ENGRAVING–HAMMERING–CASTING: EXPLORING THE SONIC-ERGOTIC MEDIUM FOR LIVE MUSICAL PERFORMANCE

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ABSTRACT

Engraving–Hammering–Casting is a live music composition written for two performers, who interact with force-feedback haptic interfaces. This paper describes the philosophy and development of the composition. A virtual physical model of vibrating resonators is designed and employed to generate both the sound and the haptic force feedback. Because the overall system, which includes the physical model and the coupled operators to it, is approximately energy conserving, the model simulates what is known as ergotic interaction.

It is believed that the presented music composition is the first live composition, in which performers interact with an acoustic physical model that concurrently generates sound and ergotic haptic force feedback. The composition consists of three sections, each of which is motivated by a particular kind of craft process involving manipulation of a tool by hand.

1. BACKGROUND

Physical modeling has been employed for decades to synthesize sound [5, 16, 15]. In real-time applications, the approach is typically to compute difference equations that model the equations of motion of virtual acoustic musical instruments [9]. However, besides merely imitating pre-existing musical instruments, new virtual instruments can be designed with a computer by simulating the acoustics of hypothetical situations [6], creating a "metaphorisation of real instruments." Sounds generated using physical models tend to be physically plausible, enhancing the listener's percept due to familiarity [7, 14].

Besides synthesizing sound, a physical model can also be employed concurrently for synthesizing visual feedback and haptic force feedback. When these feedback modalities are provided concurrently to a human, the sensory percepts can fuse in the brain of a human and provide a distinctive sense of immersion. The ACROE-ICA laboratory has a long history of working in this area [10], and they have developed extraordinarily high quality hardware for synthesizing haptic force feedback for musical applications [13]. They have also introduced key terminology into the discourse, as outlined in the book "Enaction and Enactive Interfaces: A Handbook of Terms" [12].

In this paper, the term *ergotic interaction* will be used. A human interacts ergotically with a system when the human exchanges significant mechanical energy with it and the energy exchange is necessary to perform a task [12]. For example, employing a tool to deform an object or move it is ergotic. Bowing a string or playing a drum is also ergotic. There is a mechanical feedback loop between the human and the environment: the human exerts a force on the environment, and the environment exerts a force on the human. In ergotic interaction, the user not only informs and transforms the world, but the world also informs and transforms the user [12].

As far as the authors know, there has never been a portable musical act that explored the musical applications of simulated ergotic interaction in live performance. This paper describes the development of a new composition in this area.

2. HUMANS USING TOOLS

The authors are inspired not only by the way people interact with traditional acoustic musical instruments, but also by the way people interact skillfully with tools in general. Indeed, seasoned craftspeople leverage thousands of hours of experience in operating tools. They can almost imagine that a favored tool is an extension of their body, allowing them to focus more on the result than on the tool itself [8]. They use the tool efficiently to preserve energy, while often making graceful gestures to achieve an aesthetically pleasing result.

Interaction with tools for craft was emphasized at at the Victoria and Albert Museum in London. The "Power of Making" exhibition presented over 100 crafted objects and provided a glossary outlining processes used to make the objects [18]. The following processes were particularly inspiring: "carving, casting, cutting, drawing, forging, glassblowing, grinding, hammering, incising, milling, molding, painting, polishing, striking, tapping, welding, wood turning." These words provided a strong concept and dictated the form and the sonic qualities of the composition.

3. PORTABLE, DURABLE, AND AFFORDABLE HARDWARE

Prior research has focused on accessible haptic hardware for musicians [3]. In contrast with precise yet expensive and fragile devices designed for simulating surgery, such as those manufactured by Sensable,[1] it was essential to use devices that are more affordable to musicians and more durable. For this reason, the authors have recently been using the NovInt Falcon device, which is a commercial gaming device with USB interface.

Figure 1 shows a human hand gripping the Falcon device. It does not look as artistic as we would prefer, but it satisfies our requirements for now, and it operates in three dimensions. It measures position in the XYZ Cartesian coordinate space, and it can exert a force in the Cartesian coordinate space. Furthermore, an open-source driver is a available for the NovInt Falcon for Mac OS, Linux, and Windows, and this driver has been compiled into both Max/MSP and Pure Data (pd) objects, making it easier to access the device for computer music applications [1, 2].

Figure 1. NovInt Falcon haptic force-feedback device.

