
**Eric Lyon,* R. Benjamin Knapp,[†]
and Gascia Ouzounian****

*School of Performing Arts
Virginia Polytechnic Institute
and State University
195 Alumni Mall
Blacksburg, Virginia 24061, USA

[†]Institute for Creativity, Arts,
and Technology
Virginia Polytechnic Institute
and State University
190 Alumni Mall
Blacksburg, Virginia 24060, USA
{ericlyon, benknapp}@vt.edu

**Sonic Arts Research Centre
Queen's University Belfast
University Road
Belfast, BT7 1NN Northern Ireland, UK
g.ouzounian@qub.ac.uk

Compositional and Performance Mapping in Computer Chamber Music: A Case Study

Abstract: The mapping problem is inherent to digital musical instruments (DMIs), which require, at the very least, an association between physical gestures and digital synthesis algorithms to transform human bodily performance into sound. This article considers the DMI mapping problem in the context of the creation and performance of a heterogeneous computer chamber music piece, a trio for violin, biosensors, and computer. Our discussion situates the DMI mapping problem within the broader set of interdependent musical interaction issues that surfaced during the composition and rehearsal of the trio. Through descriptions of the development of the piece, development of the hardware and software interfaces, lessons learned through rehearsal, and self-reporting by the participants, the rich musical possibilities and technical challenges of the integration of digital musical instruments into computer chamber music are demonstrated.

The Biomuse Trio was formed in 2008 to create and perform computer chamber music integrating biosignals (Ouzounian 2012). The first composition resulting from this work was the *Trio for Violin, Biosensors, and Computer* by Eric Lyon, which has been performed at the 2009 Conference on New Interfaces for Musical Expression (NIME), along with performances in London, Dublin, Atlanta, and New York City, at venues such as ISSUE Project Room and Diapason Gallery. At the outset, the challenge of composing for digital musical instruments (DMIs), with their inherent mapping problems, was a central focus in our rehearsals and discussions. As the Biomuse Trio began its work, it became clear that the anticipated DMI mapping problems were embedded within broader questions that required a consideration of our compositional and performance

practices in addition to the hardware and software of the DMI. Certain aspects of instruments come into high relief when tested in the crucible of musical creativity, and it is those aspects that we hope to illuminate in this article.

Digital Musical Instruments

In *New Digital Musical Instruments: Control and Interaction Beyond the Keyboard*, Miranda and Wanderley (2006, p. 3) define a digital musical instrument as “an instrument that contains a control surface (also referred to as a gestural or performance controller, an input device, or a hardware interface) and a sound generation unit. Both units are independent modules related to each other by mapping strategies.” The history of DMIs goes back at least as far as the GROOVE system (Mathews and Moore 1970), with pre-digital precursors such

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as the Theremin of 1919 already displaying the key property of separating the control interface from the sound generation unit. Ever since the 1980s, with the introduction of the MIDI protocol, commercial DMIs such as the Yamaha DX7 proliferated and were disseminated widely. Most commercial DMIs have been conservative in design, but the occasional experimental interface may be found, such as Yamaha's Miburi, a wearable MIDI controller. The laptop computer and related digital devices, such as tablets and smart phones, are also quite prevalent as DMIs.

Whereas commercial DMIs tend to be limited by the conservative outlook of their design, the laptop as DMI, despite full flexibility of sound generation, is characterized by severe limitations in performance intimacy, a criterion for computer music performance discussed by F. R. Moore (1988). A third stream of DMIs, developed since the 1990s, involves innovative focus on the performance interface and has centered around the NIME community since the early 21st century. Such DMIs can afford both performance intimacy and new potentials for musical interaction. The Biomuse (Knapp and Lusted 1990) falls into this category.

Biosignals and Musical Interaction

The use of biosignals for musical interaction may be found in a subset of DMIs. Miguel Ortiz (2014) has compiled a detailed breakdown of various biosignals used for musical performance. Ortiz provides a common-practice definition of biosignals as "signals that are bioelectric in nature, and that manifest as the change in electrical potential across a specialized tissue or organ in a living organism." An important precursor to biosignal-based DMIs is Alvin Lucier's 1965 composition *Music for Solo Performer*, in which electroencephalographic signals from the performer drive loudspeakers at very low frequencies, which then excite acoustic percussion instruments (Lucier 1976). The Biomuse is a biosignal-based DMI, affording control through biosignals using electromyography, electroencephalography, electrocardiography, and electrooculography, as well as through accelerometers for

kinetic control. The Biomuse has been used since 1989 in numerous musical performances and compositions, such as *Tibet* by Atau Tanaka and Ben Knapp (2002).

