Implementation and Development of Sculptural Interfaces for Digital Performance of Music through Embodied Expression

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This demonstration paper describes the conception, design and implementation of a hardware/software musical interface and its use in performance with a group of dancers and a choreographer. It investigates the design and development of such interfaces in the light of these experiences and presents material from two of these custom interfaces.

The work examines the nature of digital interfaces for musical expression through the use of multiple sensors, the data from which is used to generate and control multiple musical parameters in software. This enables levels of expression and diversity not generally available using conventional electronic interfaces, the latter frequently being limited to the direct control of a limited number of musical parameters. The combination of hardware design and algorithmic manipulation combined with the expressive potential of dance and embodied movement is of particular interest.

Reflecting links between embodied movement and expression in live performance, the feedback between form and function is also considered, as are collaborations with sculptors to develop and enhance the physical behaviour and visual appearance of these devices.

Music. Sculpture. Algorithms. Embodiment. Dance. Movement. SuperCollider. Arduino.

1. INTRODUCTION

There has never been a time when the creation of music has been so interdisciplinary. Developments in hardware and software have led to significant activity in this area, frequently prompted by the frustration electronic musicians have felt with the purely digital interface they have been using (for the most part devotedly) for the last twenty or so years. Then, MIDI-based synthesisers were enthusiastically forsaken in favour of machines that used digital recordings as the basis for their sound. When computer memory and processing power became cheap and fast enough, these synthesisers were themselves shelved.

2. CONCEPTION

As a musician who learned to love music through live performance on an acoustic instrument and the social structures of orchestras and bands, the tempting freedom of electronic music has always been tempered by a perhaps reluctant realisation that electronic music in general and computer music in particular has been a solitary pursuit, not optimised for social behaviours other than the special eccentricity for which electronics specialists are renowned. On a more visceral level, a musician's interaction with a physical acoustic instrument is a very different experience from that of manipulating a computer via keyboard, mouse or any other conventional tool of interaction.

One of the key issues defining 'viscerality' is the learning of particular physical and mental functions so well that they become autonomous (Ericsson, 1993 & 1996). This enables musicians to perform otherwise extraordinary feats of physical and mental dexterity (playing Brahms' Second Piano Concerto). It has been estimated that it takes about 10 years or 10,000 hours of practice to become expert.

Clearly an ideal mode of development for novel musical instruments would take a long time: they require development, acceptance and the construction of a repertoire. This means that those interested in designing new musical instruments and interfaces must have either a lot of patience, or methods for attempting to short-circuit these long incubation periods.

Issues of physical computing in music and other arts have been difficult to research until recently, at least without significant resources or knowledge usually situated outside one's native area. However, recent popularisation of hobby robotics, along with a blossoming of easy to use software and hardware has enabled a surge of activity in this field. That the software is usually open source and free and the hardware is often sold at little more than cost has only fuelled this interest more.

3. IMPLEMENTATION

3.1 Gaggle

The *Gaggle* interface (Hoadley, 2009b) was originally conceived as an improvisatory interface for the control of generative, automatic music (Figure 1).. Generative procedures would control specific aspects of the music including pitch, duration and timbre. This interest was in turn the result of a number of years working in the area of generative or algorithmic composition, the primary purpose being to help me understand the creative process itself through the development of software that emulated it. A very clear part of that emulation has been the recreation of those elements of 'liveness' that make live performance so satisfying. These elements, investigated in depth elsewhere (Loy, 2006), include indeterminacy, the varied repetition of melodic, rhythmic and timbral material and the encapsulation in software of global structures such as the length and order of particular groups of material. *Gaggle*'s first public appearance was at the HCI 2009 conference in Cambridge UK, where I was invited to contribute to the Open House Festival. At this point the device was an experiment in multi-dimensional control of multiple musical parameters. It comprised nine ultrasonic sensors held in place by stay-put tubing (goose-necks). The sensors were used to 'manipulate' music written using the SuperCollider audio language (McCartney, 2002).

