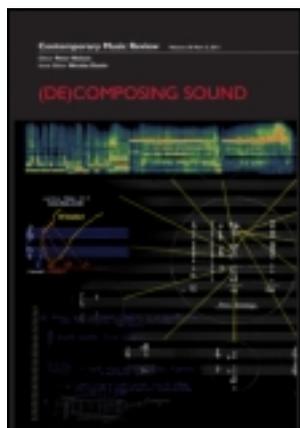


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# Haptic Augmentation of the Hybrid Piano

Lauren Hayes

*One of the most vital feedback systems that has been embedded in musicians for centuries is that of physical response. In the same way that auditory information is available and used throughout a performance, a musician will continuously reassess their playing by making use of not only their specialised sensorimotor skills, but also the tangible feedback that is relayed to them through the body of the instrument. This paper discusses approaches to the development of an augmented instrument, namely the hybrid piano, which focuses on the notion of performance as perceptually guided action. While the acoustic component of the sound energy of the augmented instrument is created within the real-world interactions between hammers, resonating strings, and the soundboard, the digital sonic events cannot be located in a similar palpable source. By exploring notions of multimodality and haptic feedback, the ongoing processes of human action and perception within instrumental performance can be maintained for the player, whilst arguably, also enhancing the experience for the listener.*

*Keywords: Vibrotactile Feedback; Enaction; Performance; Augmented Instruments*

## Introduction

Recent shifts in the understanding of human cognition, which suggest that mental processing is grounded in the body, have led to an increased discourse on the role of the body within contemporary music. In the 1960s, Schaeffer (1966) proposed a phenomenological framework for the experience of sound, which was based around the *acoustic situation*, and the idea of *reduced listening* (Chion, 1983/2009). This encouraged an abandoning of the attempted interpretation of the causal origins of sounds, replaced instead by the formation of musical meaning purely through what is heard: the sound itself. The *enactive* (Varela, Thompson, & Rosch, 1991) approach to understanding and creating music, closely related to embodied music cognition, further builds on this phenomenological perspective by suggesting that our cognitive processes have

their roots within the multimodal capacities of the body as a whole, and that meaning can be elicited through our bodily interactions with the world.

These ideas have gradually started to permeate the field of digital instrument design, especially in relation to haptic and tangible technology, where the emphasis on the interdependent relationships between body and mind is taken as key to suggesting improved ways in which novel digital musical instruments (DMIs) might be conceived, in order to create more potential for expression and a more engaged performance both from the point of view of the performer and of the audience. Of particular note are the distinct methodologies that have been proposed by Cadoz (1988, 2009), Essl and O'Modhrain (2006), and Armstrong (2006). These proponents all provide theoretical frameworks, as well as quite different practical approaches to DMI design, yet all are strongly influenced by themes of multimodality and the close coupling of action and perception. Despite the obviously different, yet related, practical outcomes, these approaches all acknowledge the importance of the enactive view, which was formulated by cognitive scientists Varela et al. (1991). It entails that '(1) perception consists in perceptually guided action and (2) cognitive structures emerge from the recurrent sensorimotor patterns that enable action to be perceptually guided'. This non-symbolic approach attempts to redefine cognition as embodied action (enaction). Although born out of the study of the organisation of living systems, enaction was largely inspired by the phenomenology of French philosopher Merleau-Ponty. Specifically, enaction develops Merleau-Ponty's (1945/1962) notion of the body as both biological (outer) and phenomenological (inner), in that we constantly oscillate between these states whilst perceiving and acting (Varela et al., 1991). As Armstrong (2006) explains, 'the enactive perspective takes the repeated *sensorimotor interactions* between the agent and the environment as the fundamental locus of cognitive development' (p. 11). Recent developments within cognitive neuroscience have provided empirical support for this interdependency between action and perception (Leman, 2007, p. 48).

