# *Proceedings of the*

# *12th Art of Record Production Conference*

# *Mono: Stereo: Multi*


Durham, M. (2019). Multi-Channel Sound Design: Instruments for 360-Degree Composition. In J.-O. Gullö (Ed.), *Proceedings of the 12th Art of Record Production Conference Mono: Stereo: Multi* (pp. 71-88). Stockholm: Royal College of Music (KMH) & Art of Record Production.

ISBN 978-91-983869-9-8

**Mark Durham**: Multi-Channel Sound Design: Instruments for 360-Degree Composition

**Abstract**

The continuing development and industry uptake of multi-channel audio is creating new potential for sound designers. This paper presents research that provides a new approach to designing sound for spatial audio applications, by investigating the potential of combining sound creation and spatialisation through performance. The research uses a practice-based approach, involving the design, development and testing of a software-based instrument that combines gestural control, multi-voice sound generation and an Ambisonic spatialisation system. The focus of the research is to prototype an instrument that is easy to learn and intuitive to use.

## *Introduction*

*Sound Design* is now a complex term to define succinctly. Its origin stems from the post-production audio sector, with the term initially used as a credit for Walter Murch on Apocalypse Now (Coppola: 1979). From this beginning, the use of the term has expanded and changed, and is now used both in its original context and by musicians in a newer one, to refer to the process of creating sounds through a design process. Often, this involves using techniques that employ synthesis, recording, effects processing or different processes in combination.

Post-production approaches to sound spatialisation have changed within recent years due to the development of new forms of content delivery. Ambisonics is currently the industry standard format for interactive applications that form part of virtual or augmented reality work. *Dolby Atmos* [1] and *Auro 3D* [2] are systems for both cinema and home, and these both allow for sound positioning within three-dimensional space. Outside of music and sound for audio-visual media, there is also a growing interest in music composed specifically for high speaker count spatial audio systems such as *4D Sound System* [3], *Envelop* [4] and *Dolby Atmos* for nightclubs.

The technique of producing sound assets in spatial audio formats, such as Ambisonics, is gaining in popularity amongst sound designers, especially those working in interactive media. This trend has however, not extended beyond this, to the techniques and tools used as a means to generate new sounds or modify existing ones, one notable exception being *Sound Particles* [11]. The majority of current approaches involve designing sound assets in mono or stereo, then spatialising these within a larger three-dimensional mix.

Due to the uptake of spatial sound formats and the growing interest of musicians in multi-channel sound reproduction, there is now potential for new instruments to be developed specifically for the creation of multi-channel sound. This research looks to question current practices and work-flow in the aforementioned areas by asking if new tools can be used to facilitate both the design and mix of sound assets that are inherently multi-channel, existing in the same spatial form - from design through to mix.

These developments in delivery formats have the potential to further bring together music and sound disciplines, providing opportunities for the development of new working practices and collaborative approaches. Alongside this, comes the potential for the creation of sound design tools that are more flexible and intuitive, with greater accessibility (i.e, they can be utilised by sound designers without programming experience). Some areas of industry standardisation further this, for example in delivery formats or loudspeaker types and arrangement, enabling material to more accurately cross from one system to another. Transferring material accurately between formats is currently possible, for example using the *Harpex* plugin [5]. Some formats previously focused on music reproduction, such as Ambisonics, can be converted to cinema formats such as 5.1 or Dobly Atmos 7.1 beds. More uniformity now also exists in playback systems, with loudspeakers capable of producing near full-range audio in surround positions.

This research looks to investigate this crossover area, where the lines between sound design and music meet, and spatialisation begins. The core aim of this research is to produce a prototype instrument that is suitable for designing and spatialising multi-channel sound assets in an intuitive way for both expert and non-expert users.

## *Objectives*

The research objectives are to:

- Develop a sound generation system that can function in the context of a multi-channel instrument, and that is flexible enough to generate a range of sounds.
- Integrate approaches to DMI design into the development towards a user oriented design, aiming to reach the creative and technical requirements of sound designers.

- Explore options for gestural control of the instrument, before integrating a control system that leverages the affordances of the multi-speaker environment.
- Link the sound generator and controller with a mapping system that is both flexible and encourages easy experimentation.
- Develop the instrument through a series of iterations, documenting the user experience and potential use cases.