The nine ultrasound sensors used in *Gaggle* are Ping units manufactured by Parallax (Parallax, 2006). These particular units work by instructing an emitter to output a 40 kHz frequency sound for 200 µs (Figure 5). The pulse is then read on its return and duration of echo calculated. This provides a quite precise indication of the distance of any solid object positioned directly in front of the unit to a manufacturer's limit of 3m. The ultrasound units were held in place with 'goose-neck' stay-put tubing potentially allowing for customization of the sensors' placements. This was established initially when I was planning to demonstrate the unit using my own movements.

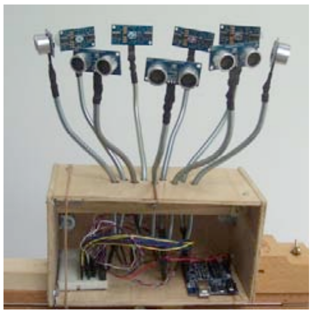

Figure 1: *The Gaggle prototypical interface*

3.2 Wired

The *Wired* interface (Hoadley, 2010a) is a highly prototypical sculptural interface (Figure 2). Unlike *Gaggle* it has been conceived and designed from the outset specifically bearing in mind the needs of a performance with a unit that has a distinct visual presence.

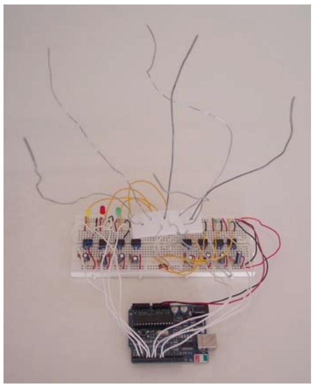

Figure 2: *The prototypical Wired interface*

With this in mind, the design involved consideration both of how the item would look and how the performers (primarily dancers, but also visitors and spectators) would interact.

The design has been very much influenced by the *Gaggle* experience; working with dancers and their freedom of expression through physical movement showed that they very much enjoyed interactions with and investigation of interesting and novel objects. The device has been demonstrated in prototypical form at the Museum Interfaces, Spaces and Technologies (MIST) workshop in Cambridge in March 2010 (MIST, 2010). The experience, like that of demonstrating *Gaggle,* showed how eager delegates were to experiment and investigate these devices. It was praised in particular for ease of use and for enabling those with little or no musical experience to 'perform' in a pleasing and expressive way.

Sculpturally, as the photograph in Figure 2 shows, the unit is simple but easy to interact with. The prototype unit pictured in Figure 3 is approximately one foot high and wide. Further sketches are given in Figure 3, offering possible variations.

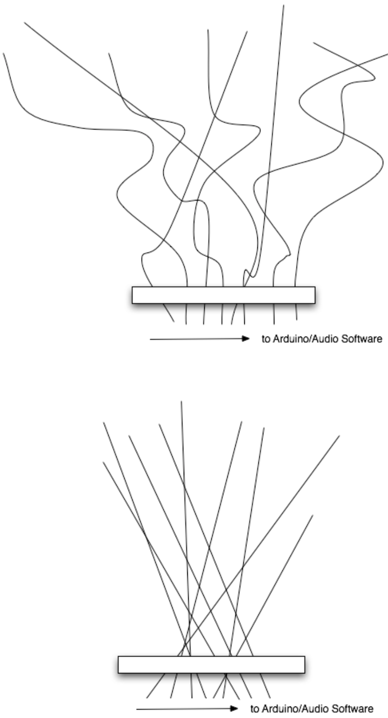

Figure 3: *Sketches for Wired*

In spite of the unit's rather unrefined state, visitors enthusiastically experimented with the wires, intrigued by how they would react.

This illustrates a particular issue with the design. *Wired* is a prototypical interface utilising the high input impedance of the trigger pin of the 555 integrated circuit. When this is triggered by the induced voltage of human body the output goes high for a time determined by two simple components: a resistor and a capacitor, enabling a simple and highly structure such as a wire to be used as touch sensor. However, it also means that the wires need to be protected in order that they should not touch each other accidentally, and also that any material supporting the wires needs to be neutral as far as touch is concerned. Of course, each wire needs to be connected to the trigger pin of the relevant 555 chip, meaning that there needs to be a general level of appropriate non-conductive support available. In the prototype, a large but thin rubber eraser was found to be appropriate. The unit is in prototype stage and is too small to be of any use visually on a stage. In order for this to be the case the unit needs to be significantly larger in all respects – for instance utilising sculptural armature wire. Because of the issues of support and conductivity mentioned above this is not a trivial matter.