Armstrong suggests that his encountering of an often negative critical reception of computer music in general may in part be due to the fact that many DMIs have failed to provide the potential for an embodied relationship between performer and instrument, due to a lack of fully developed technical and, moreover, theoretical frameworks (Armstrong, 2006). As a result, he argues, the performer often feels disengaged from the instrument and therefore also with the musical content. As a consequence, the audience also perceives this disconnect, and the performance suffers as a whole. Comparably, Essl and O'Modhrain (2006) suggest that we need to consider the various ways in which perceptually guided action might define 'the "feel" and playability of a musical instrument' (p. 294), in the quest to develop a design philosophy for new DMIs; but, they warn that we are only 'at the beginning of understanding when a sensorimotor experience is natural and believable for a performer' (Essl & O'Modhrain, 2006, p. 294). There seems to be an emerging sense of a demand for deeper thought and theoretical rigour with regard to DMI design, in the midst of increasingly inexpensive and ubiquitous technology. These concerns are echoed in recent calls for more

discussion into the nature of performance (Schroeder & Rebelo, 2009), and the relationship between body and instrument within a performance environment (Rebelo, 2006).

### Instrument–Performer Relationship

In what follows I will explore some of the methodologies related to instrument design that have emerged out of my practice as a performer of piano and live electronics, and have led to the haptically augmented hybrid piano. Before doing so, however, it is important to outline ways in which current thinking in the field of instrument design has influenced these developments, and how this thinking can be shown to support some of the conclusions that have been drawn purely through practice. Certainly, it could be claimed that the subset of DMIs known as *augmented instruments* is inherently suitable as a potential candidate for offering engaging and embodied modes of performative activity, due to the established development both of the acoustic instruments around which they are built, and the corresponding history of performance practice. Indeed, the literature surrounding the design philosophies of those DMIs in which the importance of tactility is emphasised includes a discussion of the favourable multimodal embodied engagement afforded by *acoustic* instruments, and an agreement of the tactile–kinaesthetic action–perception loops that arise during play as being crucial to performance (Cadoz, 2009; Rován & Hayward, 2000; Vertegaal, Ungvary, & Kieslinger, 1996). This seems to allow for a definition of performance as perceptually guided action:

Actions necessitate concurrent and consequent perceptions, and perceptions guide and inform actions. Thus the concept of enaction is inevitably dependent upon embodied knowledge, the kind of knowledge that is derived from being and acting in the world, with all its physical properties and constraints. (Essl & O’Modhrain, 2006, p. 287)

However, as we start to modify the instrument and inevitably construct relationships between gesture and real-time sound production, this intrinsic structural coupling between sound and touch can become fractured.

Essl and O’Modhrain’s approach to creating an embodied instrument–performer relationship takes as its basis an innovative solution to the problem of how to map input gesture to sound. This relies on the performer’s tacit knowledge of real-world objects (Essl & O’Modhrain, 2006). By grouping together sets of actions that afford common types of behaviours, different audible responses, which arise from the similar types of interaction, can be substituted. For example, physical grains, such as pebbles, are used to *make tangible* the process of granular synthesis. Moreover, the sonic result may reflect the acoustic sound of stones themselves, or indeed the sound of colliding ice cubes. Here the *structural coupling* (Varela et al., 1991) between interaction and sonic result is compelling. Armstrong’s (2006) approach,

on the other hand, looks towards creating adaptive and emergent performance environments through a combination of hardware and software, which employ various types of instrumental resistance to the performer and which engage the rich and dynamic aspects of human behaviour.

It is important to notice that the musical goals in each case are concentrated around engagement, playability, and interdependency, rather than control. This echoes Rebelo's (2006) notion of the 'multimodal participatory space' (p. 29). He argues that when the instrument is thought of as an entity, rather than merely as a functional tool, it carries its own cultural significance, created through the choices of the instrument-maker and elicited through its relationship with the performer. It should follow, then, that when it is the performer who is also the instrument-maker, the resulting instrument can be deeply personalised through prolonged embodied practice. In developing the hybrid piano, the largest amount of time spent on the project was devoted simply to playing, feeling and listening, adjusting, and playing again. Hence, the development of the instrument itself was an embodied activity.