Introducing the Biomuse Trio

The Biomuse Trio consists of Ben Knapp, Biomuse designer and biosignal performer; Eric Lyon, composer and audio programmer; and Gascia Ouzounian, violinist. Besides having these core competencies required for performance in the trio, Knapp is an accomplished keyboard player and Ouzounian is a musicologist and composer. Lyon received early instrumental training as a violinist. Thus, in addition to participation as creators and performers, each of us was well situated to participate in, and evaluate, the project from a distinctly different interpretive perspective. A DMI is characterized by its separation of gestural interface and sound production engine (Malloch et al. 2006). This characteristic divide was certainly present for our trio, requiring ongoing mapping processes. Additional mapping processes were required between composer and performers, between software interfaces to both the Biomuse sensors and audio sound production, and between the performance gestures of the Biomuse performer and those of the violinist.

The Compositional Framework

The ensemble of Biomuse, laptop, and violin presented an ideal laboratory for gestural DMI-based composition. The pairing of violin and Biomuse provided opportunities to test the expressive potential of a DMI in a chamber music context with a highly expressive classical music instrument that has a centuries-old performance practice. The laptop might have been more fully integrated into the performance arena, although in our rehearsals, we found that potentials of laptop gesture and expressivity were relatively limited compared with that of the violin and Biomuse.

An important compositional constraint was that all sounds produced by the DMI should articulate

sounds sampled from the violin during performance. Earlier chamber music compositions by Lyon, such as *Introduction and Allegro* and *Trio for Flute, Clarinet, and Computer*, demonstrated the richness and sonic variability possible from using live-sampled acoustic instruments (Lyon 2008). In the present work, additionally using the Biomuse to articulate violin sounds would bring the two instruments into greater timbral proximity than if synthetic or prerecorded sounds were used instead.

Finally, it was our intention that the composition be fixed and notated to the greatest extent possible, as the ability to accurately recreate our performances would serve as a test of the reliability and stability of our system. Essentially, we would build into the music audience-observable indicators of musical success or failure, ones that were just as clear as, say, an elegantly executed piano flourish or a flubbed brass note.

The DMI: An Overview

We begin with mapping aspects of the DMI and work our way outward to relationships that emerged in the interface across the DMI, in compositional management, and, finally, in performance of the composition with the DMI. The DMI comprises a variable configuration integrating the violin, the Biomuse, software synthesis on the laptop, and, to a much lesser extent, the laptop itself as a performance surface. We do not subscribe to the notion that the laptop is an inherently uninteresting performance interface. An earlier composition by Lyon, *Introduction and Allegro*, paired a laptop soloist with an instrumental ensemble, utilizing laptop writing that was highly virtuosic, a virtuosity that was easily grasped by the audience (Lyon 2008). It was therefore our intention at the outset that the laptop be an equal partner in the gestural performance paradigm of the *Trio*. In our initial rehearsals of compositional sketches, however, the gestural interactions between Biomuse and violin proved by far the most compelling, so the laptop was shortly dropped as a primary gesture performance instrument. The role of the laptop performer became primarily management of the

digital signal processing (DSP), such as recording and editing violin samples, initiating changes to the current DSP configuration, and initiating sample playback. The role of the violinist was to perform notated music, some of which would provide samples for the Biomuse to later articulate. The only sensor deployed on the violin was a DPA clip-on microphone.

The Biomuse

The Biomuse consists of a set of on-body sensor bands, such as armbands and waistbands (Knapp and Lusted 1990). Each individual sensor band is placed on a part of the body, and it remains there for the duration of the performance. The integration of multiple sensor bands onto the body of a single performer constitutes one of the great advantages of the Biomuse. At least ten degrees of freedom may be continuously controlled, providing a rich data stream for controlling a DMI. For the *Trio*, we used the following combination of accelerometer (ACC) and electromyogram (EMG) sensors:

- Left Forearm Front EMG
- Left Forearm Back EMG
- Left Forearm Pitch ACC
- Left Forearm Roll ACC
- Right Forearm Front EMG
- Right Forearm Back EMG
- Right Forearm Pitch ACC
- Right Forearm Roll ACC

EMG sensors record electrical activity during muscle contractions, and accelerometers measure acceleration.

