AFFORDANCES OF VIBRATIONAL EXCITATION FOR MUSIC COMPOSITION AND PERFORMANCE

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ABSTRACT

Mechanical vibrations have typically been used in the performance domain within feedback systems to inform musicians of system states or as communication channels between performers. In this paper, we propose the additional taxonomic category of vibrational excitation of musical instruments for sound generation. To explore the variety of possibilities associated with this extended taxonomy, we present the *Oktopus*, a multi-purpose wireless system capable of motorised vibrational excitation. The system can receive up to eight inputs and generates vibrations as outputs through eight motors that can be positioned accordingly to produce a wide range of sounds from an excited instrument. We demonstrate the usefulness of the proposed system and extended taxonomy through the development and performance of *Live Mechanics*, a composition for piano and interactive electronics.

1. INTRODUCTION

In recent years there has been an influx of new haptic devices and vibrotactile feedback applications geared towards electronic music performance. The aim of most of these systems is to incorporate a missing haptic modality and thereby mitigate limitations imposed by various controllers and sensor-based interfaces. As musical performance is a skilled practice, it requires the precise manipulation of the instrument by a user. To realise any musical intentions, the causal relationship between performer and instrument, either acoustic or digital, must be implicitly understood. While the feedback modalities shared by an acoustic instrument and performer are well-established, the use of sensor-based interfaces may produce *unnatural* relationships that contradict known physical performance associations imposed by years of practising.

Many technologically savvy performers develop unique sensor-based instruments; however, widespread adoption of these instruments is mitigated by the inherent unfamiliar relationships. Limited and unnatural feedback in technology-mediated performances often may result in disassociation by the performer, which can have a severe impact on expressiveness [1]. In this paper, we investigate the modality of vibrational excitation and propose a taxonomy that may encourage new applications within a creative music systems framework. We see vibrations as a tool that can not only confirm actions to a performer, and be used to communicate information between musicians, but also be part of a system capable of producing sounds. Towards creative exploration of affordances in the vibrational domain, we propose the *Oktopus*, a system that provides vibrating excitation points that can be used by performers, composers and artists. We also discuss the composition *Live Mechanics*, which uses the Oktopus as part of a creative interplay between a performer, piano, and computer interface.

1.1 Background

1.1.1 Affordances and Music Systems

Gibson [2, 3] suggests that an understanding of a relationship between object and user is limited without integrating tactile feedback, and introduces the concept of affordance to describe the relationship between the two modalities.

Norman [4] extends this concept suggesting that the design considerations of objects have inherent affordances associated with how they may be used (e.g., a chair affords sitting but not long distance travelling).

Affordances in digitally-mediated musical performances are often the result of integrating hardware capabilities with software. Magnusson [5] incorporates such affordances in the design of screen-based musical instruments, for which the performer has a metaphorical relationship that reflects creatively on how compositional ideas are formulated. Likewise, Tanaka et al. [6] found that participants were able to associate the embedded connection between controller generated affordance and the produced gesture-sound relationship. The potential of visual interaction between sound and movement is similarly investigated in [7, 8].

Musical tools have a spectrum of affordances as they invite users to work in particular ways, which ultimately colours creative output [9].

It is essential to add that listeners also make use of affordances within music performance, enabling the creation of abstract impressions in their appreciation of the sonic experience.

1.1.2 Vibrational Excitation

There is a well-established tradition of the inclusion of vibrational feedback in the haptics loop of sensor-based musical systems. Perhaps most importantly, it allows a performer to interact with a musical system without a change in focus; peripheral information is constantly present without requiring action on behalf of the musician.

Such approach has been demonstrated by the Networked Vibrotactile Improvisation System (NeVIS) [10], which provides communication cues between multiple musicians enabling interaction and improvisation. Vibrotactile communication can also take place online between remote spaces [11]. Moreover, in Digital Musical Instruments (DMIs), vibrotactile feedback is applied to provide somatosensory feedback, critical for expressive outcomes by the performers [12, 13].

