Gesture≈Sound Experiments: Process and Mappings

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ABSTRACT

This paper reports on outcomes of a residency undertaken at STEIM, Amsterdam, in July 2007. Our goal was to explore methods for working with sound and whole body gesture, with an open experimental approach. In many ways this work can be characterised as prototype development. The sensor technology employed was three-axis accelerometers in consumer game-controllers. Outcomes were intentionally restrained to stripped-back experimental results. This paper discusses the processes and strategies for developing the experiments, as well as providing background and rationale for our approach. We describe “vocal prototyping” – a technique for developing new gesture-sound mappings, the mapping techniques applied, and briefly describe a selection of our experimental results.

Keywords

Gestural control, three-axis accelerometers, mapping, vocal prototyping, Wii Remote

1. INTRODUCTION

In July 2007 the authors undertook a residency at STEIM, Amsterdam with the goal of exploring and experimenting with new methods for control and performance of digital sound using whole-body gesture. More specifically, to develop systems which support kinaesthetic-auditory synchresis, where human body motion is mapped into sound in such a way that sound production becomes an inherent and unavoidable consequence of moving the body – with the intention of engaging both performer and audience in a fluid experience of the relation between performed sound and gesture.

Our approach was multifaceted and reflected the various interests of the collaborators. Considerations included: physicality in the space, sonic and compositional form, structure and aesthetics, conceptual semantics, sensor technologies and applications. These concerns were used as the basis for devising experiments, some of which were undertaken without interactive technology. For example, in the early phases of the residency we experimented with movement-only composition, and later, some sound mappings were prototyped by improvising movement to voice or pre-recorded sound.

From the outset our intention was to research and experiment with new techniques and to document our experiments, rather than produce a completed performance work. This was motivated by a number of factors including our need to develop experience with new approaches and technologies; the desire to not be constrained by the requirements of structuring a coherent performance; and the goal to create circumstances where working in new ways was natural, rather than giving in to the tendency to fall back on tried and trusted solutions and techniques.

2. BACKGROUND & RELATED WORK

The authors have been variously engaged in the creation of performances incorporating gestural sound control for some time. Of most relevance here are Bencina's work with Simulus incorporating the P5 Virtual Reality Glove [14]; Wilde's performance interfaces such as Face Clamps [20] and hipDisk [21]; and Langley's ID-i/o [8] and work with HyperSense Complex [12]. Our combined processes include consideration of the musical, physical and technical perspectives, as reflected in the discussion of related work that follows.

Within Wanderley's review [18] our interests are located proximally to the performance practices of Tanaka (EMG based gestural control) and Waisvisz (The Hands), both cited therein. However our concerns are largely independent of Wanderley's taxonomy of sensor based input and gestural control interfaces. We seek to create performances which engage the whole body, and hence avoid dependence on hand-based sensor input or 'interface artefacts' which draw attention (of both performer and audience) away from the body towards the artefact. In this regard we relate perhaps more closely to Hahn and Bahn's “Pikapika” character [6] who embodies movements from the *bunraku* (Japanese puppet theater) where physical gesture not only corresponds to music, but dictates certain sound effects. With regard to our relation to the plethora of interactive dance systems (see discussion in [6]), we note that our goal is not to compose performances for dancers, but rather to give expressive sonic capabilities to the whole body in motion. With respect to this we find strong resonance with Bahn et al's discussion concerning the integration of the dancing body and the musical body [2] and also with Winkler's idea of “allowing the physicality of [human] movement to impact on musical material and processes.” [22]

Paine's recent publication [11] presents an instrument design approach and example composition utilising the same

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accelerometer based game controllers used here. Two significant points of difference are, firstly, his application of a parameterisation strategy based on an analysis of traditional instrumental methods of sound production (as opposed to say, the natural causality of Chion's synchretic footsteps [3], or a musical structuring model grounded in a more general sonic typology [15]) and secondly, an interface-centric rather than body-centric orientation towards control affordances. Moody et al. [10] develop a mapping strategy for gestural control of an audio-visual system, which seeks to achieve synchresis between generated audio and video. Their argument is relevant to the present work, where we seek synchresis between observed performer gesture and generated synthetic sound.

