Vibrotactile Notification for Live Electronics Performance: A Prototype System

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Abstract. In this paper we describe a prototype system for haptic notifications in the context of music performance with live electronics. In current practice there is typically no physical connection between the human performer and the live electronics system, breaking the action-perception loop, which can render performers insecure. Leveraging recent work in the field of tactile notification we aim at closing this loop by communicating information from the live electronics system to the performer via the haptic channel. We present a prototype tactile synthesizer, embedded in a Max-based modular software framework for live electronics, titled CLEF (CIRMMT Live Electronics Framework). Tactile notifications can thus become an integral part of a musical score and communicate information to performers, allowing for tighter interaction with the live electronics system.

Keywords: live electronics, haptics, vibrotaction, human-computer-interaction,

1 Introduction

The use of live electronics for mixed music, i.e. the realtime processing of musical data and sound during a performance, is a common practice in contemporary music performance. A key concern in these contexts is facilitating the interaction between the instrumental performer and the live electronics system, see e.g. [12].

Commonly, performers are left without feedback, not only in terms of immediate response to her own actions, but also about the internal state of the live electronics system. This often results in a sort of temporary "limbo", in which the performer is left without information about the effect of their actions. To improve this situation, different approaches have been taken, e.g. the use of visual or auditory displays, such as having performers observe a screen during performance, or listening to a click track over earphones. Delivering additional information via the visual and auditory channels can be obtrusive and distracting, however, as it requires performers to share the perceptual bandwidth of modalities which are already occupied by other tasks, such as reading a score, listening to the sounds in the performance space, cueing other musicians, etc. The practice of using external assistants to control the electronics, on the other hand, contradicts the idea of a performer autonomously interacting with the live electronics system, and might render her interactions almost obsolete.

A possible solution is to provide information to the performer via another sensory modality: the haptic channel. More precisely, our project aims at providing a tactile notification system which effectively communicates information, is physically unobtrusive and does not distract from music performance. The design of such a system includes both hard- and software engineering aspects, such as investigating appropriate actuators, meaningful actuation signals and flexible ways of controlling them.

2 Tactile Feedback in Music

In this paper we use *Haptics* as an umbrella term which encompasses both kinesthetic and tactile perception [6]. The importance of haptic, and especially vibrotactile cues in the interaction with a traditional musical instrument has been a growing field of interest in recent years. Chafe [3], for instance, investigated which tactile cues can actually be sensed by performers while interacting with an instrument. It has also been stated that haptic feedback is the only component fast enough to convey information about timing and articulation during expert interaction [15].

Tactile feedback has also been extensively used in the design of Digital Musical Instruments (DMIs) [1,4]: the decoupling of the *gestural controller* and the sound producing unit into separate components breaks the haptic feedback loop between the performer and the vibrating parts of the instrument. Tactile-augmented input devices have the capability of closing this loop again, making haptic feedback an important factor in instrument design.

2.1 Tactile Notification, Translation and Synthesis

The use of tactile and haptic feedback technologies in music-related contexts is of course not limited to direct performer-instrument interaction only. Giordano [5], for example, defined a taxonomy of tactile feedback, organized in three main functional categories: *tactile notification*, *tactile translation* and *tactile synthesis*:

A tactile display has been used to display vibration on the body of an audience. The vibration had been composed independently from the music using a specialized tactile composition language [7] (*tactile synthesis*). A vibrating chair has been used as a sensory substitution tool to enable those hard of hearing to experience music through vibrations on their back [9] (*tactile translation*). Tactile stimulation has also been successfully used, for instance, to guide users during the interaction with a virtual environment populated with sound objects [14] (*tactile notification*).

2.2 Tactile Notification in Live Electronics

The use of tactile notification techniques has been explored to coordinate musicians in freely improvised music performances [11]. Similar techniques have been employed to provide feedback about performer actions in live electronics [13].

In addition to direct performance feedback (i.e. in response to performers' actions on the instrument), we aim at generalizing the use of tactile notifications for the display of arbitrary data in a live electronics system. This might include discrete or continuous changes of control-variables used for audio processing, but also abstract/symbolic information. Tactile notifications should be particularly well-suited to provide informations which are otherwise difficult to communicate to a performer on stage, such as temporal (e.g. meter, cue points in a score, etc.) or spatial (the position of a virtual sound source in a spatialization system) parameters. Both the hard- and software prototypes were designed with the goal of providing a flexible, user-friendly, and robust tactile display system that can be seamlessly integrated into a live electronics system.