Cadoz warns against classifying every situation that maps gesture to real-time sound processing as *instrumental* (Cadoz, 2009). He starts by defining instruments as real-world objects, which can give rise to both acoustic and visual phenomena through the physical energy exchange that takes place when a human interacts with the object or with the environment through that object. He describes this type of interaction as *ergotic* (Cadoz, 2009). In a musical situation, only the performer experiences the direct tangible interaction with the object; the audience perceives the related visual (gestural) and auditory (musical) information. With regard to acoustic instruments, the interaction is clearly ergotic, in that the action and resultant sound are intrinsically coupled. Cadoz (2009) claims that the subtle variations in how we create and perceive the phenomena of these instrumental gestures 'are of a primordial importance for the study and the understanding of the enactive conditions for the expressive and cognitive activities' (p. 219). The problem for Cadoz arises in DMIs, where the ergotic interaction of the gesture bears no actual physical relation to the resultant sound, even if performed in real time. Here, even sophisticated mapping choices cannot remedy this, as there is no real-world continuum of energy from input gesture to sound processing. As a result, Cadoz advocates continued research into using force-feedback haptic devices, along with physical modelling techniques, as a way to transduce energy from gesture to sound.

Nevertheless, there is an obvious potential for this type of interaction within an augmented instrument. Certainly, it would be extremely difficult to imagine an augmented instrument without this capacity, unless the gestural and sound-producing mechanisms were entirely decoupled. A possible, yet trivial case would be a performance where the body of the instrument was, for example, pressed by the performer, causing no acoustic sound, but triggering, by way of sensors, digital processes. Essl and O'Modhrain (2006) describe the notion of an augmented instrument as one which takes 'traditional instruments and augments them by adding sensing technologies that offer access to aspects of the instrumental gesture' (p. 286). The actual

way in which we gain access to this physical energy, and how we use the data that we cultivate from it, must be carefully considered in the design of the augmented instrument. The goal is to create a performance environment that can facilitate a greater potential for expression and an increased sense of engagement. This arises not from creating something that can be easily mastered, but rather by ensuring that the performer's embodied experience of playing continually provides them with 'new forms of embodied knowledge and competence. Over a sustained period of time, these negotiations lead to a more fully developed relationship with the instrument, and to a heightened sense of embodiment, or flow' (Armstrong, 2006, p. 6).<sup>1</sup>

### Digital Augmentation

Having established some of the philosophy that continues to influence my own approach to building instruments, I will now outline the two layers of development of the hybrid piano, starting with the original augmentation of the acoustic instrument. The hybrid piano has evolved over the last four years through my ongoing performance practice, which includes the fields of composition and also solo and ensemble-free improvisation. I term the instrument a *hybrid* piano, to emphasise the integration and importance of both the acoustic and digital components, although, of course, it easily falls within the class of augmented instruments. The hybrid piano has been developed as a performance system that enables digital signal processing (DSP) through live sampling, synthesis and sample triggering, and so on, all of which are controlled by the performer alone. Thus, no additional performer is required to oversee the execution of the electronic aspect. The acoustic sound of the piano is usually amplified through loudspeakers, so as to match the dynamic range of the electronic sound, although this is not always necessary, depending on the performance space. It is worth mentioning that the hybrid piano has no real-world unique identity, in that it is designed to be constructed around any piano model,<sup>2</sup> and indeed has manifested on both a Bösendorfer Imperial and an abandoned upright, which was prepared in a Cagean fashion. Whilst continuously evolving through a part-modular software approach, certain aspects of the sonic character of the instrument have remained constant over the years, and as such, it can be recognised as a developing system, and not a series of radically different experiments. For example, partial tracking has been used since inception, either to resynthesise sine waves or, latterly, to generate resonances.

