Mechanical Entanglement: A Collaborative Haptic-Music Performance

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ABSTRACT

Mechanical Entanglement is a musical composition for three performers. Three force feedback devices each containing two haptic faders are mutually coupled using virtual linear springs and dampers. During the composition, the performers feel each others' gestures and collaboratively process the music material. The interaction's physical modelling parameters are modified during the different sections of the composition. An algorithm which process three stereo channels, is stretching in and out-of-sync three copies of the same music. The performers are controlling the stretching algorithm and an amplitude modulation effect, both applied to recognisable classical and contemporary music recordings. Each of them is substantially modifying the length and the dynamics of the music and is simultaneously affecting subtly or abruptly the gestural behaviour of the other performers. At fixed points during the composition, the music becomes gradually in sync and the performers realign their gestures. This phasing game between gestures and sound, creates tension and emphasises the physicality of the performance.

1. INTRODUCTION

The computer music research community has been exploring the use of haptics and force feedback within a musical context since the first explorations in the late seventies at ACROE [1]. Numerous force feedback interfaces for musical purposes have been developed since then [2–12].

The last decade has similarly presented a growing interest in musical composition with the use of force feedback technology. Compositions such as *Running Backwards Uphill* by Hayes , *Engraving Hammering Casting* by Berdahl and Kontogeorgakopoulos, *Hélios* by Cadoz, *Quartet for Strings* by Beck, *Of Grating Impermanence* by Pfalz amongst others have explored the potential of haptics in purely musical or audiovisual artistic context [13–15]. In all of these compositions for solo musicians or small orchestras such as the Laptop Orchestra of Louisiana, there was no intercoupling at the gestural level; the hands of the musicians were mechanically coupled with their musical instruments but not between them. The current paper explores this novel concept by presenting a composition based on a developed haptic digital musical instrument where the gestures of the performers are co-influenced mechanically during the performance.

Mechanical Entanglement is an electroacoustic composition and a research project on a collaborative haptic musical system. It was composed for a small musical ensemble of three performers (trio) interacting with three mutually coupled force feedback devices. The performers process in real time the same sonic material while they were interacting mechanically between them through a virtual viscoelastic network. This novel type of collaborative performance offers a new type of music co-creation based on haptic telepresence.

The paper is organised in three sections. The first section presents the technical aspects of the musical system developed. The second section offers an insight on the compositional and the performative elements of the project. The final section presents a discussion on the project holistically, both from a functional and an aesthetic point of view.

2. SYSTEM DESCRIPTION

A 3D model of the system's structure used in the project is illustrated in figure 1. As can see from this higher level description, the system consists of two main blocks withdifferent functions. The haptic component of the system executes all the haptic signal processing operations and generates the haptic responses while the sound component executes all the audio signal processing operations and generates the audio output. The following subsection presents in more details those two components.

2.1 Haptic Signal Processing

The haptic device used in the research project and composition is the FireFader [11]. This device consists of open-source hardware and open-source software elements and is optimised for introducing musicians to haptics. It offers a single-degree-of-freedom motorised potentiometer fader at a low price and can be combined with the haptic signal processing framework (HSP) where the users can quickly design and develop their own haptic, audio and visual responses and hence create complete multimodal environments and compositions [16]. HSP runs on well-known computer music languages such as Max and Pure Data which was a considerable advantage for the current project since other sound processing algorithms which interact with the haptics were developed in those languages

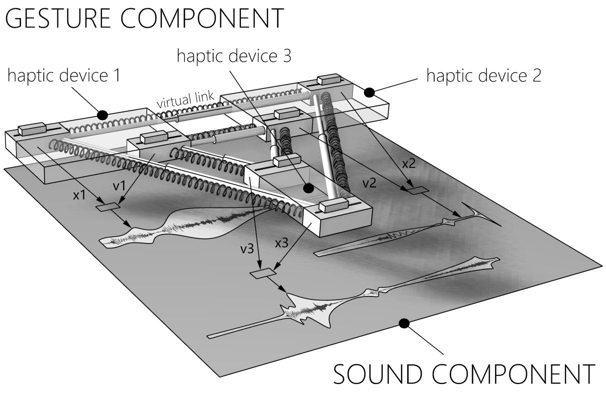

Figure 1. 3D model of the System's Structure.

too. Alternative commercial general-purpose cost-effective force feedback devices such as the NovInt Falcon from NovInt Technologies or the Geomagic Touch (formerly Phantom Omni) from 3DSystems were not considered since they do not have an appropriate form and workspace aligned with the concept of the project.

