audio analysis, allowing synchronisation of the musical line with haptic events. When the score and audio data have been captured, the data streams are synchronised.

With a trans-domain mapping engine, a set of mapping strategies translates the data within the defined parameters of the haptic feedback method. Software and bespoke hardware are required to render the haptic feedback, reconstructing data into vibrations, as well as additional media content (see Figure 1).

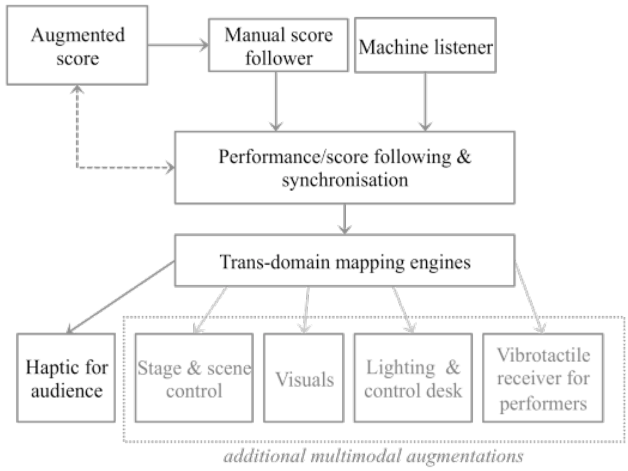

Figure 1. Overall architecture design.

3.2 Design

3.2.1 Representation

Augmentation of the musical score in this context requires the incorporation of haptic triggers to cue tactile events. In the example considered later in this paper, the haptic controls are pre-composed. Pieces composed specifically for the system are converted directly into the machine-readable format. At this stage, other events and cues can be added to the score including triggers for the additional modalities (lighting, visuals etc.). Further dialogue about scoring haptics is given in Section 3.2.5. Optical music recognition techniques (OMR) can be applied to pre-existing scores, converting them to a machine-readable representation with additional multimedia capabilities [15,16].

3.2.2 Performance Tracking and Synchronisation

There are two tracking operation models implemented in this system, including manual, or assisted score following techniques, similar to those employed by Dannenberg [17]. In this instance, the beat is communicated through tapping. Simultaneously, the live signal produced by the ensemble is analysed to detect audio events and trigger haptic cues. This is referenced with the manual score following, matching the onsets from the audio source to the score in a localised, small window. These data streams are then integrated and synchronised realising a multimodal approach to score following.

3.2.3 Haptics Hardware Design

The hardware used to translate the control signals into haptic feedback consists of a two dimensional array of actuators. The initial prototype interfaced the motor array with a single driver, with 16 individual outputs and a microcontroller; this allows control of pulse width modulation (PWM), onset and duration of each individual motor. At this present stage, a grid of 4 x 4 vibrating motors has been implemented (see Figure 2).

The overall design and integration of the array is key to allowing ease and flexibility of installation on a range of chairs. Presently, a light aluminium structure of four horizontal and four vertical narrow strips has been implemented, allowing the cover to be moulded to the contours of the seat. The structure is held in place at the back of the chair with straps.

3.2.4 Haptics Software Design

A configurable and extensible transdomain mapping strategy is currently being employed. Informed by existing literature on haptic perception and psychophysics [18, 19], a prototype algorithm to precisely control the actuator output and facilitate haptic rendering has been developed. At this stage there are several parameters of vibration that can be controlled by the software including duration, intensity, and location. The system is currently designed to facilitate haptic reconstructions preprogramed and triggered by the composer, with a view to extending it to include functionality to produce *ad-lib.* reconstructions for pre-existing works.

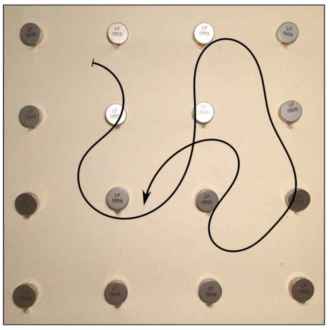

Figure 2. Haptic gestural path through VAM.