The initial instrumental strategy in composing for the Biomuse was not to determine specific sensors or gestures in advance, but rather to specify in the score the desired musical result of a Biomuse performance gesture. The mapping of Biomuse gestures to musical results was determined through experimentation in rehearsal. Each gesture involved two stages of mapping: first, the selection of one or more sensors to accomplish a musical task, and second, the choreography of the bodily motion

Figure 1. An excerpt from Trio for Violin, Biosensors, and Computer, showing Biomuse gestural notations.

The figure shows a musical score excerpt for three parts: Violin, Biomuse, and Laptop. The Violin part is in treble clef, starting with a mezzo-forte (mf) dynamic. The Biomuse part consists of two staves: a treble staff with rests and a bass staff with notes and rests. The Laptop part is a single staff with rests. Annotations include 'play tremolo: right arm pitch up 1/3 of maximum', 'left arm throw (forearm front EMG [tremolo auto-fires])', 'lower pitch - right arm up 2/3 of maximum', and 'Sample Tremolo'.

that activates these sensors. The first stage was concerned with reaching a particular value, or motion between values, for one or more sensors. The second stage involved deciding on the specific gesture to properly activate the sensor, considering the expressive content of the gesture as well as its physical efficacy. Finally, choreography was designed to connect successive gestures into musical phrases. The design of the gesture would often include its preparation—for example, the position of a wrist prior to turning it, or the relaxation of a muscle, prior to tensing it. Once a gesture, or series of gestures, proved successful in rehearsal, it was notated into the score (see Figure 1).

Interfacing to Max/MSP

The DMI consists primarily of an interface between the Biomuse and the laptop. Output from the various Biomuse sensors is linearly mapped in EyesWeb

(www.infomus.org/eyesweb_ita.php), with simple filtering to stabilize the output. EyesWeb sends Open Sound Control (OSC) messages over Ethernet to a laptop running Max/MSP. The OSC messages received by Max/MSP are mapped in two stages. The first is a linear calibration stage. The full range of a sensor band might not be comfortably accessible to the performer, so in the calibration stage, the comfortable minimum and maximum values are measured and stored. Once both these values have been acquired, the range between comfortable minimum and maximum is linearly mapped from zero to one. Once calibrated, the sensors can be mapped in any number of ways to sound-production and sound-processing algorithms. The sensors are mapped either singly or in combination with other sensors, and the mappings are sometimes nonlinear. This great flexibility in mapping sensors to a large variety of sound-producing strategies constitutes one of the great advantages of DMIs over traditional acoustic instruments. Because all sound produced by

Figure 2. The opening bars of *Trio for Violin, Biosensors, and Computer*.

Trio for Violin, Biosensors, and Computer

Eric Lyon

$\text{♩} = 80$

Violin

Biomuse

Laptop

ff

p

f

left arm throw (forearm front EMG)

left arm throw (forearm front EMG)

Sample first chord and crop to a new buffer

the DMI is based on recordings of the violin played by Ouzounian that were made during performance, the violinist herself must be considered as part of the DMI. This is particularly the case because, in certain passages, the DMI does not directly produce sound but rather modifies the sound of the violinist in real time.

Mapping Gesture to Sound

In this section we will discuss two gestures from the *Trio* in detail, and then describe several other gestures that involved striking mapping strategies.

A Gesture from the First Movement

The first gesture performed on the DMI is heard in measure 3 of the first movement (see Figure 2). It is notated as a “left arm throw (forearm front EMG),” where the actual sound is an aggregation of several transpositions of the sampled chord.