The technical development of the sensor filtering and mappings described below has been informed by a range of literature concerning gestural control of music [18], pragmatic accelerometer-based motion analysis [4, 9], and more specifically, accelerometer controlled synthesis [13, 17]. Much of the inertial motion analysis literature is concerned with more elaborate sensing and filtering schemes than were applied here, however we found the mathematical development in Ilmonen and Jalkanen's system for analysis of conductor gestures particularly helpful [7].

3. TECHNOLOGY OVERVIEW

Although we were interested in exploring a range of gestural input technologies, the Nintendo Wii Remote was settled on as a sensor platform for prototyping. The Wii Remote was chosen for pragmatic reasons as it provided a wireless 3-axis accelerometer in an off-the-shelf package. As we were primarily concerned with gestural input, only accelerometer data from the Wii Remotes was utilised. Masayuki Akamatsu's aka.wiiremote Max objects [1] were adapted to simultaneously convert accelerometer data from up to 6 Wii Remotes into an OSC data stream that was used as an input to AudioMulch, where mapping and sound synthesis was performed. Mappings were developed using an embedded Lua script interpreter running inside AudioMulch.

4. PROTOTYPING PROCESS

The schema for gesture≈sound prototyping arose out of a belief that interweaving the development of sound and movement would open up new ways of thinking about gestural sound performance and lead to gestural sound synchresis. We adopted a strategy of minimal development – pursuing development in each modality sufficient only to allow or provoke advance of the work as a whole. We were thus prevented from falling back on known methods and solutions, or staying in our comfort zones. The different modalities – sound, movement and technology – were developed in tandem. A new vocabulary was allowed to emerge from our existing skills and the area of inquiry. Our approach included 'vocal prototyping', discussed below and, while neither extensively nor rigorously evaluated, resulted in each of us working in new and unexpected ways, with positive outcomes.

4.1 Moving Musicians

According to our criteria, a gesture controlled sonic performance needs to engage the body of the performer in movement which incorporates a broad spectrum of physical expression. Successfully engaging musicians and technologists in physical exploration can prove challenging, as typically they do not focus on, nor do they have highly developed skills in this area. How might musicians/technologists explore physical expressiveness in extended ways?

While there was no desire to privilege the physical, we felt it important to short circuit the musician and technologist's tendencies to de-prioritise their body's expressive range – to create a different mindset from which to launch our investigation.

Our working process began with free-form brain and body storming. We brainstormed possible uses of the sensor technology before plugging in the Wii Remote and playing with it, to avoid imaginations being tempered by knowledge of the device's limitations, and to encourage working directly with the body as a medium through which we could undertake our research. Similarly, we created short physical vignettes without setting a specific point of departure or other assistive limitations, thus forcing open engagement of the imagination to be linked directly to the body from the outset. This process enabled the musician/composer collaborators to familiarise themselves with extended physical expression and with varying levels of physical proximity. It also formed a platform from which we could begin to talk about movement.

For the duration of our working process, we made a point of preceding discussions, brainstorming and ideation sessions with movement sessions. This allowed us to approach non-physical and physical tasks alike in a 'physically ready' gestural state.

4.2 The Approach

Over the course of the residency we engaged in a range of activities to develop our gesture sound mappings, continually striving to broaden the parameters within which we were thinking and working. We investigated ideas stimulated by the sensor technology such as how and where the Wii Remote could be placed on the body and what kinds of gestures it might be able to sense and measure. We thought directly about sound – without limiting our ideas to the constraints of the technology; and worked directly from a consideration of the body's affordances and dynamic capabilities. Throughout, we engaged in repeated ideation sessions, developed simple patches in response to ideas, and tried to understand what different choices afforded and what directions might be valuable for us to pursue. All of our experiments were captured on video to enable ongoing assessment and review.

Although we kept our attention on the technology, we remained cautious that its demands not draw our focus away from other areas of inquiry. One method we used to counter this tendency was to vocally prototype our ideas so that we could discuss and explore links between sound and movement without being limited by the technical constraints of the mapping process.