Three FireFaders with two motorised faders each are connected through USB to a computer that performs mainly the haptic calculations and runs the haptic models designed by the authors on the Max programming environment. The audio signals are generated on a different computer, connected to the first one through the open sound control protocol (OSC). Therefore data captured in real time from the haptic faders on the first computer are transmitted through an Ethernet twisted pair link into a second computer in order to control the audio playback and processing. More details regarding the audio processing part of the setup is given in the following section. Finally, each haptic device has two bright LED lights offering visual feedback of the force applied to each motor. This feature added an interesting angle to the performance which is further explored in section 3.

The physical model designed and developed for the project is based on the lumped element modelling paradigm and more precisely on the Cordis-Anima system [17]. A simple mass-interaction network, connecting linearly the three haptic devices between them was implemented on the Haptic Signal Processing framework using the Max programming environment. Each faders physical knob behaves like an ideal material element in the virtual mechanical network. Those ideal masses are linked between them mechanically using linear springs and dampers. The spring constants and the damping coefficients are modified dynamically during the length of the composition as each section corresponds to a different set of parameters. Figure 2 presents the block diagram of the overall signal processing system developed in this project.

Therefore the three haptic devices are part of the same oscillatory system. The performers are controlling the same sound processing algorithms with their gestures while they are "internally" interacting between them via the virtual

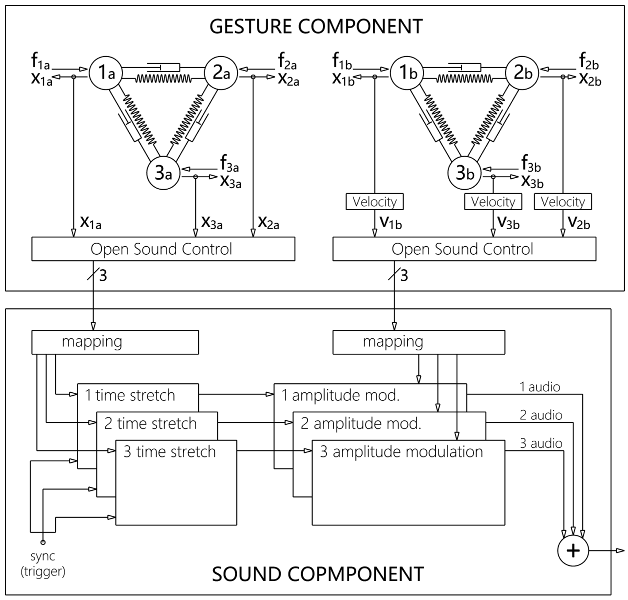

Figure 2. Block Diagram.

links in the virtual network. Their hands are in continuous mechanical interaction which creates a mysterious reciprocal influence. The whole process is coherent energetically because of the nature of the force feedback devices and their coupling with the physical models. This is what Cadoz calls *ergotic interaction* [18]. The OROBORO controller futures some similar aspects where they introduced a haptic mirror in which the movement of one performers sensed hand is used to induce movement of the partners actuated hand and vice versa [19].

2.2 Music Signal Processing

All sound is produced through the Ableton Live digital audio workstation with the embedded Max For Live environment (Max4Live). Therefore, the Live software forms the space in which the composition is created in a traditional linear timeline and at the same time hosts all the necessary software that enable the faders to control the performance through the OSC messages. This software was created as two Max4Live software devices, that is, special Max/MSP patches that can be loaded as plugins in the Ableton Live environment.