There are two aspects to the mapping. First is the choice of sensor, in this case the forearm EMG band, which triggers the chord on exceeding a threshold of muscle tension hard-coded into the Max patch that forms the audio software side of the DMI. The second aspect of the mapping is the choreography of the gesture, which was devised by the biosensor performer (Knapp, from here on described as the “biomusician”). The gesture is a “throw” away from the biomusician’s body toward the violinist in which his hand opens at the end of the gesture, as if releasing the sound to her. There are many ways in which the biomusician could produce the desired spike in EMG muscle tension, including gestures that would be largely invisible to the audience. Thus the articulation of the gesture as an open hand release is an aesthetic decision to convey affect to the audience, much like the gestures of a conductor (who, given a properly rehearsed orchestra, could produce a similar sonic effect from mechanical beating as from flamboyant gesticulation). Although the combination of sensor choice, threshold setting, and gesture choreography accurately describes

this particular gestural moment, the full gestural phraseology is more accurately described starting from the opening of the piece: The violinist first puts sound into the space. The laptop performer then captures the sound to computer, and hands it off to the biomusician. Finally the biomusician gives the sound back to the violinist in a multiplied fashion. This integral analysis of the gesture underscores our view that an instrument, including a DMI, is not truly a *musical* instrument until one takes into account not just the affordances of the instrument, but the actual ways that performers transform those affordances into music.

A Gesture from the Second Movement

In the first movement there was a compositional focus on relatively basic uses of the Biomuse, which were not always the most idiomatic, as it turned out. For example, the use of EMG as a triggering sensor proved reliable for single triggers, but unreliable when articulated multiple times in sequence. In order to strenuously test our systems, all biosensor motions were fully notated, and there was no room for improvisation. In the second movement, we began to introduce mappings in which the biomusician controlled a relatively large number of parameters simultaneously. In a digital signal processing configuration affectionately referred to as the “pleasure ball” (the basic hand positions of the biomusician are reminiscent of Woody Allen’s character holding the “orgasmic orb” in the 1973 film *Sleeper*), the biomusician simultaneously controls six parameters that modify a live-captured sample of a violin crunch tone.

The synthesis patch is shown in Figure 3. The parameter controls are as follows: the pitch (in the sense of motion) of the left forearm accelerometer controls filter speed; the pitch of the right forearm controls frequency deviation, the roll of the right forearm accelerometer controls granular transposition; the roll of the left forearm controls tuned resonance; the right forearm EMG combined controls the low-pass filter; and the left forearm EMG controls the amount of filter feedback.

The Max subpatch that routes the biosignal controls is shown in Figure 4. The score excerpt notating this gesture is shown in Figure 5. A system of gating is used such that control signals are only routed to a given synthesis algorithm when that algorithm has been activated in the piece. Given the complex parameter space, it was deemed unrealistic to notate simultaneous motion of limbs within the control space. Instead, the biomusician is instructed to improvise a passage, giving him the freedom to explore the parameter space at will. This passage was uniquely enabled by the integral control of multiple sensor bands operated simultaneously by a single human body. The continuous, coherent, simultaneous manipulation of this parameter space would not be possible by trying to manipulate a bank of sliders; this was a truly idiomatic use of the Biomuse. It is notable that our principle of compositional control broke down in favor of improvisation at precisely the moment where we discovered this maximally idiomatic passage. Experimentation with the DMI overrode our preconceptions of how the piece should work.

Further Gesture Mappings

Many more gestures were mapped onto the DMI. We briefly mention here a few that we considered of particular interest. The entire score can be downloaded at this article’s Supplementary Content page, (http://www.mitpressjournals.org/doi/suppl/10.1162/COMJ_a.00257) and the two movements of the *Trio* can be viewed online at youtube.com/watch?v=N1dBo7V4dzA and youtube.com/watch?v=nlyJK80lYuE. In measure 23 (1:28 into the first of the two videos), the biomusician initiates a granular texture by tensing both forearms. Part of the gesture requires that the hands be spread apart from each other. The next part of the gesture involves gradually bringing the hands together, changing the density of the granular passage. Another hand clench causes the granular sample to be played backwards. A final opening of the hands gradually changes the spectral “peakiness” (i.e., the amount of spectral variance) of the granular texture. The accordion-like two-handed nature of the biomusician’s gesture

Figure 3. The multi-parametric synthesis subpatch affords correlated control for the biomusician.