4.3 Vocal Prototyping

The aim of vocal prototyping was to challenge our usual ways of thinking about movement and sound and to begin to understand the kinds of relationships we might make between them. Through this process we generated a substantial amount of material and made concrete steps towards formalising a gesture sound vocabulary. As outlined below, vocally prototyping ideas naturally flowed out of other approaches.

We began by exploring a range of processes to develop appropriate sounds. Working individually we identified sounds from the Freesound creative commons database [5], which we used as a basis for discussing and understanding the qualities of sonic space we each desired to create. This was followed by free-form sound generation using the voice only; physical performance making sessions during which we vocalised sounds that were suggested by movement; and free-form movement and sound generation using the voice and entire body.

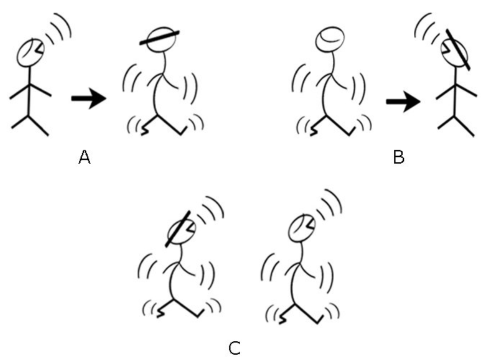

Figure 1: sound to movement to sound

To expand our movement sound vocabulary we undertook a range of exercises, including those outlined in Figure 1:

A. first person vocalise, other find movement that corresponds [x10 sounds]. Swap and repeat

B. first person gesture, other find vocalisations that correspond [x10 gestures]. Swap and repeat

C. each make their own movement/sound pairings [x10]. Work concurrently. When ready, perform one for the other.

We then physicalised the four elements (Earth, Air, Fire and Water) together in the space without vocalising or adding other sound, reviewed the video, then physicalised Thunder – one by one, alone in the space for five minutes with the others observing. This work, inspired by the unseasonally tempestuous weather experienced in Amsterdam at the time, served to extend our movement vocabulary by providing a familiar, yet imaginary impetus for highly abstract movement. The challenge throughout was to extend our movement vocabulary and habits in the performance space by focusing on the physically expressive body and its relationship to sound.

Other approaches included:

FREESOUND SOUNDS: work through the previously collated Freesound sounds to arrive at corresponding gestures/movements.

CONVERSATION: (isolated voices): pass gestures and sounds back and forth to create a kind of conversation between two (or more) people. E.g. The first person gestures while vocalizing (or vocalises while gesturing), the other responds with a different vocalised gesture/gestured vocalization. This leads to characterisation and helps to break vocal and gestural habits.

OVERLAPPING CONVERSATION: As above but the improvisation is less structured and can overlap.

PREPARED VIGNETTES: Take 10 minutes to compose a short gestural/vocalised vignette that is then performed. Decide where the sensor technology would be placed and how the data would affect the sonic output. Experiment with the imagined placement of technology – identical to the other person, mirrored, completely unconnected. Experiment also with possible sound output and effects, performance relationships, etc.

While the above is not exhaustive it gives an indication of our approach in what we hope is a repeatable manner. As mentioned previously the challenge was to find new ways of working with and thinking about both sound and movement. 'Vocal Prototyping' was found to be ideally suited to this task, it also released us from the constraints of technology development. The methodology was both rich and fecund.

4.4 Incorporating Technology

In order to incorporate technology we reviewed the material generated during the 'Vocal Prototyping' sessions and considered further development. Questions included: *What ideas or fragments did we consider worth pursuing?* and *How could we implement them through the technology?* We were interested in how particular vocalized sounds might be reinterpreted through synthesis. We didn't want to simply translate what we had discovered we wanted the creative process to continue.

The outcomes of vocal prototyping formed one of a number of inputs to the process of generating sound to movement and movement to sound mappings. Other inputs included free-form ideation around categories of possible mappings, possible sonic responses to particular motion events and other abstract sonic, musical and movement ideas.

From these varied sources we developed simple patches that would enable further exploration. From this point forward the development of technology, movement and sound was interwoven, and we continued to test the patches and rework them. The aim, ultimately, was to take individual outcomes to a trial performance level so that we could undertake further assessment.