Finally, in terms of the general appearance, decisions have to be made about how many wires to use, whether they should all be implemented with their own 555 chip and whether the wires should be curly, straight or both! Would it be appropriate or interesting to enable the unit's orientation to be rotated in one plane or another (Figure 4).

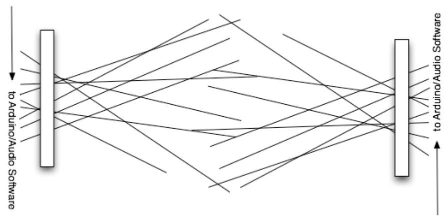

Figure 4: *Sketches for Wired*

3.3 Arduino

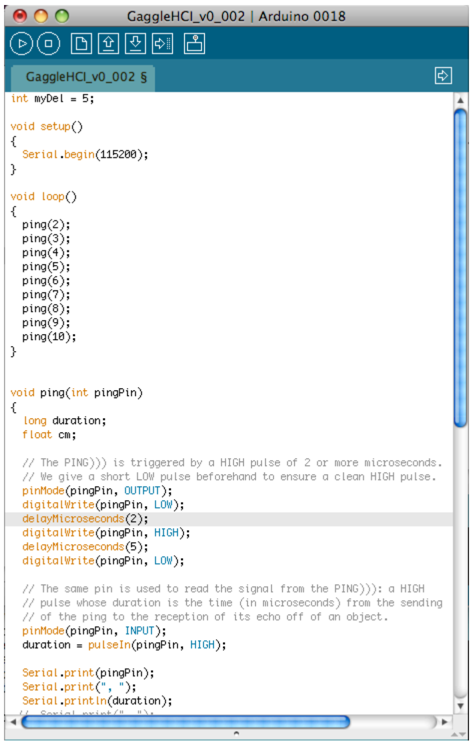

Figure 5: *The Arduino Coding Environment*

Currently, both *Gaggle* and *Wired* interface with Arduino prototyping boards. This cheap but effective and increasingly ubiquitous platform uses a straightforward and simple to learn programming language. This results in each sensor sending a stream of values to the SuperCollider audio language (McCartney, 2002). The limitations of this particular use of the Arduino platform were here manifest as there was significant latency between the readings from each ultrasound unit (see below). To reduce this latency a Teabox interface (Allison and Place 2005) has been used experimentally, the signals of which, running as they do at audio rate, provide much higher resolution and lower latency.

All other manipulation happens in the SuperCollider environment in order to minimize load on the Arduino's CPU but in any case the only other requirement as far as the hardware interface is concerned is that the readings should be calibrated in accordance with room size and performance requirements.

3.4 SuperCollider

An earlier musical composition provided the basis for the specifically musical part of the project on the occasions mentioned, although with us this 'repertoire' will expand. *One Hundred and Twenty Seven Haikus* (Hoadley 2009a) had been prepared for a concert at Kettles Yard Gallery, Cambridge in May 2009. It is an entirely automatic composition, constructed so that it will be 'different' each time it is 'performed' (or perhaps more strictly speaking 'run'). Crucially, however, at each performance it should be as recognisably the same piece as any previous performance, emulating the different but similar performances given by a live performer.

Algorithmic, pattern-based processes generate streams of data, which are used to trigger sonic events, timed so as to create a typical time-based musical structure. A function might generate a stream of time-controlled values between 0.0 and 127.0 from time x to time y. These values might be used to control sonic events. The sonic events are pre-defined functions comprising a variety of unit generators (ugens) and other utilities. These functions are themselves constructed so that certain parameters of the sound are controllable. One stream of values might direct frequency or pitch, another the attack part of an envelope, a third the index of modulation used to determine the voice's timbre. In musical terms, one of the most interesting parts of this process is the way in which the asynchronous control of this number of parameters can create such a 'lively' sound, literally. It is my contention that it is this complex of control that provides the best currently available metaphor for that particular live 'feel' that is created by a live musician.