3 The CIRMMT Live Electronics Framework

The CIRMMT[4] Live Electronics Framework (CLEF) is a modular environment for composition and performance with live electronics, developed by the first author. It leverages concepts first implemented in the Integra GUI, the prototype graphical user interface for Integra Live [2].

Key design factors for this environment –which is geared towards musicians and composers– are extensibility, portability, and ease-of-use. Consequently, it is implemented natively in Max and does not rely on external programming frameworks or software libraries. This makes the environment easily customizable, extensible and portable. All communication in CLEF is handled over a shared message bus using a common syntax in the *OpenSoundControl* (OSC) format [17]. Storage, recall and interpolation of data is handled via Max *dictionaries* and the *pattr* system. Since all functionality is accessible through OSC messages, the environment can be remotely controlled, e.g. through custom graphical user-interfaces, a text console, or via OSC-enabled input devices. The general architecture is based on 3 major components:

- An infrastructure for hosting *Modules*
- A score system, structured into *Events* and *Cues*
- A graphical user interface providing *Views* containing *Widgets*

CLEF has been used for the realization of artistic research projects at CIRMMT and is taught within courses for electroacoustic composition at the Schulich School of Music of McGill University. As a detailed description of CLEF is beyond the scope of this paper, we will only outline the main concepts of *Modules* and *Events* in the following two subsections.

[4] CIRMMT is the "Centre For Interdisciplinary Research in Music Media and Technology" in Montreal, Canada.

3.1 The CLEF Module

A *Module* in CLEF is an abstraction encapsulating specific processing functionality. The processing part (*core*) of a module is wrapped into a hierarchical OSC namespace which is accessible through the global messaging bus. When a Module is 'instantiated', i.e. loaded into the environment, it is assigned a unique address, its namespace is registered, and its signal in- and outputs are connected to a global routing matrix. The hierarchical structure and common syntax of the OSC namespace allows addressing groups of modules or parameters efficiently via OSC's pattern matching features.

3.2 The CLEF Event

Graphical *widgets* can be dropped into Events, such as breakpoint-function-editors, dsp-routing widgets, etc. to specify static or dynamic control data. Events have attributes themselves, such as duration, sample rate, etc. which allows for scrubbing, re-sampling and looping of time-varying data. CLEF also provides functionality for the creation of dynamic/interactive scores: Events are represented as Max *patchers* which can be freely programmed. Thus, users can program Events that generate data algorithmically, respond to changes in the environment, control other Events, etc. We found this a flexible model, suitable for a broad range of applications, from the manual design of automation curves, to the development of interactive, network-like topologies. Fig. 1 shows a screenshot of a number of graphical user interfaces in CLEF.

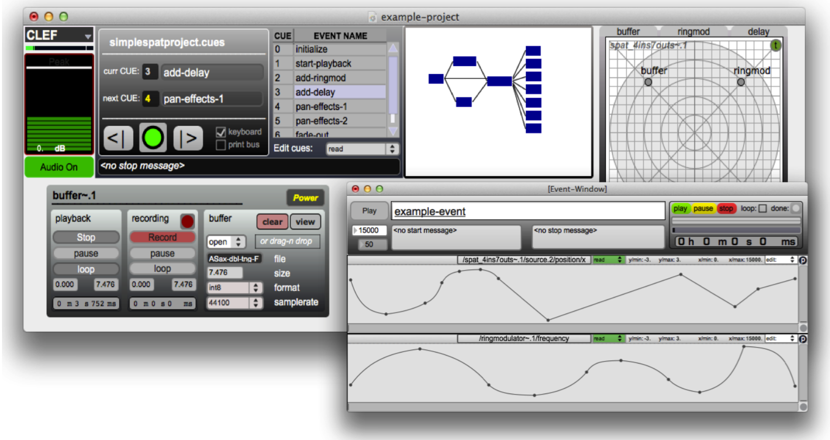

Fig. 1: Screenshot showing graphical user interfaces in CLEF. In the background: the *Performance view* with graphical widgets for real-time control. In the foreground: an *Event view* with graphical widgets containing temporal data.

4 Developing a Tactile Feedback Module for CLEF

The first phase of the project consisted in identifying which types of actuators were most adequate for our purposes. We chose to build a tactile display consisting of two rotating eccentric masses[5] driven by a PWM signal generated via an Arduino Nano board connected to the computer using a USB or wireless Xbee interface.