5. MAPPING

Three-axis accelerometers are powerful sensors for gestural control applications. Although raw three-axis acceleration signals have only limited applicability for musical control, a range of useful signals may be derived from them. Since it is not generally possible to separate acceleration due to the earth's gravity from that applied by a performer wearing the device, nor rotational vs. linear acceleration, useful derived signals are (at best) considered pragmatic approximations of physical parameters such as orientation, velocity, etc.

This section describes the transformations applied to the raw three-axis accelerometer data in order to produce useful audio control signals. Here the focus is on the low-level mathematical processes applied, motivated by the idea that it is helpful to document such procedures. The hope is that an organised framework of such mapping strategies may emerge, in the spirit of work begun in [16]. Application of these control signals to specific sound generation strategies is discussed further in the outcomes section.

5.1 Calibration and Normalisation

A number of the applied transformations depend on the sensor data being normalized such that the computed 3D acceleration magnitude for a stationary sensor be constant at 1.0 irrespective of the sensor's orientation. The calibration was performed according to the procedure described in [19] and resulted in the computation of an offset and scaling factor for each sensor axis. Calibration was performed once for each sensor, with the resulting values stored in a lookup table. During operation the calibration data was used to compute a normalized floating point acceleration vector (a_x,a_y,a_z) such that a sensor axis aligned to the direction of gravity would have a value of 1.0, corresponding to the acceleration induced by the earth's gravitational field. Similarly, the 3D vector magnitude of the stationary sensor in any orientation was also 1.0.

5.2 Basic Derived Quantities

For the benefit of the authors, and those readers less mathematically inclined, a few basic operations that can be performed on the normalized three dimensional acceleration values (a_x,a_y,a_z) are reviewed here:

5.2.1 Single axis angle to gravitational field

Under the assumption that the sensor is stationary, it's acceleration will vary between 0 and 1 based on its alignment to the direction of gravity. The angle (in radians) between the sensor axis and gravity is given by the arcsine of the single axis acceleration $angle_{axis} = \arcsin(a_{axis})$. Assuming the sensor is mounted parallel to the spine (for example) this value can be useful for sensing how far off-centre the performer is leaning.

5.2.2 Two axis tilt amount and angle

Given a plane defined by any two sensor axes, say a_x and a_y, we can apply the Pythagorean theorem to compute the amount of tilt:

$$tilt\ magnitude_{xy} = |a_{xy}| = \sqrt{a_x^2 + a_y^2}$$

Assuming a stationary sensor accelerated only by gravity, $|a_{xy}|$ will vary from 0.0 (when the plane is parallel to the ground) to 1.0 when the plane is at right-angles to the ground. We can compute the direction in which the plane is tilted using:

$$tilt\ direction_{xy} = atan2\left(\frac{a_y}{a_x}\right)$$

Where *atan2* is the four-quadrant version of the arctangent function commonly found in modern programming languages, which gives an angle in the range (-π,π]. Two axis tilt values may be used, for example, to respond to the orientation of the trunk of the body towards the ground.

5.2.3 Three dimensional acceleration magnitude

Applying the Pythagorean theorem in three dimensions we can compute the *absolute vector magnitude* $|a_{xyz}|$ defined as:

$$|a_{xyz}| = \sqrt{a_x^2 + a_y^2 + a_z^2}\ .$$

This is the total magnitude of acceleration affecting the sensor including both the gravitational and gesture motion components. As noted above, $|a_{xyz}|$ will remain constant at 1.0 for a sensor at rest. When put in motion by a performer the acceleration magnitude will usually increase, although under certain circumstances it may temporarily decrease (if the performer rapidly accelerates the sensor towards the ground for example).

5.3 Approximations

Given the above quantities and some assumptions about the way a human body moves in performance, we computed additional signals useful for driving gesture controlled sound synthesis.