The first appearances of the instrument were in the context of compositions involving live electronics, which explored the notion of using the instrument both as the sound source and as the controller. This makes use of the enactive knowledge already accumulated within the motor skills of the pianist. These early works employed machine listening techniques, in which the acoustic material was continuously analysed by the computer for various information such as pitch, dynamic, phrase length,<sup>3</sup> and perceived silence. Through intimate exploration with the system, there emerged a strong desire to adhere to what I only later learned could be classed as Cadoz' *instrumental gesture*, in the sense that the ergotic interaction and resultant

sound should be energetically coupled, as described above. Using the piano as both the sound source and the interface to the digital sonic world would help to facilitate this type of union. This leaves the pianist free from having to operate additional controllers, and hence able to negotiate the instrument and focus on the playing, extended techniques, and general musicality within the performance. In a sense, this is not so far removed in ideology from the approach of Essl and O'Modhrain: in both cases it is the sensorimotor skills already known to the user that are exploited in their relationship to the instrument. The case of a musician using an augmented instrument is simply a subset of the more general case. Similarly, the coupling of gesture to sound in the hybrid piano used the idea of making tangible the type of real-world forces at work. Hence, just as granular synthesis was physically represented through colliding pebbles, the hybrid piano uses, for example, the attack of the hammer on the string to *bring forth* an impulse through a resonant filter.

In the context of the compositions, the use of MIDI foot pedals was avoided. Their use is a commonly encountered performance practice within compositions involving acoustic instruments and live electronics, used either as a trigger for sound file playback or to advance preset sections within the software. Instead, within those compositions that used a timeline, a more fluid approach was employed, which made use of time windows combined with dynamic or pitch-based triggering systems. Thus, realisations of compositions, which often featured improvisational elements, could be more easily moulded into a form more fitting of a particular performance, as determined by the particular environment. So, for example, if the performer<sup>4</sup> feels that the present section needs more development, then they may extend it within the given time frame. In this way, as well as giving the performer more of a sense of value to their movements, there is more chance that the audience will perceive the sonic and semiotic information as resulting from a particular instrumental gesture, which will contribute to the listeners' experience of the music.

Tied into the themes of tangibility and interaction is the idea of the work, or effort, contained within a musical exchange. 'Physical effort is a characteristic of the playing of all musical instruments' (Ryan, 1991, p. 7) is a view that is universally accepted for acoustic instruments, but often neglected when building digital ones. Acoustic instruments resist the will of the performer, and it is within these precarious negotiations that expression is formed. Evens (2005) states, 'Music does not result from the triumph of the musician over the resistance of the instrument, but from their struggle, accord and discord, push and pull' (p. 160). The body of the acoustic instrument already resists the performer: pressing a key takes a small amount of effort; playing rapid *staccato* scales smoothly demands a different type of work; and on plucking a string inside the frame, another set of resistances and forces is felt. The piano, then, could be thought of as a force feedback or *haptic* interface to the computer. The obvious difference in the case of the hybrid piano is that instead of data read directly from physical parameters, such as, for example, the distance that a key is depressed, parametric data are derived from the acoustic properties of the instrument. However, this can certainly still be a useful measure of performance *energy*.

Comparatively, when working with the Novint Falcon,<sup>5</sup> an inexpensive three-dimensional games controller with force feedback, aside from the programmable forces offered to the user, the output data sent to the computer is simply  $x$ ,  $y$ , and  $z$  position information. There is no obvious reason why this is a better choice of representing the physical energy put into a system than an analysis of the produced auditory information.