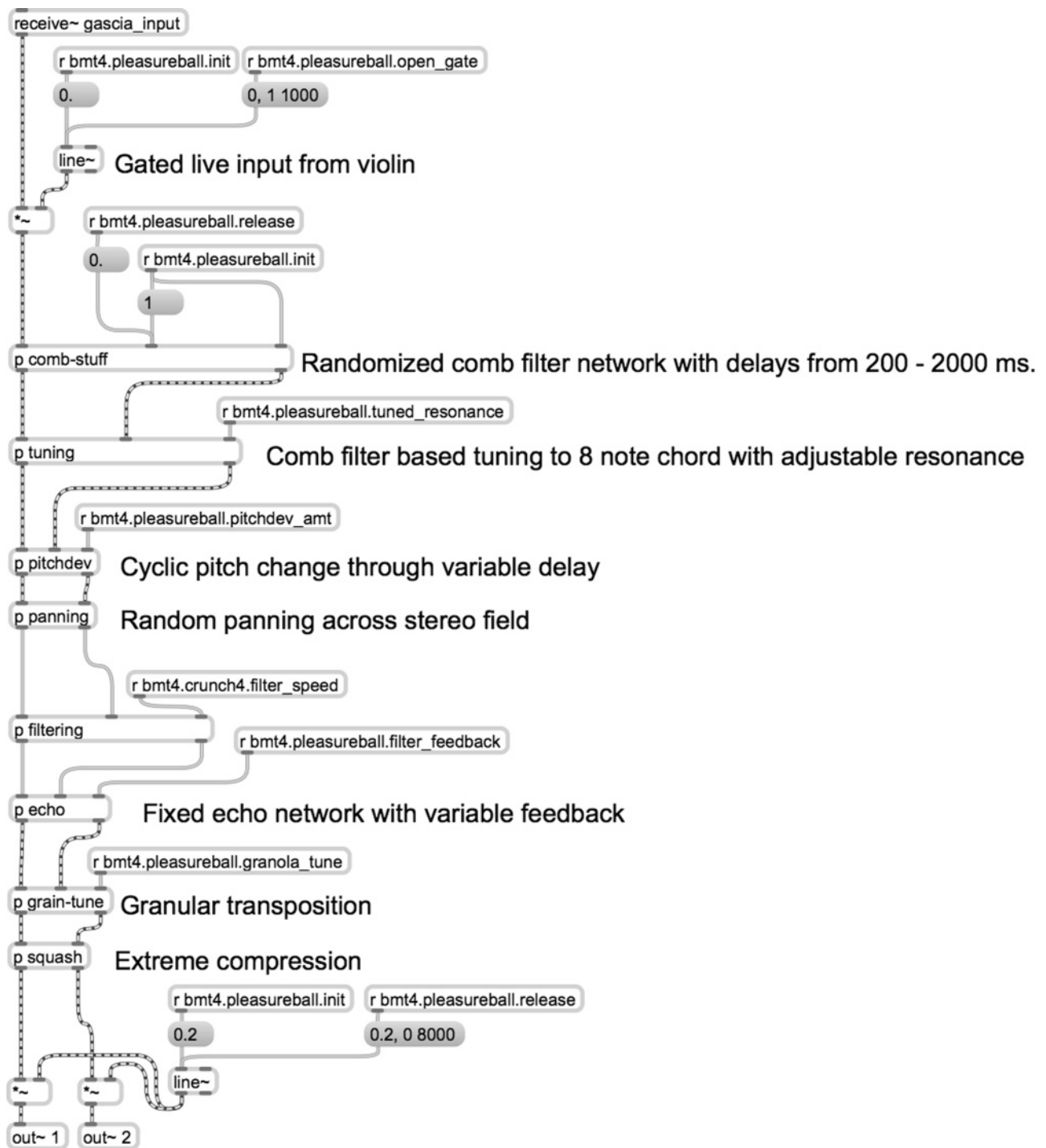