Below is one example of the general interactive blueprint that exists between *Gaggle* and SuperCollider code. A similar configuration occurs between *Wired* and SuperCollider. This system includes a variety of types of interaction. Below is the use each of *Gaggle*'s sensors was put to during this particular performance.

(i) set the index of modulation depending on proximity;
(ii) trigger a textural pattern;
(iii) randomize modulation indices;
(iv) trigger a haiku (a melodic fragment);
(v) trigger a 'finickey' (a melodic fragment);
(vi) trigger a glissando or slide in a previously sustained sound;
(vii) trigger a harp-like sound – the pitch dependent on proximity;
(viii) set the modulation index for this slide;
(ix) unset for the HCI2009 performance.

None of the above results in literal repetition of material, although to arrange this would be trivial. In all cases, and most clearly in the cases of 4 and 5 above (the 'melodic fragments'), the triggers involved the real-time development of new, but clearly related melodic material. This emphasises one of the issues of the project involving the investigation of different consequences following use of the relevant metaphor used – and indeed the investigation of what 'rules' might operate in these scenarios. It is also important to bear in mind that any or all of the scenarios outlined above can be quickly and easily replaced. In fact, one of the sensors could be programmed to automate this function.

4. FORM AND FUNCTION

4.1. Old and New Musical Instruments

In terms of musical instrument development, there seems to be a clear distinction between traditional instruments that, with a few notable exceptions (Wagner tubas and saxophones, for instance), have developed gradually over time, and attempts at 'new' instruments and interfaces. Particular examples of the latter include Perry Cook's intriguing instruments (Cook, 2001) and some of the offspring of the MIT Media Lab (Weinberg 2002; Young 2002) have, along with contributions from the New Interfaces for Music Expression conferences and Make magazine (O'Reilly, 2005-2010) changed the academic status of novel interface development in music significantly.

Probably the artefact closest to the current version of the unit called *Gaggle* described presently is the 'Sound=Space' installation by Rolf Gehlhaar (Gehlhaar, 1991). This variable room-sized installation is described as having a number of configurations and purposes: including use as sound-art installation, use for dance and therapeutic use. Gehlhaar describes a series of possible topographies for use in different environments and for different purposes, for instance 'changes in themes and rhythms' (ibid, p. 68) or action creating a melody. The principal disadvantage apparent in this system concerns its lack of flexibility. The installation is based around a number of units each of which used a single pair of ultrasonic sensors (to a maximum of 48 at the time of the article's writing). These are set up around a space (rather than in it) and the topography is put in place to express particular kinds of activity and in order to obtain particular results.

My own experience with *Gaggle* is that while further developments involve more work on different topographies, significant areas for development lie in other types of interfaces made from clusters of varying sensors, materials and environments. The realization of a monolithic scene that is capable of being flexible enough to display sufficient quantity and quality of expression is, I think, optimistic. I would suggest that future expression would be small, flexible and heterogeneous.

4.2. Interaction with *Gaggle* and *Wired*

Figures 6-8 show photographs of the dancers interacting with *Gaggle*. One of the clearer impressions to emerge from these demonstrations is the ease with which people interact with these objects.

Figure 6: *Dancers interacting with Gaggle: open hands, pulsing.*

It is very clear from analysis of these images and videos that it is the role of the human, judged from whichever perspective that is of crucial significance in deciding the purpose, quality and function of the device. If the human feels they are a performer who would expect to spend some time learning and understanding the interface, maybe working hard at particular features in order to achieve particular technical ends (Brahms' Second Piano Concerto, maybe), then they will have very different expectations from someone who is pleased to generate interesting sounds without too much effort having just wandered into a gallery. The two most common initial responses are delight (particularly from those who would class themselves as non-musicians), and scepticism ('where's the learning' – that part of the pleasure of playing a musical instrument is the learning of it). Interestingly, a number of visitors commented that their positive experience was enhanced by their view that the music produced 'sounded nice' in contrast to what they felt was the often harsh and aggressive sound world of some electronic music.