1.2 Motivation

2. TAXONOMY OF VIBRATIONAL EXCITATION

While vibrotactile feedback has received much attention within the human-computer interaction (HCI) field [14,15], vibrational excitation for sound generation has been a relatively understudied area in the literature. We believe it has the potential to yield musically interesting results due to: (1) the close relationship between fine-resolution control mechanism and the sonic output of excited instruments or objects; and (2) the possibilities of communication between systems and performers, which can contribute to the expressivity of a piece. We, therefore, propose a taxonomy of vibrational excitation to include sound generation. We present the Oktopus as an example system by which we realise all taxonomic categories and a musical piece produced using the Oktopus as a case study, demonstrating the worth of this mode of interaction to musical performers and composers.

The remainder of this paper is structured as follows: Section 2 presents the proposed taxonomy of musical sounds possible through vibrational excitation. We present the developed vibrational excitation instrument in Section 3, and discuss a performance of a piece composed using vibrational excitation in Section 4. Finally, conclusions and future work are then discussed in 5.

2.1 Interactive Vibrations

As discussed in earlier research by [1, 13–15], vibrations produced from the motors can be directly applied to the body as part of the vibrotactile feedback experience. For this paper, we consider the described vibrotactile feedback as affordances of vibrational excitation. We consider the way an active agent (the performer) manifest interactive vibrations from a non-active agent (the music system). We address non-active agents as music systems that can process incoming data from external sources as well as generate appropriate data to provide vibrotactile feedback to the user. The active agent should be responsible for initiating interactions between active and non-active agent. While a system may be able to initiate interactions and provide vibrotactile feedback through artificial intelligence, we exclude such approaches from this taxonomy. We focus how vibrotactile feedback provides information about the past, present and future states of the system.

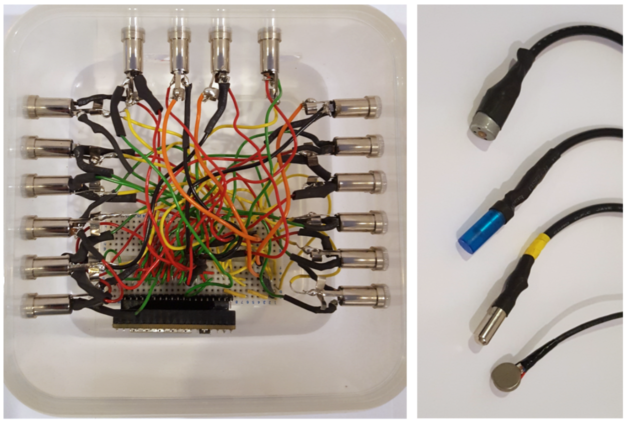

Figure 1. An overview of the Oktopus prototype. The control mechanism (*left*) is an x-io Technologies x-OSC device, housed in a plastic enclosure with $\frac{1}{8}$” jacks attached to the housing. From top to bottom, the Precision Microdrives (PM) motors (*right*) used, including the PM 312-004, PM 307-103, PM 306-117, PM 310-113.

2.2 Communicative Vibrations

In addition to the use of vibrations to accommodate relationships between human and non-human agents, we employ vibrotactile feedback to support the relationships between two or more active agents. Vibrotactile feedback We use vibrotactile feedback as a tool to mediate communication between performers, composers, and audiences. In a typical ensemble music performance, audio can be seen as the primary source of communication—along with visual feedback (e.g., knotting, eye contact, other non-verbal interactive attributes). The interaction that takes place between different members of an ensemble dramatically affects the outcome. Through vibrations, new communicative links can be established further exploring the creative interplay as can be seen in [10, 11].

A wide range of information can be used to drive the vibrations and communicated to others. For example, in a laptop duet performance, vibrations can be used to synchronise a new tempo, alert one another about the upcoming climax, change of sections or provide feedback of each other’s use of faders. Furthermore, movements, gestures, heartbeat rate and other biometric data can be used to communicate between the two.

2.3 Motor Excitation, Sound Vibrations

We use motors to generate sounds from musical objects by either securely attaching them, resulting in vibrating and resonating the object acoustically; or by placing them loosely, which enables the motors to act as a small hammer constantly bouncing on the surface. Different surfaces and materials (e.g., wood, metal, plastic) produce distinctive sounds. This also includes larger objects that encompass a variety of materials and shapes. A violin, for example, is made of wood (body) and metal (strings) and has a distinctive design that resonates and characterises the sound. There is a different sound when a motor is attached to the back of the violin from one that is produced when the motors are let loose to bounce on the body. Furthermore, the sound of this interaction is also affected by the type of motor used. In Section 3.3 we describe some fundamental characteristics of particular motors to demonstrate their complex relationships with the sonic outcome.