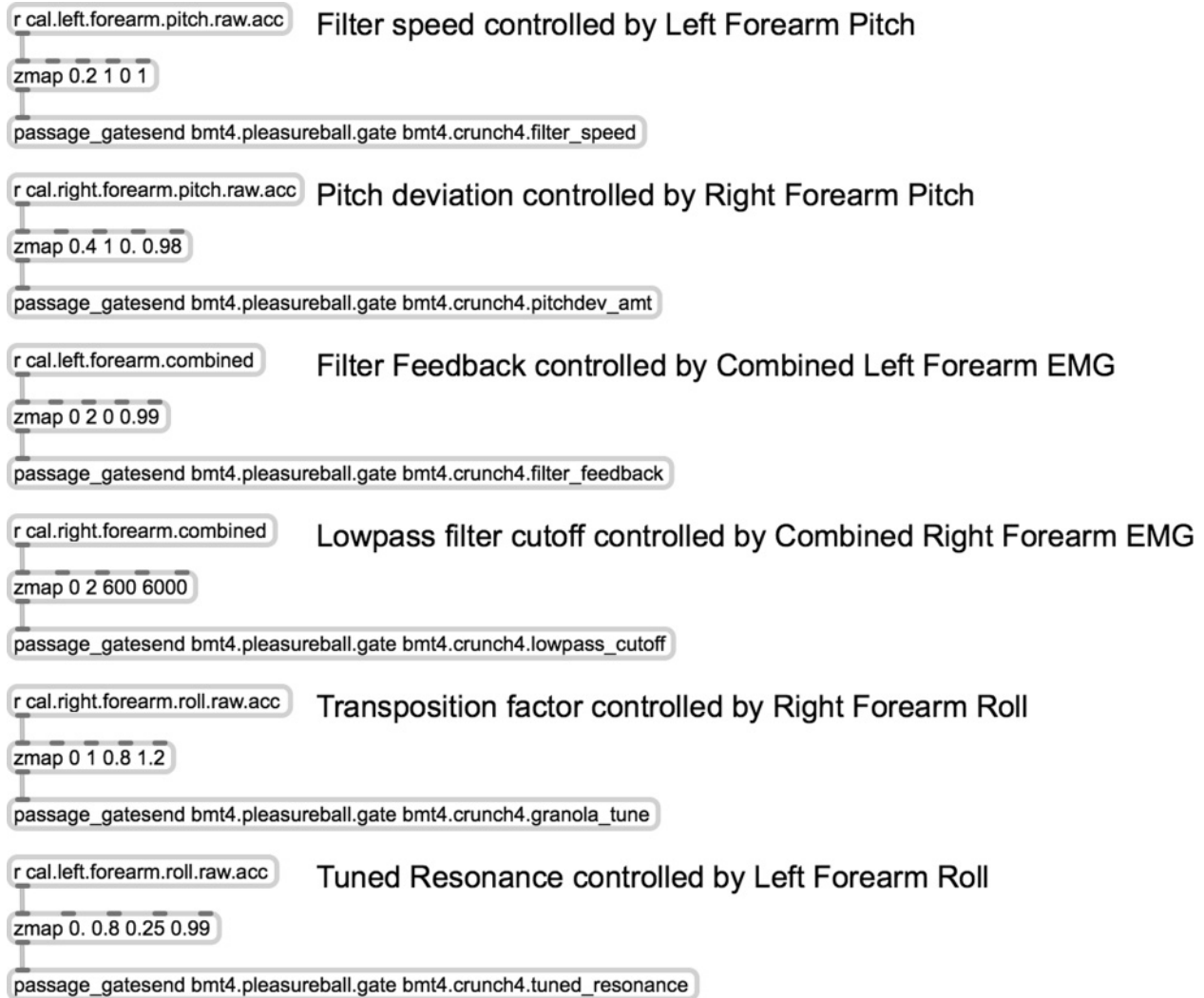