4. MODEL

The authors of this paper designed and implemented a reconfigurable model that allows the performer to experiment with sonic-ergotic "sounds" that could correspond to crafting processes listed in Section 2. The shape is simple so that we could choose to expand upon it someday in future compositions. In the model, the musician reaches inside a virtual shape and can interact with the sides (see Figure 2). The square has been used because it is the only regular polygon with angles of 90°, allowing the hand to quickly move around striking all sides without getting stuck in any corners, while leaving open the possibility to bounce back and forth within one corner at will. Since the model is two-dimensional, the performer is allowed to move freely within the third dimension.

Each of the four sides is modeled as a rigid side moving in and out according to a lumped model. The lumped model is reconfigurable, and the ergotic interaction is simulated using a form of the Cordis-Anima equations for simplicity [11].

According to the authors' opinion, the simplest musical model is that of a single mechanical resonator, which vibrates only at a single frequency when vibrating freely.

[1] http://www.sensable.com

Figure 2. Hand reaching inside of a square to interact with it

It is enjoyable to interact with simple models such as this one, particularly while making early explorations of the sonic-ergotic medium; however, it has been decided eventually to add additional resonances to each side in order to enable a wider range of sounds. Thus, each side's lumped model corresponds to the mechanical equivalent diagram in Figure 3, in which the blue arrow emphasizes the fact that, at least for the purpose of modeling the sound and ergotic interaction, the movement is assumed to be orthogonal to the surface.

For example, the ith resonance is modeled by the mass m_i, which is connected to mechanical ground by a spring k_i and damper R_i in parallel. The performer interacts with the ith resonator by a similar parallel link combination of spring k and damper R, with the exception that k and R only engage when the position of the haptic force-feedback device is beyond the position of m_i. In other words, k and R allow the performer to push into the mass, but only when the performer is touching the mass. The mass m_i does not "stick" to the performer. This contact spring-damper link (k,R) element is referred to as the BUT element in the Cordis-Anima formalism [11]. There is a separate link (k,R) for each resonator so that the tuning of each resonator is independent of the other resonators. It is inspiringly remarkable that so many diverse sounds can be obtained with this basic model, simply by employing different physical gestures and by adjusting the parameters of the model.

5. COMPOSITION

Ergotic interaction is an integral part of our compositional medium. We do not merely synthesize or create the sound; instead, we transform and deform it, while it transforms and deforms us physically and mentally. Ergotic interaction inextricably links the gesture of the musician with the sound. We believe that the audience can comprehend this linkage and appreciate it, as we explore the new possibilities of artistic expression enabled by the sonic-ergotic medium.

5.1. Structure

The composition consists of three sections. In the first section, the performers interact with model parameterizations designed to evoke perceptions of *engraving*. With

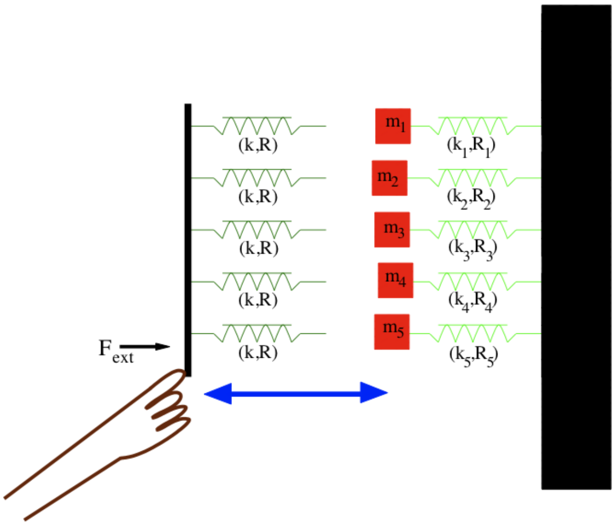

Figure 3. Mechanical equivalent diagram for hand/haptic device touching five independent resonators on the right-hand side

high resonance frequencies and low masses for the resonators, the sound is delicate and responds intimately to the small, precise movements made by the performers.

In the second section, the resonators are re-tuned to sound more like pieces of metal or bells. The performers make *hammering* gestures to play melodic-like passages.

Finally, in the third section, the k and R parameters of the contact links are varied rhythmically in time. Through this modulation, the virtual instrument seems to gain the ability to exert forces on the performer. It asserts a rhythmic form on the gestures of the performers, as if it were *casting* the performers' gestures into a specific form.