More sophisticated actuators, such as loudspeaker-like tactile transducers were also examined. Although these devices allow for more complex stimuli to be presented to the skin of the user, we decided to develop a simpler interface allowing us to focus on interfaces and control-strategies for the fewer actuator parameters at our disposal. Another factor was providing a system which is user-extensible. Thus, we chose components which are are inexpensive, widely available, and do not require any specific engineering knowledge to be assembled.

4.1 The Hardware Prototype

The two vibrating disks (rotating eccentric masses) were driven using the PWM output from an Arduino Nano board. The positioning of the actuators was determined in several testing sessions with the performers involved in the project. The disks were attached to a Velcro® band which can be securely worn around the chest. In this configuration, the actuators would be in constant and firm contact with two points on the back symmetrical about the spine, with sufficient distance between them to discriminate left vs. right side stimuli [8]. The display was judged unobtrusive, and the stimuli were very easily detectable even at low intensities.

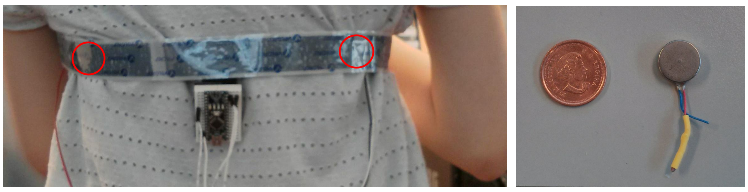

Fig. 2: On the left, a prototyping version of the display worn by one of the users, red circles mark the position of the actuators attached to the velcro band. On the right, one of the actuators used for the display.

[5] `https://solarbotics.com/download.php?file=159`

The types of disks we used, which are commonly found in pagers and mobile phones, do not allow for individual control of frequency and amplitude. The duty-cycle of the PWM wave driving them is the only control parameter which is accessible though the Arduino board. This parameter can be indirectly linked to the perceived intensity of the vibration [10]. In fact, as will be described in the next subsection, we found that the combined use of two actuators provided enough flexibility for the synthesis of a variety of tactile stimuli.

4.2 Tactile Module and Mapping Parameters

Given the infrastructure provided in CLEF, we implemented our prototype as a synthesis module, which can be seamlessly integrated in (existing) live electronics projects and controlled through the global messaging system. As with any other CLEF module, its parameters (accessible through its OSC namespace) can be controlled either explicitly, e.g. using a graphical widget, or implicitly, as a function of other variables in the environment (as a *mapping*). A key aspect in the design of our prototype system, was to make it straightforward for users who were already familiar with CLEF to integrate tactile notifications in their live electronic projects.

Two main modalities were implemented in the tactile feedback module: an *"individual mode"* and a *"balance mode"*. As shown in Fig. 3, in *individual* mode, the actuators (identified as `actuator.1` and `actuator.2`) can be independently controlled. Individual triggers (i.e. single buzzes) can be sent to each of the two actuators, and for each trigger duration and duty-cycle can be specified. The `discrete` stimuli are intended for the display of individual events, such as the beginning and ending of a recording process, and/or in response to performer's interactions using external controllers (such as foot pedals or switches).
In addition to individual triggers, two types of `continuous` actuation are also available: `sustain` and `pulse train`. When the `type` of actuation is set to `sustain`, the motor will keep vibrating at the specified `pwm` value. For the `pulsetrain`, the `frequency` between individual triggers, their `duration` and `pwm` value can be specified. A variety of pulsation patterns can be achieved using these 3 parameters. The `continuous` actuation was conceived as a way of displaying dynamic changes within the system, such as time-varying control parameters for a module. When using continuous vibrations over extended periods of time, for example, the `pulsetrain` type is preferable to prevent sensory adaptation effects [16].

The `balance` mode is intended to display relative values, or ratios between two boundaries, useful e.g. for the display of a "position" on a line, or a weight between two values. This effect is achieved by controlling the relative intensity of vibration between the left and right actuator. In our informal tests, for instance, we used this mode to display the horizontal position of a sound source in a spatialization system. A pulsating `type` of vibration is also available in *balance* mode, for which the duration and duty-cycle of the pulse can be adjusted.