## *Background and Related Work*

There is a large body of cross-disciplinary research covering approaches to multi-speaker sound, ranging from those using Ambisonics (Lossius & Anderson: 2014), (Schacher: 2010), to more industry focused analysis [12], along with comparisons of the various benefits and drawbacks of different systems (Kostadinov et al: 2010), (Satongar et al: 2013), (Pulkki & Hirvonen: 2005). Examples of work that couple spatialisation and sound synthesis are of the most relevance here, these include research focused on ambisonic granular dispersion (Mariette: 2009), (Wilson: 2008), control of systhesis parameters through gestural control (Wanderley & Depalle: 2004), (Schacher: 2007), and live diffusion of sounds using gestural control (Di Donato & Bullock: 2015), (Cannon & Favilla: 2010).

The uniqueness of this research is the combination of synthesis methods, spatialisation and focus on performance during the sound production stage, embracing approaches to software design from the research area *Human Computer Interaction* (HCI), more specifically the development of *Digital Musical Instruments* (DMIs). A commonly used definition of a DMI is provided by Wanderley & Depalle (2004), “An instrument that includes a separate gestural interface (or gestural controller unit) from a sound generation unit. Both units are independent and related by mapping strategies.” Figure 1 demonstrates the connections between the various components of a DMI.

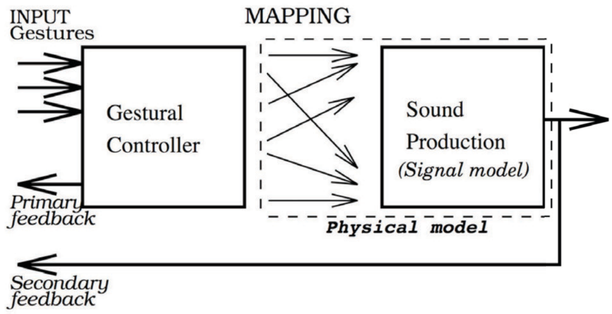


*Figure 1: Makeup of a DMI (Rovan et al: 1997).*

Dividing up the components of the DMI, research focused on the control of electronic or digital instruments through gesture includes understanding the requirements of controllers (Wanderley: 2001), (Wanderley & Depalle: 2004), (Schacher: 2007), nd analysis of playability and leveraging the potential for musical expression (Poepel: 2005), (Dobrian & Koppleman: 2006). Also within this field a large amount of research has been conducted into the mapping of control data to instrument parameters. This is accepted as being crucial to digital instruments, especially in enabling expressivity (Dobrian & Koppleman: 2006), (Rovan et al: 1997), (Wanderley & Battier: 2000). More complex mapping or recognition of gestures is one area that can potentially enhance this, where control of sound needs to be both "intimate (finely detailed) and complex (diverse, not overly simplistic)." (Dobrian & Koppleman: 2006, p.278). Rovan et al (1997) further defined a system for categorizing mapping into three categories:

- One-to One Mapping: A single control signal is mapped to a single parameter on an instrument
- Divergent Mapping: A single control signal is mapped to multiple instrument parameters
- Convergent Mapping: Multiple control signals are combined to modify a single control parameter

*Trends in Gestural Control of Music* (Wanderley & Battier: 2000) conducted a comprehensive round table discussion titled 'Electronic Controllers in Music Performance and Composition', sending questions to several composers and instrument designers. Machover (in Wanderley & Battier: 2000) suggests that "part of the interest in new controllers is to extend the range of what is manipulated, whether in the density of sound textures or the complexity of musical structures."

Waisvisz (in Wanderley & Battier: 2000, p.422) also describes a feedback loop between performer and instrument, highlighting why a fast response is a key factor in DMI expressivity, the components of which are illustrated in Fig. 3.