5.2. Score

The score for the composition consists of six staves, which are notated in a special manner but also contain traditional marks from Western music notation such as remarks, dynamics, etc. The first staff describes which sides the first performer should play and at what time (see Figure 4, top). The "*f*" note describes the right side, the "*a*" note indicates the left side, "*c*" indicates the bottom side, and "*e*" indicates the top side.

Consider the engraving section, for which k is small and R is big, resulting in a kind of frictional interaction. Arrows on the score indicate bowing-like gestures to be performed. For example, subject to this interaction, the hypothetical top staff in Figure 4 would specify that the performer should first play a rest for four beats, and then for five beats the performer should slowly push down into the bottom "*c*" side. Next, the performer should push to the left into the left "*a*" bar, at a position low enough (see Figure 2) that both the bottom and the left sides will create sound. Similarly, the second staff (see Figure 4, bottom) would indicate that only in the third measure, the second performer should play by gradually pushing into his or her the bottom side.

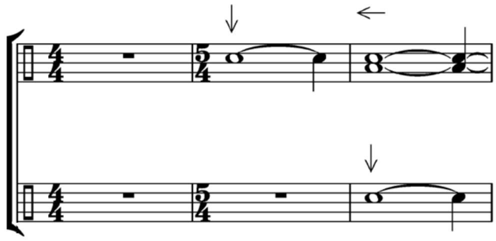

Figure 4. Top two staves indicating to the two performers when to play which sides.

The stiffness (k) and damping (R) interaction parameters are prespecified by the score and *not* under the control of the performers. The lower four staves of the score specify how k and R interaction parameters vary during the composition. In the excerpt from the *engraving* section shown in Figure 5 (left), the interaction stiffness remains low for both performers while the interaction damping gradually increases over five bars for both performers. Figure 5 (right) shows another example in which the damping remains generally low for both performers. The stiffness for performer one varies periodically to emulate engraving, and after three bars, the stiffness for performer two also begins to vary to emulate *casting* for performer two (see Figure 5, left). Through the variation of the interaction parameters, the haptic force-feedback device asserts its influence over the performers, in a sense casting their gestures into a form that suits the model's programming.

6. CONCLUSIONS

The form of the composition is shaped by the affordances of the force-feedback device. The NovInt Falcon is designed for simulating interaction with virtual tools, and the composition explores interaction with tools within part of the sonic-ergotic medium. The authors also explore the limitations of the force-feedback device. Because there is a delay in the feedback control loop of the device, it will become unstable for sufficiently large k and R. In this case, the device will tend to chatter when coming in contact with the virtual resonators, which produces a sound characteristic of the haptic drum [4]. The chattering interaction is not ergotic, but it is nevertheless interesting because it could not normally occur without the "external" energy source of the force-feedback device's motors. Indeed, in contrast with other human-input devices, haptic force-feedback devices allow for the possibility of the device to *assert* partial control of a performer [2, 17]. In the context of the current composition, the devices only behave assertively for short time frames, in order to augment and accentuate the gestures of the performers, as left up the volition of the performers.

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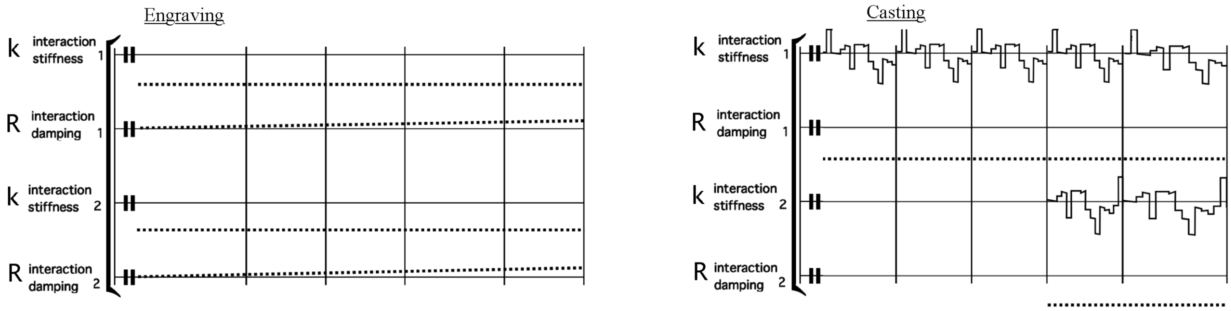

Figure 5. Two example excerpts of bottom four staves specifying the interaction stiffness (k) and interaction damping (R) for the two performers (left excerpt: from *engraving*, right excerpt: from *casting*).

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