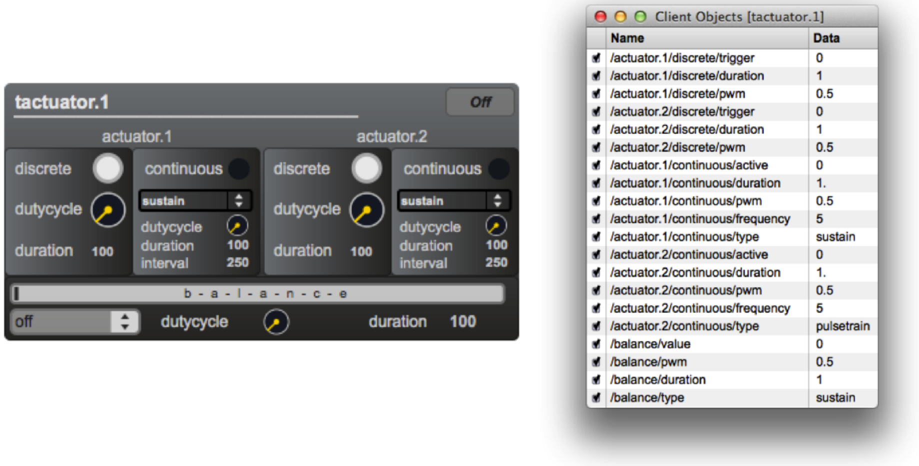

Fig. 3: The graphical user interface of the tactile notification module (left), and the pattr clientwindow showing its namespace (right).

4.3 Preliminary evaluation

To evaluate the effectiveness of tactile notifications for the display of temporal and spatial information, two musical tasks were designed using the different actuation modes described above. The tasks were performed by a percussionist who was familiar with CLEF but had no prior experience with tactile actuation devices for music performance.

In the first task, we tested the use of tactile stimuli to communicate information about tempo and meter by creating a "haptic click track" displayed as series of discrete pulses at regular intervals to the skin of the performer. The task consisted in recording a rhythmical phrase (4 bars at MM 120) into an audio buffer and create more complex structures by recursively overdubbing the buffer in a loop.[6] All control parameters for recording, playback, looping etc. were controlled by an automated sequence of CLEF events with no user interaction. Before the recording started, two bars of count-in were displayed to the performer via the "haptic click-track", which was then kept on during the entire overdubbing sequence. This is an example use-case in which the actuation signals are not directly related to performer actions or audio processing, but are specified as part of a live electronics score.

In the second task, we tested the effectiveness of our system to display continuous spatial information: the position of a sound source in a spatialization system. Contrary to the first task, in which we provided regular, periodic notifications, here our goal was to create a situation in which the live electronics

[6] This practice is commonly known from improvisational performances with so-called "looper pedals".

system generates control parameters in an irregular or indeterministic way, which would force the performer to continuously rely on haptic information. Therefore, we designed a CLEF event, in which the audio input is fed into a spatialization system and the virtual sound source position is continuously moved back and forth along a horizontal line. The duration of the movement, however, is randomly varied between 3 and 5.5 seconds. The task consisted in improvising short musical phrases which needed to be varied in tempo as to start and finish at the "turning points" of the sound source, i.e. the tempo of the phrases had to be adapted to the speed of the sound source. This is an example use-case in which the haptic display is correlated with a control parameter of a processing module in the system, which can be considered a form of mapping.

4.4 Performer feedback

We conducted a brief interview with the performer in order to obtain qualitative feedback about the display and the tasks we designed. Effectiveness of the display in conveying both temporal and spatial information was rated as very high by the performer. The device was judged as unobtrusive and it did not hinder performer's movement and musical expressivity. Tactile display was rated "*second best*" in conveying information about his interaction with the system, after visual feedback but before auditory feedback. He also remarked that:

> "*...in a situation where performers must focus their attention on the sheet music or difficult musical passages or when performers need to be in close visual contact with another performer, tactile feedback is the perfect solution to provide the necessary information to the performer.*"

which confirms our hypothesis that communicating information via the haptic channel is less distracting than using sensory modalities which are already focusing on other tasks. The performer also expressed interest in using the display for future performances/rehearsals.

5 Conclusions

We presented a prototype system for flexible synthesis of tactile notifications integrated into a modular framework for live electronics. We described design criteria for the implementation of our hardware and software prototypes.
The system allows for control and synthesis of tactile stimuli in order to address the problem of the communication gap between human performer and live electronics system.

In our preliminary tests the hardware prototype was perceived as unobtrusive and effective, both in the case of stimuli correlated with audio processing parameters, and for communication of abstract parameters. This suggests that tactile cues can be used by performers and integrated with auditory and visual cues. The software implementation as a CLEF module made it straightforward to integrate tactile stimulation into live-electronic projects and allowed for rapid and flexible design of actuation signals. The successful use of the system in our preliminary tests is suggestive that tactile notifications could effectively become a parameter included as any other musical parameter in scores for live electronic pieces.

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