Our composition was created as a Live Set, that is, the type of document that you create and work within Ableton Live. It comprises three identical but independent of each other tracks corresponding to the three pairs of haptic faders. Each track hosts the two Max4Live devices serially connected that we developed for the purposes of this composition. The first device plays back a predefined audio file at a variable playback speed without affecting its pitch, while the second controls the amplitude of its output. Each pair of faders controls a single track. The position of the first of the two faders in the pair controls the playback speed, so that it varies between normal to the extreme 0.1 x the original speed, which resembles a freeze effect. The velocity of the second fader controls the amplitude, so that when the fader does not move no sound is coming out of the trackss output. A linear mapping between velocity and amplitude was used with an adjustable scale factor.

All three tracks play the same audio file which is preloaded into memory using a shared buffer Max object. Playback starts at the beginning of the file and in synchrony between the three tracks. However, as the playback speed varies according to the position of each fader, a phase difference between the tracks accumulates. However, each playback device is equipped with a sync button, which sends its playback position to the other playback devices (through send-receive Max objects), effectively forcing playback in all tracks to align again. Before the tracks jump to the new sync position, they smoothly fade out leaving only a single track sounding for a short duration of about 2 sec, before all tracks start playing back together in synchrony. The amplitude dropping not only helps avoiding undesirable cuts in the sound but it also emphasizes the synchronization.

Besides controlling the performance, the Live Set was used to structure the composition into sections. To this end, a separate track was used to send OSC messages to the haptic faders system through a dedicated Max4Live device. In this way, we could choose dynamically or according to the timeline the parameters of the physical models corresponding to each section of the composition. Since our composition comprises several sections that need different audio files, several memory buffers were used to load the audio files of each section at the beginning of the performance, ensuring a smooth transition between the sections. The playback devices were simply switching between memory buffers at the beginning of each section.

3. COMPOSITION

3.1 Ideas and Concept

The music project is based on the concept of stretching: physically-stretching a simulated material while simultaneously time-stretching a pre-recorded music material. It aspires an integration of auditory, haptic and even visual cues with use of dimmed LED lights as we will see in the following section. Figure 3 illustrates metaphorically what was happening at a mechanical level during the performance.

Each performer is allowed to move at his own speed by the time-stretching algorithm through the given material, a process which Michael Nyman calls *people process* [20].

The tensions created by this process, form the "sculptural" elements of the musical composition. The action-reaction pair of forces from all the performers, acting together on the same musical parameters is creating points of equilibrium, sonically and gesturally. The principal compositional process employed is *phasing* [21]. The time-stretching algorithm simultaneously processes three stereo audio channels, stretching in an out-of-sync three copies of the same music recording.

The simultaneous playback of the same material at different speeds creates tension both harmonically and rhythmically [22]. This tension is resolved when the playback between the tracks is forced to realign at certain moments in

Figure 3. A metaphor: hands stretching a physical material.

the composition (through the sync button on the playback Max4Live devices described in section 2.2). This resolution does not last long as the playback drifts anew between the tracks. Nevertheless, these moments of ephemeral synchronisation function as structural anchors in the composition.

Rhythmically, layering the same rhythmic pattern at three different speeds presents the listener with three different possible metrical frameworks, each at a different tempo and phase. Some listeners might focus on the stream that has a moderate tempo (in the range 80-130 bpm) as Parncutt has shown, [23], or on the stream that is closer to the original speed and therefore more recognisable. As the speed and tempo of each stream varies, the attention focus of the listener constantly shifts between them.

At the same time, each tracks rhythm is the result of the interaction between the amplitude modulation and the rhythm resulting from the playing back at a variable tempo. However, even though each tracks audio is manipulated independently, both the tempo and amplitude modulation are the result of a single physical model realised in the network of haptic faders. The interaction between the performers is what drives the variance between the tracks. After all, until the performers interact through the faders no sound is produced as the tracks move forward through the audio files silently and in synchrony. Any tension arising from layering different versions of the same material reflects the tension and forces between the faders arising from the physical model system connecting the performers.