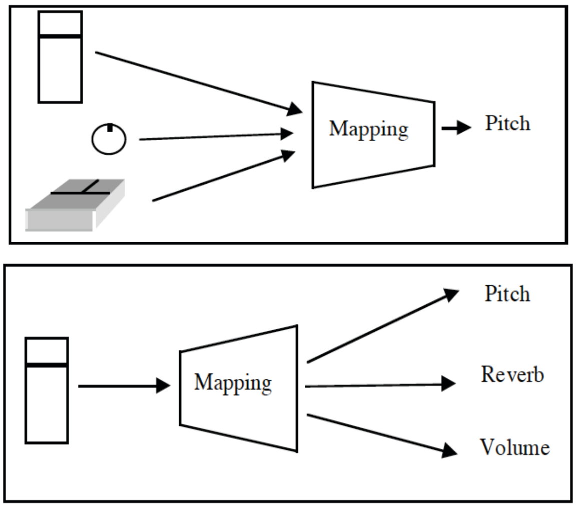


*Figure 2: Convergent and Divergent mapping strategies (Wanderley & Battier: 2000).*

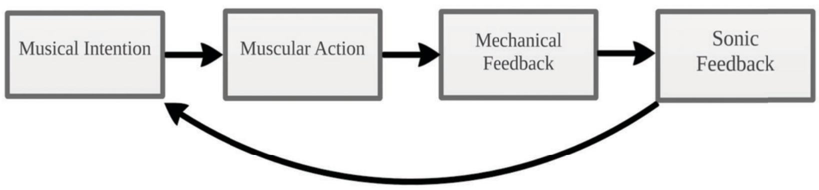


*Figure 3: Visualisation of Instrument feedback loop (adapted from Wanderley & Battier: 2000).*

## Methodology

Max/MSP [17] was chosen as a development environment, chosen for its balance between flexibility and ease of use for rapid prototyping.

### Gestural Control

The primary requirements of the control system were ease of use and the expressive potential of controlling both sound generation and spatialisation parameters. Initially two controllers were tested within the system: The Leap Motion controller [6] and the MYO armband [7]. These were attractive options as they are both capable of producing accurate hand position data in three dimensions, and have a proven background as alternative controllers in a DMI (Di Donato & Bullock: 2015), (Nymoen et al: 2015). Later in the development of the project a third controller, the MacBook Pro trackpad, was introduced to gauge the benefit of a three-dimensional controller that did not require open-air gestural input.

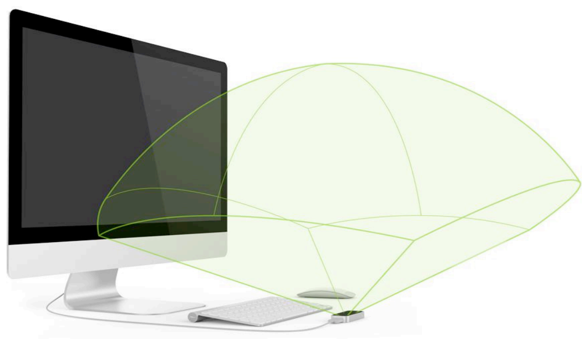

*Figure 4: Leap Motion controller with interaction area highlighted [6].*

The Leap Motion controller is capable of skeletal tracking of both hands in three-dimensional space, alongside inbuilt sensing of various gestures built in to the Leap Motion SDK V2 Skeletal Tracking Beta. This provides a range of data that is potentially usable for controlling a musical instrument. This implementation uses the Leapmotion external developed by Jules Fran-

*Figure 5: Myo armband [9].*

coise [8] to connect to the Leap and make the data available within Max/MSP for mapping to instrument parameters.

The Myo controller is a wireless armband that is worn by the user. It provides a range of sensor data from a 3D gyroscope, 3D accelerometer and eight electromagnetic (EMG) sensors that measure muscle actuations. The Myo implementation uses the Myo for Max/MSP external [9] for obtaining raw data from the Myo armband.