Figure 4. The controller subpatch displays mappings from on-body sensors to synthesis parameters.



seemed particularly apropos to the “stretching and shrinking” sound of the musical passage.

In measure 55 (3:47 into the first video), a right-hand EMG grab is used to lock an audio-buffer playback munger into a fixed loop (the *munger* is an algorithmic reordering of the contents of a sample buffer). The gesture of grabbing seemed quite appropriate to the musical idea of locking a sound loop into place.

Starting in measure 59 (4:05 into the first video), a sequence of chords is traversed by either right or left forearm EMG, with the choice of arm given to the

biomusician. The actual gesture that the audience sees is a light lift of the hand, which is symbolic of the general lightness and upper-midrange tessitura of the passage.

In measure 89 (0:08 into the second video), the start of the second movement, the violin is sampled into a comb filter with a right-hand clench. We found it particularly interesting to use a grabbing motion to symbolize capturing a sound.

As these brief examples demonstrate, we were as much concerned with the expressive potential of the gesture as we were with the effective use

Figure 5. Notation of the
“pleasure ball” passage.

Crunch tone - play just until tone is fully active in Biomuse part

Violin

ff

PARAMETRIC MAPPINGS:
filter speed - left forearm pitch
LPF cutoff - right forearm combined
echo feedback - left forearm combined
resonance - left forearm roll
transposition - right forearm roll
pitch deviation - right forearm pitch

Gestural improvisation

Biomuse

Laptop

Open gate

fade out

of a sensor to produce specified musical effects. It was crucial that the biomusician be as comfortable as possible with these mappings, so these creative decisions on gesture choreography were largely made by the biomusician in consultation with the composer, and also often in consultation with the violinist about how the expressivity of the gesture might complement her corresponding musical passage.

The Performance Experience

A crucial element in the evaluation of an instrument comes from its use in performance. In this section, we summarize observations about the rehearsal

experience from both primary gestural performers of the Biomuse Trio. For Knapp, there were two main areas of reflection: first, approaching the design of the DMI from an engineering standpoint, and second, the actual experience of performing the DMI in a chamber music context. The design began on a whiteboard with a list of sensors, and abstract gestural ideas. At this stage, the question was, “What can we use for control, and how do we sense these controllers?” We would start with a taxonomy of rudimentary gestures and then build more complex gestures on top of them. For example, in considering the rotation of an arm as a controlling gesture, we asked what sensor would be most appropriate, what was the range of values we could extract from the sensor, and what was the

consistency of the calibration. From that point we could build more complex gestures, such as sampling the current position of the arm, redefining that point as zero, and generating a new mapping from the new zero to the previously calibrated maximum. That allowed us to use arm rotation without requiring the arm to first be unnaturally moved all the way to one side before performing the gesture. After coding these chains of calculations, we would test them to see how well they performed. If there was sufficient reliability in sensing the gesture, we added it to our vocabulary of useful gestures for the DMI.

Another aspect of the design concerned the mappings on both hardware and software. Every stage of mapping adds a layer of complexity, and even before being tested in performance, our DMI involved mapping from a sensor to a control surface, mapping from a control surface to one or more parameters of sound, and finally mapping from the parameters to the sound itself. The mappings of sensors on the EyesWeb side are linear, with the possible addition of simple stabilization filtering. On the Max side, the mappings might be either linear or non-linear, such as in the case of live calibration discussed earlier. And prior to this mapping chain are questions of the Biomuse interface itself: reaction time, latency, and stability, such as how steadily the performer could hold a particular level of muscle tension.

Knapp further observed that the kinds of complex multi-sensor mappings we were creating at the software level raised a hardware design question of the trade-off between modularity and possible integration of multiple sensors into a single band. A key motivator here was the perceived coherence of the sonic space. It is not just how many controllers are used, but how they are mapped. A pianist playing six different notes is not a single coherent sonic space, but a biomusician simultaneously manipulating six interacting parameters could well be coherent. (Consider that a pianist can trigger each note independently of the others, whereas most of a biomusician's physical gestures will simultaneously affect multiple sound synthesis parameters in a continuous manner, constrained and integrated by the sensor-on-human-body system.)

At the performance level, Knapp observed the deep nature of the collaboration, which extended directly from our work methods to the nature of the DMI performance. In our rehearsals, despite clear divisions of labor regarding hardware management and performance, software management and performance, and violin performance, each member of the trio was constantly questioning aspects of the ensemble beyond his or her own role. Constant discussion was a central feature of all our rehearsals. And in the DMI, there was a seamless line from muscle to skin, to sensor, to EyesWeb, to Max, to digital audio, to speakers, and in a converging line from violin to microphone, to analog-to-digital converters, to Max, and then over to the biomusician's body again. Knapp reports feeling this connection profoundly in performance, with Ouzounian tossing sounds to Knapp, which he would then sculpt as if reaching in and pulling sounds from the violin.