3.2 Performance in the Gallery

Mechanical Entanglement was performed in M.A.D.E. gallery in Cardiff in June 2016. It was not a typical concert situation, which created a captivating experience both for the performers and the audience. The composers of the piece, also the performers in that occasion, tried to create a serene environment which matched the quiet nature of the composition. They sat on cushions on the floor in close proximity to each other, each holding a haptic device on their hand while the audience sat or stood around them. The room was dark enough in order to emphasise further

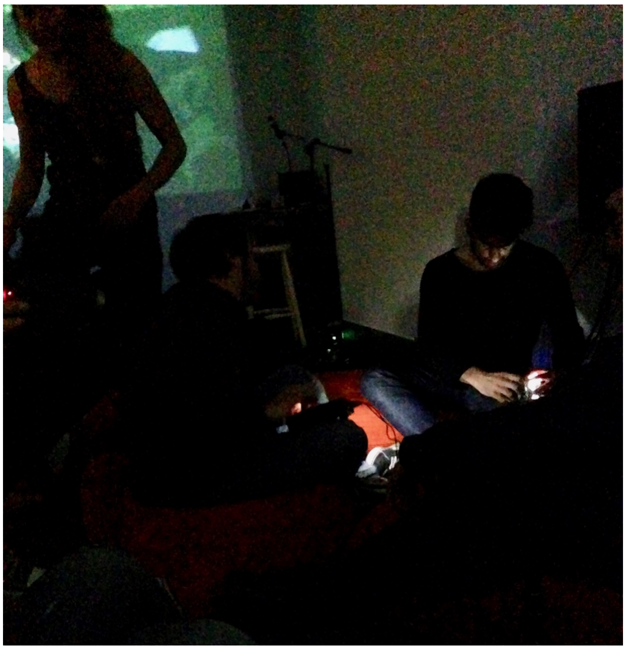

Figure 4. The performance in the gallery space.

the force feedback activity with the use of responsive LED lights as mentioned in section 2.1 and depicted in figure 4. This created a dramatic atmosphere, where the hands of the performers were cast with light in the moments of the performance with high physical tension. A camera operator was also filming the process and projecting it on a gallery wall.

The music material may vary each time the piece is performed. The following list is the selection of music tracks that were used completely or partially in the performance in M.A.D.E. in the order of appearance. The total duration of the concert was approximately 30min.

- *Pavane pour une Infante Defunte* by Maurice Ravel
- *Superman* by Laurie Anderson
- *Cello Suite no1* by Johann Sebastian Bach
- *Drumming pt. II* by Steve Reich
- *Prelude and Fugue No 1* C by J. S. Bach
- *Symphony No 6, 5th movement* by L. van Beethoven
- *Blue Moon* by Elvis Presley
- *Bolero* by Maurice Ravel

Each section of the composition corresponded to a different music track and had its own physical modelling parameters. Therefore it allowed different type of gestural interaction, from very fast ones to smooth and precise ones where the nuances amongst the performers where felt more intensively. A few excerpts from the performance can be heard on the following link [1], as recorded from a stereo microphone positioned in the middle of the room of the gallery space. The music tracks were chosen according to how they responded to the time-stretching algorithm and their overall texture. The authors prefered to include well-known tonal musical compositions from different genres with clear and preferably repetitive musical structure and moderate dynamic range.

It is interesting to mention that during the performance, the modelling coefficients often took values impossible to occur in nature such as negative damping between the interaction of the performers, thus creating very unfamiliar interaction sensations. Moreover, instabilities that occurred due to the long feedback control delays made the gestural and sonic dialogue very difficult and quite often unpredictable. This is a difficult problem in haptic interaction and is related to the latency between the hardware and the software components of the device. The total latency all the way around the control loop with audio running in Max ranges between 7ms and 15ms due to jitter as measured and reported on the firmware of the FireFader device. In the current occasion the composers decided to use creatively these instabilities and make them part of the compositional and performance discourse.

4. DISCUSSION

The performers constantly shaped and explored a "viscoelastic" environment of gestures and sound. In the physical-tactile level they were always feeling the flow of interactions between them and had to find ways of anticipating the unpredictability of their instrument behaviour. The fingertips functioned simultaneously to express the performers own musical intention and experience the intentions of others. As such, the act of performing was indispensably connected with the act of tactile-listening, forming an enhanced tactile environment, where every performing force is applied upon forces produced by the other performers. By participating in this mass-interaction network the performers could perceive themselves as active counter weights on an oscillatory system, which had no fixed point at all. This intercoupling at the gestural level provided a haptic telepresence where each performer preserved a unique "view point" or *tact-point* as authors called them, of the performance space.