Figure 7: *Moving in a line, circling the unit*

Figure 8: *In a line, gesturing*

4.3. Metaphor and Interaction

The nature and relevance of metaphor in the interface has been analysed on many occasions (Blackwell, 2006) and is still the subject of much discussion, but one of the crucial ideas of the metaphor is that it encourages chains of expectation. If an object (usually in the virtual domain) behaves like an object (usually in the real domain) in a convincingly realistic way, a series of expectations can arise that other behaviours will be similar, and there can be both pleasure and reassurance from this experience.

As an example of this, visitors, even quite technically literate ones, find it hard to understand that a unit such as *Gaggle* doesn't actually make any sound! This seems very much a consequence of the fact that they feel that the response of the unit is quite physically related to changes in the sound and that therefore the unit must itself be responding. This demonstrates the power of what some might call a metaphorical equivalence with the fact that objects in the real world (for instance musical instruments) make their own sound.

Another example would be a perceived link between proximity and intensity. *Gaggle* is usually set up so that the closer you are to the unit, the more amplitude you will get from it, presumably reflecting the general human experience that closeness generally implies intensity?

Finally, those interacting with *Wired* wanted to run their fingers up and down the wire. This happened even after they had been told that the wires were simply touch switches so that in this case *where* or *how* the wires were touched is irrelevant. It appeared that the desire to express something was more important than even the reality of whether they were actually expressing something or not. In the case of *Wired* running one's fingers up and down the wires was one of the only ways of 'performing' expressively. This seems rather similar to the experience of pianists, who, although they are aware that they have no physical control of the note once it has been struck will frequently continue to 'express' themselves by continuing to move their fingers expressively.

Bearing these examples in mind, what does it mean specifically for a metaphorical link between form and function to exist? There is a balance to be drawn between the interface metaphor 'making sense' and therefore helping the performer use the resources available, and a more playful approach where part of the joy of investigation is in the discovery of stimulating responses and behaviours. On the one hand we have traditional musical instruments: attractive and with a very successful track record, but usually very difficult to become expert in (Ericsson 1993), on the other we have new technologies: playful, analytical, metaphorical and above all else, *not* traditional.

4.4. Other Considerations

In addition to elements such as use, intention and expectation and the role that the idea of metaphor or notation plays these fundamentals, this research also highlights a number of other issues mentioned below. These are only mentioned briefly, but are no less important for that and all are worthy of more intensive study themselves.

4.4.1. The instrument is the composition
Are devices such as these musical instruments or parameter controllers or perhaps compositions themselves, in the manner of many installation pieces produced by visual artists and sculptors?

While there have been many attempts at making new instruments to replace existing ones, so far the replacements have in general signally failed to make much impact on the usual selection of 'standard' instruments. This may be because performance on a musical instrument is the totality of the experience of a real human manipulating a real object. What, from this continuum, is it possible to use in the HCI? A device such as the iPod shows that it is not necessarily the total functionality of any particular device that is important, but the balance between that functionality and ease of use. One of the features of the iPod is indeed this compromise.

Another option is that the instrumental design becomes a part of the creative process itself and is no longer assumed to be an independent item (although this possibility doesn't need to be ruled out). This option satisfies the differing requirements of differing performers on differing occasions: one might want more traditional expression, challenges and skills; another might want more playfulness.

4.4.2. Is programmability a curse?
Programmability is one thing that is not possible in the domain of the 'real' musical instrument. One has only 'real' options: physical interferences such as muting, mutating and hacking (sometimes literally). Things that are programmable do not possess that boundary of solidity beyond which we cannot go. We have either a flute or a clarinet. Replace a flute's mouthpiece with a clarinet's and what do you have – a soprano saxophone? Probably not a flute, but your (Yamaha-Roland-Akai) 'hyper-flute' can be anything you wish – a flute, a trumpet; even a drum machine! So what is it exactly? A synthesiser.