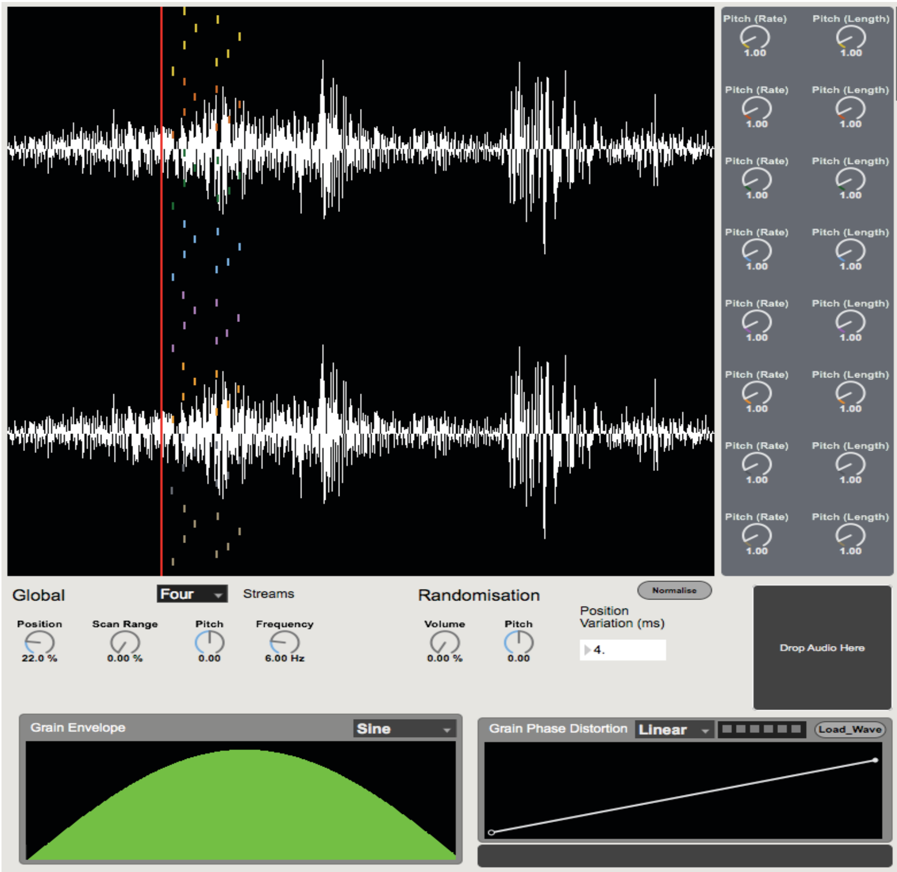


*Figure 6: Granulator user interface.*

### Sound Generation

In an attempt to meet the requirements for an instrument with the widest timbral range possible, the development focused on a granular synthesis solution. This approach was attractive for several reasons that aligned with the research objectives. Firstly, it is attractive due to relative ease with which timbrally-rich sounds can be synthesized, providing there is suitable source material available. Secondly the process is flexible through its ability to de-couple parameters of pitch and playback speed (Roads, 2004). Many of the control parameters required by a granular system are also relatively intuitive and lend themselves well to direct mapping. Finally, the process is relatively computationally inexpensive, enabling multiple oscillators to present a solution towards a spatial sound instrument.

Figure 6 shows the design of the granulator user interface, intended to provide clear visual feedback to the user.

The sound generator was created in Max/MSP specifically for implementation in this instrument. At its core, the device generates up to eight mono streams of grains using a synchronous granular technique as described by Roads (2004).

### Global Controls

These controls set the grain generation parameters across all granular oscillators. *Position* sets the base starting point for each grain before any modulation is applied. The control unit choice is a floating-point percentage value through the sound file loaded into the instrument. *Pitch* controls the global pitch of all of the grain streams simultaneously; within the Max/MSP patch this control is affecting the speed of the master phasor~ object that drives playback across the entire instrument. The control is set as semitones and cents, providing four octaves of pitch control in both positive and negative directions. *Scan Range* sets the extent of any position modulation input into the device. *Streams* sets the density of grains present in a single cycle of each oscillator, from a single pair of phase offset grain generators to up to four overlapping grains per-stream. Towards the bottom of the interface it is possible to set the *Grain Envelope* and to also define whether the playback is linear or non-linear with the *Grain Phase Distortion* control,which distorts the phasor~ as it reads over the audio buffer.

### Randomisation

The randomisation controls also affect sound generation at a per-grain level, introducing user definable amounts of fluctuation into all grain-streams. *Volume* introduces a varying level of volume reduction, defined at the start of grain generation. *Pitch* introduces a controllable range of pitch variation up to one octave, either positive or negative. *Position Variation* introduces a varying level of fluctuation in the grain start position after the current global value. In terms of implementation, each value is derived from scaling a white noise source. This is applied at the level of individual grains, to ensure fully random values across the instrument.

At the right-hand side of the interface there are controls for setting the pitch of each grain-stream. *Pitch (Rate)* adjusts the pitch by increasing or decreasing the speed of the phasor~ ramp, whilst *Pitch (Length)* adjusts the oscillator pitch by varying the size of the buffer area being sampled by each grain.