The auditory experience was common for every performer; by aligning the performers to a common task gave the shift for an intense collaborative group experience to happen. The auditory level acted as a catalyst for the abstract and mental aspects of the composition to permeate into the physical level. The performers were challenged to focus on the flow dynamics of the group's interaction environment, instead of solely mastering a deterministic musical instrument.

This approach is aligned with Chadabe's taxonomy of electronic musical instruments as a continuum between deterministic and indeterministic function [24]. The current project fluctuates continuously between those states, since the shared control with the other performers (and not with algorithms as in Chadabe's case) often gives the impression that the instrument in itself generates unpredictable information to which the performers have to react.

[1] https://onecontinuouslab.net/Projects/#MechanicalEntanglement

A minor problem of the design of the haptic devices was that the auditory experience was interrupted by sounds made by the haptic device itself, when the fader was reaching its end points during abrupt oscillation moments. This problem can be solved partially by designing a more robust enclosure for the haptic device, a direction which the team has started to explore after the performance [2].

From the point of view of the audience, the LED lights provided a pleasant visual feedback of the interactions and gestural activities but often proved inadequate to offer a coherent understandable connection between the composition and the haptic system. However,, they reveal the systems idiosyncratic nature at moments of apparent inactivity but with strong counter forces at the fingertips of the performers.

It would be interesting to recreate the same conditions in the future, with haptic digital audio effects as described in [25]. In this scenario, the physical audio effect models implemented likewise with the mass-interaction physical modelling paradigm would provide force feedback to the performer without any disruption of the energetic loop between the performers, the haptic device and the physical models. The audio processing and haptic processing algorithm belong to the same physical model. Therefore the performers would be fully immersed in a mechanical network that would equally produce the haptic responses and the audio output without any "artificial" mapping strategy. Finally network music performances and further research on the topic of haptic telepresence within the music context are planned in the future.

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5. REFERENCES

[1] C. Cadoz, A. Luciani, J.-L. Florens, and N. Castagne, "ACROE-ICA: Artistic Creation and Computer Interactive Multisensory Simulation Force Feedback Gesture Transducers," in *Proceedings of the 2003 conference on New Interfaces for Musical Expression*. Montreal, Canada: McGill University, 2003, pp. 235–246.

[2] C. Cadoz, A. Luciani, and J.-L. Florens, "Responsive Input Devices and Sound Synthesis by Simulation of Instrumental Mechanisms: The Cordis System," *Computer Music Journal*, vol. 8, no. 3, pp. 60–73, 1984.

[3] B. Gillespie, "The Touchback Keyboard," in *Proceedings of the International Computer Music Conference*, San Jose, CA, 1992, pp. 77–80.

[2] https://onecontinuouslab.net/Projects/#HapticFaderEnclosure

[4] C. Nichols, "The vbow: A Virtual Violin Bow Controller for Mapping Gesture to Synthesis with Haptic Feedback," *Organised Sound*, vol. 7, no. 02, pp. 215–220, 2002.

[5] B. Verplank, M. Gurevich, and M. Mathews, "The Plank: Designing a Simple Haptic Controller," in *Proceedings of the 2002 conference on New Interfaces for Musical Expression*. Dublin, Ireland: Media Lab Europe, May 2002, pp. 1–4.

[6] J. Carlile and B. Hartmann, "OROBORO: A Collaborative Controller with Interpersonal Haptic Feedback," in *Proceedings of the 2005 conference on New interfaces for musical expression*. Vancouver, Canada: University of British Columbia, 2005, pp. 250–251.

[7] T. H. Andersen, R. Huber, A. Kretz, and M. Fjeld, "Feel the Beat: Direct Manipulation of Sound during Playback," in *First IEEE International Workshop on Horizontal Interactive Human-Computer Systems*, Adelaide, Australia, Jan. 2006, pp. 123–126.

[8] R. Oboe, "A Multi-Instrument, Force-Feedback Keyboard," *Computer Music Journal*, vol. 30, no. 3, pp. 38–52, 2006.