To approximate the magnitude of performer acceleration excluding gravity we subtracted 1 from the total 3D acceleration magnitude and took the absolute value:

$$a_{performer\ motion} = \| a_{xyz}| - 1| = |[\sqrt{a_x^2 + a_y^2 + a_z^2}] - 1|$$

Even with fast gestures the bandwidth of acceleration signals induced by muscular action alone is generally quite low (on the order of 10-20Hz) when compared to acceleration induced by physical stops (footfalls transmitted through the skeleton for example). To focus on muscular gestures we often applied low pass filtering to the acceleration signals. When only rapid motion was of concern, a high pass filter (usually 10 Hz) was employed to extract only sudden changes in acceleration.

$$a_{HPF\ performer\ motion} = HPF(|a_{xyz}|)$$

In theory, when the sensor's orientation to gravity is fixed (i.e. when the sensor is not allowed to rotate) it is possible to completely remove the effects of gravity using a high-pass filter. Although this procedure was not practical in most situations we encountered, it led us to an approximation of velocity magnitude computed by integrating the high frequency acceleration of each axis independently using a leaky integrator and then computing the magnitude of the resultant 3D velocity vector:

$$v_{axis} = v_{axis} * 0.99 + HPF(a_{axis})\ ,\ \ |v_{xyz}| = \sqrt{v_x^2 + v_y^2 + v_z^2}$$

This is the extent of the approximations utilized in the present work to date. The interested reader is advised to consult [7] for a more elaborate scheme for double integrating displacement from acceleration using a second accelerometer to compensate for angular rotations.

5.4 General Mapping Primitives

In the mapping discussions below we refer to the following additional primitives: lowpass filters with various cutoff frequencies, denoted $LPF_{cutoff}(x)$; envelope followers with separate attack and release times, denoted $ENV_{attackT,releaseT}(x)$; gates, where sound (or some other behavior) is only triggered when a sensor value exceeds a threshold; leaky counters which “charge” when sensor signals exceeded a threshold (often the charge amount is influenced by the sensor value), and “discharge” over time, with the counter value modulating the audio signal in some way. Unless noted, sensor data ranges were linearly scaled and clamped into synthesis control signal ranges.

6. OUTCOMES

This section describes a selection of experimental outcomes which were developed and presented to the public[1]. An attempt is made to give an impression of the sonic, performative and mapping aspects of each experiment.

HEAD SCRAPE (Figure 2): A hyperinstrument in which a sound generator is triggered by the motion of one performer's head. The resulting sound is processed by a bank of resonators whose

[1] STEIM wiiiiiiii concert, 24 September 2007. See: http://www.steim.org/steim/archief.php?id=209

Figure 2: Head Scrape

frequencies are modulated by the motion of a second performer. When the first performer's $a_{HPF\ performer\ motion}$ exceeds a threshold, a gate is opened which causes a granular glitching sound to be generated. The processing performer wears two sensors, each controlling an amplitude modulated delay line and a bank of spaced resonators. The modulation rate and resonator frequencies are modulated by $LPF_{5\text{Hz}}(|v_{xyz}|)$ while an envelope follower $ENV(|v_{xyz}|)$ controls the amount of signal entering the filter bank.

MOTION SHATTER: A smooth continuous drone of Tibetan monks chanting is fed through a granulator. As the performer spins in a circle holding the sensor in an outstretched hand the sound becomes less smooth. Spinning faster causes the sound to become gritty, and eventually to break up. It is necessary for the performer to spin in circles, in an increasingly desperate manner in order to effect a complete cessation of sound. The controlling signal $LPF_{0.6\text{Hz}}(|a_{xyz}|)$ reduces grain durations (from approx 500 ms down to 10ms) while increasing the randomised interonset time from 2.6 to 500ms causing the sound to slowly break up with increased centripetal acceleration.

LEG RATCHETS: Sensors are attached to the performer's lower legs. Each leg controls a similar synthesis patch, which granulates a different sound. The patch iterates a pulse generated by gating a granular texture (pulse rate ranging from 5 to 40 Hz) with pulse rate, transposition and gain modulated by $||a_{xyz}|-1|$. When the sensor is at rest the pulse is slow, silent, and lower pitch. The legs' movement results in accelerated pulses or rhythmic modulation.