When we consider the way the motors can be activated and controlled through pulse-width modulation (PWM) (see: Section 3.1) a new sonic palette is available for exploration. As a result, there are endless sonic combinations that can enhance the creativity of performers, composers and artists.

3. THE OKTOPUS

We present the Oktopus, a system that allows for the exploration of vibrational affordances associated with the taxonomy presented in Section 2. The system was designed for general purpose operation to provide a performer, composer or artist with a base vibrational excitation system for which specialised software may be applied for the task at hand. In the following, we first discuss the process by which vibrational excitations are generated through the use of motors (Section 3.1), and subsequently the system design chosen for the prototype (Section 3.2).

3.1 Vibration Production

There are a variety of ways to artificially produce vibrations; in the following, we examine the use of enclosed eccentric rotating masses (ERM), which are commonly used for providing vibrotactile feedback on the body. Relatively compact, ERM motors are suitable for wearable feedback and can be controlled with voltages below 5v which makes them preferable when driven through PWM signals. Furthermore, ERM motors are reliably consistent in their response, which is of utmost importance when—for example, exciting stringed instruments at a constant pitch.

There is a wide range of such motors available in different sizes, weights, and attributes. Two of the main features responsible for driving the motors are *vibration amplitude*, which measures the intensity of the applied vibration (monitored in G-force) and the *vibration frequency* of the motor, which depends on the applied voltage. Both of these characteristics are inextricably linked and cannot alter one without affecting the other. A third vital feature to consider is the *typical start voltage* that indicates when the mass on the enclosed motor will rotate and start vibrating. Depending on the size of the motor, different start voltage is required to drive the enclosed mass which introduces latency. As discussed above, PMW is often the preferred method for providing the voltage for driving the motor. PWM has three main components; the *PWM Voltage* which is dictated by the microcontroller; the *Frequency* that is the period of one clock cycle and the *Duty Cycle* that is the ratio of the on-time to the off-time, which controls the resulting voltage. All the above components contribute to the way a motor may produce vibrations.

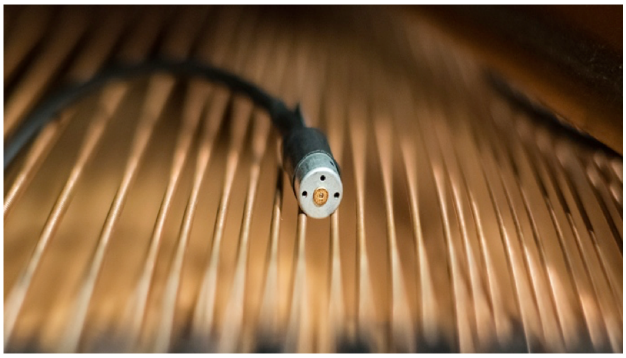

Figure 2. Motor placement on lower register strings of the grand piano. While placing motors between strings creates predictable tonalities, leaving them atop the strings leads to an unpredictable movement across various strings.

3.2 System Design

Figure 1 presents an overview of control mechanism (left) and the motors used (right). At the core of the Oktopus is an x-io Technologies x-OSC device, [1] an inertial measurement unit (IMU) prototyping board able to generate up to sixteen simultaneous outputs and sixteen input signals [16]. The x-OSC was selected as it allows for both switchable inputs (analogue or digital) and outputs (PWM or digital). The PWM outputs, which are responsible for driving the motors, are capable of 16-bit resolution and range from 5Hz to 250kHz. Communication (inputs and outputs) is over an ad-hoc Wi-Fi network on the x-OSC and delivered through Open Sound Control (OSC) messages. The system may be powered by either battery or by a power source via USB. A plastic enclosure houses the device with $\frac{1}{8}$" female mono jacks attached to the housing, which enables a pluggable connection between motors and sensors. Connected to the x-OSC device are eight PWM outputs that are used as end nodes for connecting the motors that will be driven by the device. The remaining eight end nodes are used as inputs.