[9] J. Rodriguez, A. Shahrokni, M. Schrittenloher, and M. Fjeld, "One-Dimensional Force Feedback Slider: Digital Platform," in *IEEE VR 2007 Workshop on Mixed Reality User Interfaces: Specification, Authoring, Adaptation*, 2007, pp. 47–51.

[10] R. Gabriel, J. Sandsjo, A. Shahrokni, and M. Fjeld, "BounceSlider: Actuated Sliders for Music Performance and Composition," in *Proceedings of the Second International Conference on Tangible and Embedded Interaction*, Bonn, Germany, Feb. 2008, pp. 127–130.

[11] E. Berdahl and A. Kontogeorgakopoulos, "The firefader: Simple, open-source, and reconfigurable haptic force feedback for musicians," *Computer Music Journal*, vol. 37, no. 1, pp. 23–34, 2013.

[12] J. Bak, W. Verplank, and D. Gauthier, "Motors, Music and Motion," in *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction*. ACM, 2015, pp. 367–374.

[13] E. Berdahl and A. Kontogeorgakopoulos, "EngravingHammeringCasting: Exploring the Sonic-Ergotic Medium for Live Musical Performance," in *Proceedings of the International Computer Music Conference*, Ljubljana, Slovenia, Sep. 2012, pp. 387–390.

[14] L. Hayes, "Performing Articulation and Expression Through a Haptic Interface," in *Proceedings of the International Computer Music Conference*, 2012.

[15] J. Leonard, N. Castagne, C. Cadoz, and A. Luciani, "The MSCI Platform: A Framework for the Design and Simulation of Multisensory Virtual Musical Instruments," in *Musical Haptics*, S. Papetti and C. Saitis, Eds. Springer, 2018, pp. 151–169.

[16] E. Berdahl, A. Kontogeorgakopoulos, and D. Overholt, “HSP v2: Haptic Signal Processing with Extensions for Physical Modeling,” in *Proceedings of the Haptic Audio Interaction Design Conference*, Copenhagen, Denmark, Sep. 2010, pp. 61–62.

[17] C. Cadoz, A. Luciani, and J.-L. Florens, “CORDIS-ANIMA: A Modeling and Simulation System for Sound and Image SynthesisThe General Formalism,” *Computer Music Journal*, vol. 17, no. 1, pp. 19–29, 1993.

[18] C. Cadoz and M. Wanderley, “Gesture-Music,” in *MM Wanderley and M. Battier (Eds.), Trends in gestural control of music*. Ircam, 2000.

[19] K. Mcdonald, D. Kouttron, C. Bahn, J. Braasch, and P. Oliveros, “The Vibrobyte: A Haptic Interface for Co-located Performance,” in *Proceedings of the 2009 conference on New interfaces for Musical Expression*. Pittsburgh, Pennsylvania, USA: Carnegie Mellon School of Music, 2009.

[20] M. Nyman, *Experimental music: Cage and beyond*. Cambridge University Press, 1999, vol. 9.

[21] S. Reich, *Writings on Music, 1965-2000*. Oxford University Press, 2002.

[22] E. F. Clarke, “Levels of Structure in the Organization of Musical Time,” *Contemporary Music Review*, vol. 2, no. 1, pp. 211–238, 1987.

[23] R. Parncutt, “A Perceptual Model of Pulse Salience and Metrical Accent in Musical Rhythms,” *Music Perception: An Interdisciplinary Journal*, vol. 11, no. 4, pp. 409–464, 1994.

[24] J. Chadabe, “The Limitations of Mapping as a Structural Descriptive in Electronic Instruments,” in *Proceedings of the 2002 conference on New Interfaces for Musical Expression*. Dublin, Ireland: Media Lab Europe, 2002, pp. 1–5.

[25] A. Kontogeorgakopoulos and G. Kouroupetroglou, “Low Cost Force-Feedback Haptic Interaction with Haptic Digital Audio Effects,” in *Lecture Notes in Artificial Intelligence: Gesture and Sign Language in Human-Computer Interaction and Embodied Communication*, E. Efthimiou, G. Kouroupetroglou, and S.-E. Fotinea, Eds., vol. 7206. Springer Verlag, 2012, pp. 48–57.