This project is particularly interested in illusions, or psychophysical phenomena, that can enhance user experience and reduce hardware requirement. We are currently trialling an implementation of VAM, with coin-type ERM motors (see Figure 2).

4. HAPTICS IN COMPOSITION

The instrumental ensemble work *Traum* (see Figure 3) was designed as an initial system prototype to validate an approach for the simultaneous notation and implementation of haptic stimuli and musical instruments. In this work the haptic line, much like the instrumental lines, is derived from a stochastic process applied to a data set. It is conceived as an individual instrumental alongside acoustic instruments. Using a similar notation style to traditional western transcriptions, but with custom "H" note-head, the haptic *notes* contain data relating to vibration onset, duration, speed and position. Combinations of these parameters were specified as part of the compositional process.

Figure 3. Scoring for haptics in the composition, *Traum*. The haptic line is the 5th stave from the top.

5. ON-GOING AND FUTURE WORK

5.1.1 Hardware Design

A more advanced actuator hardware design is currently being prototyped using the Texas Instruments DVR2605 haptic driver. These drivers come with pre-loaded waveforms and are compatible with both eccentric rotating mass (ERM) and linear resonant actuator (LRA) motor types, something that was unable to be implemented in the previous design iteration.

An individual microcontroller is used for each driver circuit to give maximum flexibility. The PWM signals and extra control available allow different configurations to be tested without changing the hardware. For further prototype iterations, different casing materials, including silicon are being explored to provide a comfortable seat, with efficient vibration

5.1.2 Hardware Validation

In validating the system as a whole, a particular focus is upon perceptually measuring the user's response to haptic stimuli when combined with audio, and the nature of a user's organic and learned response. This will allow a basic understanding of the psychophysical correlates between musical and haptic gestures. This is an on-going project; the validation results of this prototype will guide future revisions, and results from an initial validation comparing the experience of users during a performance with and without the vibrating system are currently being analysed.

5.1.3 Haptic Composition

Several compositional works, incorporating the use of this haptic motor array are currently in development. These works consider haptics as a medium to augment compositional practice in different ways, as a static or dynamic entity in fixed media and generative works, as well as an interactive object in ensemble performance.

One significant consideration for the composer has been the role of the haptic line in terms of its ability to act as both a 'standalone instrument' and an expressive control mechanism, behaving congruently or incongruently with sound. As a purely congruent structure, the haptic line features as a physically analogous sound representation that although useful in the appropriate scenario, does not fully exploit the affective multi-sensorial potential of the technology.

The standalone approach is apparent in a percussion work in progress that considers the actuators as an instrument, composed as part of a stochastic process that defines the rest of the musical lines. Conversely, a fixed-media stereo work is implementing haptics as an expressive, control-based tool to reflect a sense of tactile-auditory space to the listener.

Once the aforementioned hardware design refinements have been completed, we hope to expand the number of composers working with the device, encouraging a richer discourse around the aesthetics of the haptic compositional language.

6. CONCLUSIONS

This paper considers the use of haptics in live music performance to enhance immersion and engagement of audience members. A survey of related literature has been presented, including discourse relating to the sense of touch from both physiological and psychological perspectives, the use of haptics in entertainment and accessibility applications, and the integration of multimodal techniques into compositional practice. An overall view of the system is given, alongside an analysis of current hardware and software developments for the haptic audience system. Closing, the work reflects on work currently in progress, and considers its on-going application in compositional practice.

The system itself has clear implications for the hearing-impaired in a live performance scenario. Physical reconstructions of sound could allow the hearing impaired greater awareness of their surrounding sonic environment. It also has implications in technology-enhanced learning, where the haptic array could be used to assist listeners with score following using a physical representation of tempo and rhythm. This is all part of the on-going and future direction of the work. A discussion of additional multimodal reconstructions being developed alongside this work can be found in Ng *et al.* [20].

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