### Haptic Augmentation: Perceptually Guided Action

Over an extended period of research, which included regular performance with the hybrid piano, it became apparent that developing a palpable sense of the physicality of the electronic sound was just as important as the analysis techniques, DSP, and the transducing of physical gesture into corresponding changes within the software. It became clear over time that while I was receiving the usual physical vibrations from the acoustic part of the instrument, through the acoustic resonance naturally felt in my hands, along with the more subconscious vibrations felt through my feet in connection with the pedals or floor, for the digital audio there was no analogous tactile feedback mechanism. I had to rely purely on my ears (and eyes via the laptop screen) to receive information about the sonic digital counterpart. The electronic sound would emerge from loudspeakers placed proximally to the piano, when the concert setup would permit this, or on either side of the stage, when this was not feasible, as is an unfortunate reality of many concert scenarios. Even with stage monitors, however, I felt a strong sense of disconnect; a feeling of being literally *out of touch* with what I was playing, despite being able to hear it, to some extent. Furthermore, reliance on the screen is problematic when using augmented instruments (Hayes & Michalakos, 2012), as it can be distracting and interrupt the sense of absorption in the task at hand. When this occurs for the performer, the audience are likely to perceive it too.

Attempts have been made to address the issue of the lack of tangible feedback in DMIs by embedding the vibrotactile feedback in the instrument itself (Berdahl, Steiner, & Oldham, 2008; Marshall & Wanderley, 2011; O'Modhrain, 2001). Collin Oldham's *Cellomobo* is perhaps one of the more established new musical instruments that features vibrotactile feedback. A speaker driver is used to create the haptic feedback and, in combination with a resistive ribbon controller, makes up a virtual bowed string setup (Berdahl et al., 2008). Hence, when the player bows the instrument they are provided with a physical representation of the slip-stick motion of a bowed string, while concurrently providing gestural input data for controlling sound synthesis. It was precisely this haptic information that Oldham felt was lacking in previous instruments. Like Marshall and Wanderley's approach, the vibrotactile feedback is embedded in the DMI itself, to make it *feel* more like an acoustic one. My motivation for the further augmentation of the hybrid piano with vibrotactile feedback was to maintain perceptually guided action through play, by being physically *in touch with* both the acoustic and digital sound worlds.

From a practical perspective, *embedded* vibrotactile feedback would not be appropriate for a piano. Firstly, the pianist is accustomed to the most direct vibrations being felt through the hands and thus would have to be in direct contact with the instrument in order to perceive the embedded feedback. This would work for the direct, instrumental gestures described earlier, but would be problematic for auditory responses that were not directly linked to the performed gesture. For example, a sound with delayed onset, or long duration, would no longer be perceived once the hands had been lifted from the piano. The solution to this was to *embed* the vibrotactile feedback directly onto the skin of the performer, instead of the instrument. This was done by placing small vibration motors on the hands of the performer using a thin, light-weight glove. Other work in the field has explored using vibrotactile rings (Rovan & Hayward, 2000), but it was decided that a fingerless glove would be less invasive for a pianist. By driving the motors with pulse width modulation, a large dynamic range of sensations can be felt, from a barely perceptible tingle to overbearing full vibration. Details of the technology employed can be found in Hayes (2011), although it should be noted that the original system required the performer to be relatively close to the computer, as the motors were sent information from the computer via a microcontroller via USB (Figure 1). The system has recently been improved with the support of Marije Baalman at STEIM,<sup>6</sup> Amsterdam, to allow numerous vibrotactile devices to function simultaneously and, more importantly, wirelessly.

As mentioned earlier, the hybrid piano takes form over numerous acoustic pianos, and thus by developing the technology around the musician instead, it becomes much easier to cater to every possible performance situation. By correlating the haptic



**Figure 1.** Performing at the Sonic Arts Research Centre, Queen's University Belfast, with the Haptically Augmented Hybrid Piano.

feedback with the produced digital sound through a simple amplitude mapping, the performer of the hybrid piano receives immediate, private feedback about both the acoustic (through the piano itself) and the electronic (through the haptic device) sound worlds. The potential for performance as perceptually guided action is fully enabled through the mutually affecting relationship between performer and instrument. Again, Cadoz (2009), in support of the enactive view, suggests that ‘The (ergotic) gestural interaction (which may concern the whole body) ... is inseparable from a specific perception, the tactilo-proprio-kinesthetic perception (TPK), and this perception is needed for the action just as the action is needed for this perception’ (p. 217). The possibility to play, and to perceive this on the skin, from outside the body, now exists. A consequence of the decision to place the haptic feedback directly onto the performer would suggest a discussion of embodied cognition within the realm of cybernetics, although this is beyond the scope of this paper.