3.3 Motors

To increase the variety of sonic results capable by the Oktopus, we utilise a variety of motors each with unique characteristics (e.g., enclosure material, weight and vibrational features (Section 3.1)). The motors used in the case study are developed by Precision Microdrives [2] (PM) and are presented in the right image of Figure 2 from top to bottom as follows.

PM 312-004: Metallic enclosure; typical start voltage 1.1v; typical vibration amplitude 5G; weighs 8.8g; body diameter 12mm; body length 20mm; typical lag time 12ms; typical stop time 44ms.

[1] http://x-io.co.uk/x-osc/
[2] https://www.precisionmicrodrives.com

PM 307-103: Plastic enclosure; typical start voltage 0.35v; typical vibration amplitude 7G; weighs 4.6g; body diameter 8.7mm; body length 25.1mm; typical lag time 8ms; typical stop time 49ms.

PM 306-117: Metallic enclosure; typical start voltage 0.45v; typical vibration amplitude 2.2G; weighs 5g; body diameter 7mm; body length 24.5mm; typical lag time 14ms; typical stop time 53ms.

PM 310-113: Metallic enclosure; typical start voltage 1v; typical vibration amplitude 1.34G; weighs 1.2g; body diameter 10mm; body length 3.4mm; typical lag time 47ms; typical stop time 112ms.

The various features result in different response characteristics for each of the motors. For example, the PM 312-004 has a metallic enclosure with an average vibration amplitude of 5G and weighs 8.8g whereas the PM 307-117 has a plastic enclosure with an average vibration amplitude of 7G and weighs 4.6g. Based on these characteristics the PM 307-103 will *bounce* more than the PM 312-004 as it has a higher vibration amplitude and is lighter. Similarly, the PM 312-004 would be a better option for resonating larger objects—for example, a low-register string on a piano as shown in Figure 2.

In addition to the composition presented in Section 4, we have generated a small sample library to demonstrate the possibilities of the interaction between the Oktopus and a grand piano. [3]

4. CASE STUDY

The case study looks specifically how vibrations can be used to create and perform sounds. In the following, the composition *Live Mechanics* (composed and performed by the first author) is discussed as well as the system Oktopus that facilitates the process.

4.1 Live Mechanics

The case study looks how vibrations can be used to create and perform sounds. In the following, the composition *Live Mechanics* (composed and performed by the first author) is discussed as well as the system Oktopus that facilitates the process.

Live Mechanics for piano and interactive electronics uses vibrations to excite the strings of a grand piano. [4] Five vibrating motors are used to resonate the strings of the piano to generate sound mechanically. An overview of the control structure of the piece is presented in Figure 3. The performer controls the degree of vibrations (i.e., the duty cycle and frequency) through a bespoke pressure sensor glove worn on the right hand. The glove consists of five pressure sensors placed on the fingertips of the right hand; these correspond to the five vibrating motors of the Oktopus. As mentioned in Section 3.3, each motor has a different specification (e.g., shape, material, rotation speed), which results in unique sound outcomes.

The motors are placed loosely on the strings inside the piano to enable movement between various strings when vibrating. Unlike a traditional piano timbre, this can produce a distinctive string-like sound, not unlike a high-speed pizzacato. The loose motors tend to bounce across a variety of notes nearby, thus producing various melodic lines similar to a chromatic scale.

The sound manipulations are performed by applying pressure on the right-hand side of the piano, facing the instrument (Figure 4). In this way, the audience can both view the gestures of the sonic creation and form an abstract representation of the sonic causality. A linear one-to-one mapping relationship is achieved between the pressure sensors and the vibrations. An increase in pressure produces greater excitation of the motors, which ultimately generates string vibration. As the intensity is increased the movement of the motors becomes intentionally unpredictable, and the performer is unable to control the direction. To reign in effect, the performer may use the sustain pedal to regain overall control of the resonating strings.

The left hand of the performer controls the parameters on a touchscreen tablet device (viz. Apple iPad) with TouchOSC. [5] The tablet communicates with the laptop wireless through Wi-Fi and uses OSC messages to control parameters of various audio processing effects in Ableton Live. [6] During the performance, the tablet is kept out of view from the audience and placed inside the piano.