At some point an error was made with this patch and the acceleration value was offset by -0.35 which resulted in the performer having to move one leg to make sound, and the other leg to stop its corresponding sound. This opened up as yet unconsidered possibilities, and provided a rich space for performer experimentation.

BLADES OF GRASS: Each performer wears a Wii Remote aligned to their spine, which is associated with a synthesis patch consisting of processed noise with a resonant filter swept according to the angle and direction in which they are leaning. $tilt\ direction_{xz}$ is processed into a triangular shaper which produces a periodic sweep as the performer rotates the tilt of their spine. This is multiplied by the amount the performer is leaning ($tilt\ magnitude_{xz}$) and mapped to the resonant filter cutoff frequency.

SPEED HARMONICS (Figure 3): The performer wears a sensor on each forearm. The sound world consists of two resonant harmonically tuned oscillator banks, one controlled by each arm. As the speed of the arms increase (sometimes requiring spinning the whole body), white noise and additional bass is faded in, and comb filters are swept across the spectrum creating a swooshing sound. $LPF_{4\text{Hz}}(|v_{xyz}|)$ sweeps the comb filter between 400 and 4000Hz with increased performer velocity. $LPF_{1\text{Hz}}(|v_{xyz}|)$ controls the introduction of the white noise and bass boost through a sweeping shelf filter. The filtered velocity signal is also quantized into 10 steps, and used to select one of the harmonics of the oscillator bank: the velocity signal is applied to an envelope follower associated with the selected harmonic, which boosts or sustains the current harmonic level. When the velocity no longer excites a particular harmonic it slowly fades to silence.

Figure 3: Speed Harmonics

TONE CHANGE: Two performers each perform with two Wii Remotes, one in hand and the other attached to the hip. Each Wii Remote is associated with two sine wave oscillators. One is slightly detuned from the other with the detune distance increasing by an offset of between .01 and 20Hz with increased $LPF_{1\text{Hz}}(|v_{xyz}|)$. The amplitude of each oscillator pair is modulated by $ENV_{500\text{ms},1500\text{ms}}(|v_{xyz}|)$. The polarity of the filtered Z velocity is tracked. When the $LPF_{2\text{Hz}}(v_z)$ sensor has been at rest and starts moving again in the opposite direction a new random note from a diatonic scale is chosen. Thus, the performers start and stop to change notes, and move in various ways to articulate their tones, creating slowly modulating random chord sequences.

7. DISCUSSION & OPEN QUESTIONS

In each of the experimental outcomes outlined above, we strove to maintain a balance in the relationship between movement and resultant sound that was easy to perceive for audience and performer alike. The mappings discussed were intentionally simple. More complex mappings, while more satisfying from a performance perspective require careful consideration and tuning in order for the relationship between movement and sound to attain synchretic coherence. The development of such mappings is a clear direction for further investigation.

Engaging the body in performance necessarily raises notions of the body as interface, and, for the audience, physical theatre, or theatre of the body. We feel that it is difficult to escape a theatrical mode of interpretation when confronted with a musical performer without an instrument, which of course also invites a dramaturgical mode of composition. We consider the dialog between musical and theatrical creation to be a significant area for future development in whole body gesture sound performance.

As previously observed by Bahn et al. [2] performing with the whole body involves skills not always possessed by musicians – some of the authors are now considering training in this area to continue the research.

Finally, the sensor technology employed so far has been adopted as a pragmatic prototyping aid. We are now considering options for smaller, wearable sensor platforms.

8. CONCLUSION

The gesture ≈ sound experiments outlined in this paper represent, for the authors, a solid foundation from which to continue our research. While many questions remain unanswered, the process has both provoked and supported new ways of grappling with the problem of mapping gesture and sound. The importance of getting musicians to think through their bodies has been highlighted. By consistently approaching non-physical and physical tasks alike in a ‘physically ready’ and gestural state, our way of working, thinking and creating shifted dramatically. Our clear intent to develop movement and sound mappings in tandem was central to our approach, and was integral to providing the outcomes presented here.

In our search for gesture sound synchresis, we have established clear directions for ongoing research and an approach which promises to support development of a diverse performance vocabulary.

9. ACKNOWLEDGMENTS

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