Ouzounian, reporting from the perspective of an instrumental performer, found the interaction fascinating in different ways. Having not previously worked with physiological interfaces in a performance context, she found it wonderful to be involved in conversations around gesture, expression, movement, and calibration when the piece was in development. In contrast to the violin, she found the biomusician quite limited in the range of gestures he could perform in the notated sections. At the same time, she and the biomusician had to find ways of interacting in a chamber music context, so the main question was how to play with someone, respond, and initiate different musical ideas when the person's instrument is, essentially, his or her physiology. Ouzounian found that playing with a biomusician required a different kind of sensitivity because of the unpredictability of human physiology. There was a much higher risk of failure compared with other forms of computer-based interactive music that she had been involved with. At the same time, in the most successful moments, Ouzounian found a degree of musical intimacy that was quite unique. Because the DMI was not a fixed instrument, but a constantly changing environment, she needed to learn what kinds of violin sounds, articulations, or timbres might be most fruitful in a particular section of the piece. Above all, she found

it exciting to perform with someone with an expert understanding of physiology and of physiological response in performance contexts.

Commenting on the rehearsal process, Ouzounian observed that developing music with biosensors is much more laborious compared with chamber music situations involving traditional instruments. The group felt truly experimental in the sense that every new gesture or idea had to be investigated through multiple lenses and would succeed or fail in multiple, unpredictable ways. There was a high degree of learning that came with being involved in the group, which was found to be exciting, and also sometimes terrifying.

It should be clear from this self-reporting by the performers that the biosensor-based DMI we developed afforded strikingly different musical opportunities than would be possible using acoustic instrumentation, or even computer-augmented instruments.

Audience Reactions

In presenting the work to an audience, we needed to decide whether the biomusician should wear the sensors visibly or hide them under a suit jacket. We chose the latter, as we wished to present the human body, rather than the technology, as the primary instrument. As a result, audience members did not see the full extent of the DMI, though in any case they would not have seen the Max patch, since showing the patch would have been an unacceptable distraction from the human musical interactions onstage.

Audience members generally understood quickly that the body of the biomusician was directly performing and controlling sound. This was largely due to early, directly observable analogies between performed gesture and resulting sound. Once this link was established, even the performance of complex sounds driven with multiple sensors was accepted as plausible, despite the audience's not necessarily understanding the exact relationships between aspects of the performer motion in its entirety, on the one hand, and a complex synthesis algorithm, on the other.

One audience member observed being struck by the "naturalness" of the movements of the biomusician, and correspondingly, she did not notice any particular difficulty or virtuosity. In fact the Biomuse part is quite difficult to perform, requiring constant intense concentration and precise control of body motions. It is a virtuoso performance. The opaqueness of virtuosity to the observer might be taken as a flaw in the DMI; we do not view it as such, however. The virtuosity level of a composition tends to degrade over time. For example, the virtuosity embedded in Niccolò Paganini's *Caprices* (Paganini 1973 [1819]) was truly extraordinary when they were first composed in the early 19th century. Since the 20th century, though, thousands of young violinists trained in conservatories have routinely been able to manage the techniques required by the *Caprices*. Virtuosity is not that important to us. We would prefer to move the audience with expressivity, rather than dazzle it with the show of technique.

Comparison to Improvisational Performance Strategies

A key element of our approach has been the use of a fixed score that notates not only traditional elements such as notes and rhythm, but also DMI-specific controls. Improvisational passages are incorporated into the compositional structure, but in every case are constrained by both the kind of violin sounds specified as input, and the audio DSP and DMI control configuration specified for the passage. Above all, the relatively fixed nature of the composition required repetition and testing of gestures. Gestures that initially did not work were either reassigned new sensors, practiced until they did work, or removed from the composition. The score provides a benchmark of accuracy for evaluating musical gestures in both rehearsal and performance that is not available for fully improvised performances. We believe that this approach is highly complementary to improvisational uses of DMIs that focus on expressivity, as in Atau Tanaka's Biomuse performances (Tanaka 1993), and the expansion of sonic variety for established instrumental performers, such as

the collaboration by Marsh and Paradis (2006) with improvisers Barry Guy and Jos Zwaanenburg.

Conclusion

In this case study we discussed mapping issues that arose in the composition and rehearsal of Eric Lyon's *Trio for Violin, Biosensors, and Computer*. We argued that mapping for DMIs is not just a question of assignment of controllers to parameters. The performance context and specific musical uses dictate a much broader understanding of the mapping question. It is only through musical exercise of a DMI that we can discover unique affordances that might significantly broaden the expressive potential of computer chamber music.

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