### Embodying the Composition

Just as the various structural materials of acoustic instruments, not to mention changes in environment and temperature, will give different sensations to the performer, it is worth exploring the range of perceptual possibilities that the vibrotactile feedback paradigm offers. Firstly, alternative mediations between the digital sonic output and the haptic vibration can be introduced. For example, by feeling the *density* of the sound on the skin, or the amplitude of a *single* process within the electronic part, the performance can differ drastically, especially in the case of improvisation, as the sensory perception will be completely changed. Of course, multiple sensations can be experienced simultaneously, but this quickly results in a sensory overload, which becomes unhelpful to the performer. Since the practice of using sensors to extract information about the gestures and movements of the performer is almost ubiquitous in the world of electronic music, it seems worthwhile to explore different filtering or analysis methods to extract information from the digital auditory signal to send back to the performer.

Moving away from purely instrumental gestures, I will extend this notion by proposing that the artificial feedback may be used to convey not only a physical representation of the audio, but other dimensions within the *black box* that we might wish to embody.<sup>7</sup> This idea was explored in the composition *kontroll* (2010) for prepared piano, self-playing snare and live electronics. Here, vibrotactile feedback was used to send the performer information about successful triggering, time windows, and cues within the piece, through a series of symbolic vibrations (Hayes, 2011). In this scenario, the action (the performing) is still very much perceptually guided, but, where direct amplitude-correlated haptic feedback affects action-perception on the near-instantaneous micro-level, this secondary type of information will influence playing on the conscious macro-level of musical structure, influencing aspects of timing or phrasing. For example, if I am guided towards an approaching change in the development of the piece, by way of a vibration that increases in intensity, I may adjust my

playing accordingly, building up (or down) towards the change. Perhaps more crucially, the performer is no longer confined to checking for feedback awkwardly on the laptop screen, or worse, worrying about whether a particular trigger was successful or not.

## Conclusions

Within the area of digital and electronic instrument design, the focus is overwhelmingly directed towards methods for yielding input data, with minimal attention given to the feel of the instrument for the performer, and the instrument–performer relationship. This paper has attempted to delineate some of the historical thought that has informed current research into the use of haptic technology within this field. By examining various enactive approaches to DMI design, we can see that common threads emerge of multimodal interaction, structural coupling between sound and interface, and the notion of action as guided by perception. The haptic augmentation of the hybrid piano was demonstrated to have evolved out of these ideas, despite already offering what appeared to be a largely embodied mode of interaction for the performer. I will conclude that this feedback system allows the performer and instrument to be more closely intertwined, which in turn significantly influences the musical outcomes, not only in the live performance situation but also within the compositional process, helping the composer to gain insight into how the music actually feels through the process of creation.

## Notes

- [1] See Dreyfus and Dreyfus (1999) for a description of the various stages of skill development. Even at the expert stage, the performer will make use of their acquired embodied knowledge as they instinctively play by feel.
- [2] This will be shown to be of importance in the next section, with regard to implementing haptic feedback.
- [3] Phrase length was determined by setting a maximum period of silence between notes before a new phrase was registered.
- [4] In all my works involving the hybrid piano, I am the sole performer, but I refer to ‘the performer’ here, and elsewhere in this work, in the third person, to emphasise the application of these ideas to the more general case of performance.
- [5] [www.novint.com/index.php/novintfalcon](http://www.novint.com/index.php/novintfalcon).
- [6] [www.steim.org](http://www.steim.org).
- [7] Although it is beyond the scope of this paper, the vibrotactile system was also used as a method of communication between two improvisers, each playing an augmented instrument (one of which was the hybrid piano) (see Hayes & Michalakos, 2012, for details).

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