4.4.3. Multiple parameters and conscious control
One of the features of acoustic instruments is that, while in comparison to their technological counterparts they may seem simple, in reality they are not. We have become used to these interactions and tend to ignore their most important features – most obviously, the quantity of information available from any 'simple' expression. This information comes about through the use of continuous control information on a set of simple but continuous parameters. A flute has a fixed number of finger holes, but the breath control is continuous and infinite. There are unlimited ways of controlling a flute's tone through breath (also finger holes need not be fully opened): it is the most significant factor in expression on the instrument. Any 'standard' acoustic instrument has similar characteristics. A musician practices using these continuous controls; becoming a good player usually means no longer needing to utilise these controls consciously. Lower level activities such as fingering and breathing become automated, allowing increased concentration on higher level tasks such as musical expression.

One of the main experimental strategies in developing the new units here described is the mapping of controllable parameters in particular areas and using particular sensors so that conscious control of all parameters is more challenging. This itself is a stopgap solution to a larger problem: eventually users would get used to any particular set of mappings and as this point is approached unless some other goal is identified boredom may well result.

4.4.4. Latency

This is a technical issue involving the speed and quality of response. Imaginative users often first test for this: gesticulating as in figures 6-8, starting slowly in order to ascertain how the unit will react initially, but soon testing the speed and abruptness of a response, using sharp and sudden movements. *Gaggle* has not been set up to respond in this way, although it could be programmed to be more immediately responsive. One of the reasons is that the Arduino card used is not enormously fast, and although a fairly large amount of quite high-resolution data (0-1023) is transmitted, with nine sensors latency is inevitable. This matter can easily be overcome with cash, by using an interface such as the *Teabox*, which operates at a faster audio rate. As this product is significantly more expensive that the Arduino board developer may wish to be meticulous in deciding when to use each board.

4.5. Balancing Form, Function, Use and Expectation with Sculptural Interests

The development of new interfaces is clearly itself a complex interaction between all of the above factors. Under these circumstances it is hardly surprising that developing new musical instruments has proven so complex.

Mappings of one form of expression onto another – composing music to image is one of most popular – is a very common human mapping, so it shouldn't be surprising if some of us are captivated by attempts to mimic this impulse. Experience shows, however, that this apparently intuitive mapping is far from simple to replicate technically. Light and sound are fundamentally different; image and music are themselves metaphorical developments of these fundamentals; any formalised link (say using software) between image and music has a long way to travel if it is to remain meaningful: simple video editing in response to audio amplitude simply won't do.

Exactly the same impulses are behind my particular desire to infuse the devices with artfully crafted physical form that also, completing the feedback loop, then contributes to the music making itself, and all this while retaining intact the meaning from each domain. The process inevitably requires some compromise on both sides.

5. FURTHER DEVELOPMENTS AND CONCLUSIONS

As some may recognise, one of the main influences on the design of a unit like *Wired* is the sculptor Alexander Calder (see Figure 9).

Figure 9: *Alexander Calder, 1941*

His delicate creations, many of them wire-based mobiles and wall sculptures, strike me as ideal for investigation of sensor based music solutions, but alternatively, more monumental shapes and figures might be as exciting.

The author has made contact with a number of sculptors who are interested in collaborating in this project – most obviously Douglas Jeal (see Figure 10), (Jeal, 2009). A sketch of a potential interface constructed from coloured perspex and utilising, amongst other phenomena, light and colour as a primary interface: in the sketch, the level and nature of the light would be varied by the interaction between ambient lighting and that reflected from the dancers costumes which are themselves abundantly decorated and floridly designed.

In such collaborations there would need to be a significant level of partnership in the process and inevitably there would be some competition as two art forms collide. In some respects, sculpture might be seen as one of the least ephemeral, most solid of the arts and therefore perhaps one least appropriate for association with music – especially at this suggested level of interaction. On the other hand, the example of kinetic and sonic sculpture indicates that there is a tolerance for these objects. Of crucial significance is how much of this tolerance is because kinetic sculptures with sonic components use the material of which the sculpture is made.

The issues determining the success of any such collaboration will almost certainly involve the nature of any of these supposed metaphorical links and how they balance with the essential nature of each object: sculpture and music.

Figure 10: *Sketch for Sculptural Interface and Dance, Douglas Jeal (2009)*

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