As the glove is connected directly to the inputs of the Oktopus system, all gestures are captured and analysed, providing data from the sensor glove directly to the motors. The sound generated from the interaction between the motors and the piano strings is then captured through a microphone and processed through Ableton Live. The performer has in their arsenal a wide range of audio processing possibilities (e.g., looping, granular synthesis, reverb, panning, pitch bend) that are predefined and strategically mapped. Also, pre-recorded audio from the vibrational excitation of the strings is triggered at crucial moments during the composition.

There is no traditional notation employed, instead of written guidelines about the layout of different audio processes and functions. The performer improvises through the learned system and as a result, there are many different performance versions without one necessarily being truthful to the score. There is a need for two-hand coordination to perform this piece. The right hand creates the sound while the left-hand crafts the sound. The ability to have control of the performed sound through the fingertips of the pressure sensor glove brings back the energy from the performers' actions thus having direct and creative interpretation with the sound. While the composition uses the piano as the sounding instrument, the performer is not required to be a pianist to perform the piece skillfully. The vibrat-

[3] Hyperlink to samples.
[4] `https://youtu.be/8AnkWhwhXtM`
[5] `https://hexler.net/software/touchosc`
[6] `https://www.ableton.com/`

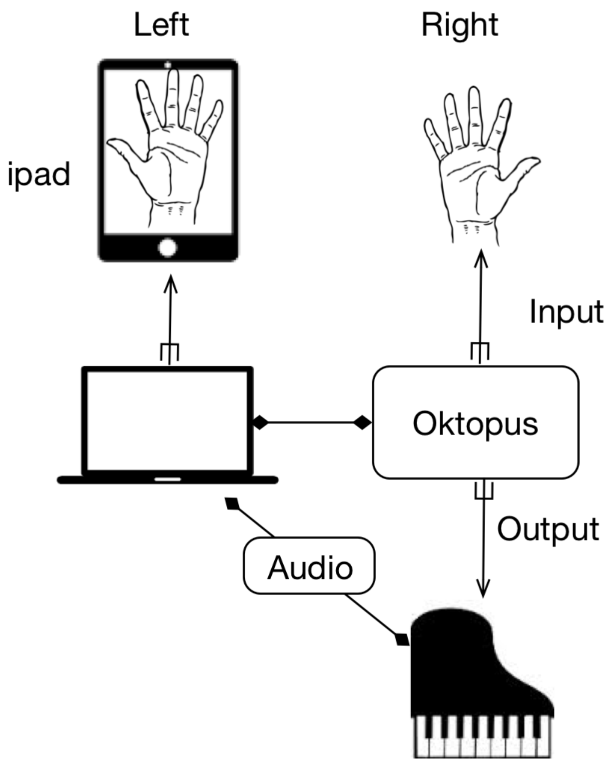

Figure 3. Overview of the control structure for *Live Mechanics*. The right hand controls sensors that manipulate motors of the Oktopus, which in turn vibrate strings of the piano. Audio from the piano is transformed through audio effects—the parameters for which are manipulated by the left hand.

ing motors and the relationship between the mechanical production of sounds, allows the performer to develop an embodiment relationship with the instrument and provides expressive performance nuances through the technology.

5. CONCLUSIONS

The excitation of motorised vibrations has typically been used within performance environments to either inform performers of relevant system functions or as a mode of information exchange between performers. In this paper, we have proposed an extension to this taxonomy to include sound generation for music performances by vibrational excitation of an object. To explore the range of possible affordances associated with each of these categories, we have introduced the *Oktopus*, a system for vibrational excitation through the use of subtly controlled motors. The usefulness of the system has been demonstrated through the performance of the composition, *Live Mechanics*, for piano and interactive electronics. Future work could investigate the benefit of additional motor types for further nuanced control and control structures beyond PWM that might drive the motors in ways unexplored within the scope of this work. As we have thus far used the Oktopus mainly to excite the strings of a grand piano, we also intend to utilise the controller in conjunction with other instruments; in this regard, we foresee exciting results with percussive

Figure 4. Pressure sensor glove driving the motors placed on the strings of the piano.

or amplified string instruments such as guitars.

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