## Mapping

The mapping approach was intended to be flexible, with a focus on usability. Sonami (in Wanderley and Battier: 2000) suggests a flexible mapping system is a vital part of any DMI, encouraging experimentation and faster development between instrument and performer. With this in mind a modulation matrix was implemented to route controller data to parameters of the instrument. Alongside basic mapping, values can be scaled, offset and inverted to provide more user control. Visual feedback of mappings and their current value is provided in the instrument user interface shown in Figure 7. Potentially useful parameters from the controllers were made available to the instrument mapping system throughout the prototyping phase of the project.

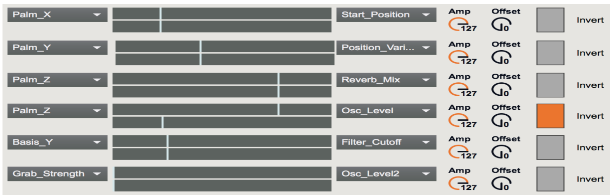


*Figure 7: Modulation matrix user interface.*

### *Spatialisation*

The spatialisation approach uses third order Ambisonics, chosen primarily as it is capable of accurate spatial positioning, but also because of the expandability and scalability of the system to a range of other formats (Lossius & Anderson: 2014).

The Max/MSP implementation uses the ICST Ambisonics library (Schacher: 2010). Third order was selected as the most appropriate scale, following guidelines advice in the ICST package that there should be as many speakers as components in the B-Format.

## *Ambisonic Panning*

The initial implementation focused first on creating an Ambisonic panning system. To critically judge the effectiveness of the system a 14-speaker Ambisonic array comprising of an upper quad, lower quad and ear height hexagon of speakers was used. A basic mono source was manually panned around the space with sufficient spatial accuracy.

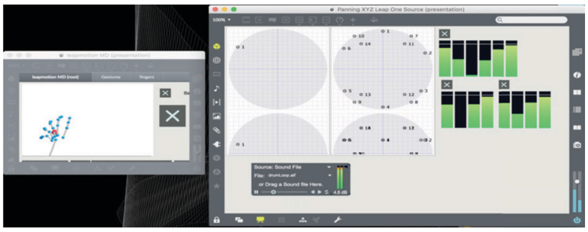

*Figure 8: Motion controlled panning with a mono source.*

An early research objective was to implement motion controlled panning within the system using a 1-1 mapping strategy on all X,Y,Z axis. This was completed using the Leap Motion controller, with the controller position in the middle of the interaction area being paralleled by the position of the user in the mixing space (see Figure 8). In effect this allowed the user to intuitively pan towards any point in the room, simply by moving their hand around the Leap.

## *Spatialised Grains*

Connecting the granular synthesizer to the Ambisonic panner allowed for individual mono grain streams to be positioned anywhere within the Ambisonic soundfield. Control over the parameters of individual streams within the synthesiser allows the user to build a soundfield with sonic variation in three dimensions. Useful approaches to this include varying the pitch of each grain stream, through either changing the grain length or rate of grain playback, along with the position of the stream in the soundfield.


*Figure 9: Soundfield analysis using the Harpex- X Plugin [5].*

Additional visual analysis of the spread and intensity of each stream was evident using the Harpex Ambisonic plugin.

Example output demonstrating analysis [13].

## *Gestural Control of Timbre*

To experiment with the control of timbral parameters through motion, each grain stream was panned to fixed positions, evenly placed around the user. This created a very spatially alive sound, but shifted the emphasis away from panning, allowing for an exploration of gestural mappings from the Leap Motion to the synthesiser and effects parameters.

Initially the following mappings were made:

- Palm Position X to Grain Start Position
- Palm Position Y to Grain Start Position Variation Amount
- Palm Position Z to Oscillator Level

The result of this mapping approach creates the following effects:

- Palm position X-axis to Grain start position: Moving the hand from left to right distributes the grain start position along the sample loaded. As the pitch remains constant (through the implementation of a granular oscillator), this effectively selects an area of the sample to granulate.
- Palm position Y-axis to Grain start position variation amount: Moving the hand vertically adjusts the level of randomisation added to the grain start position. The perceived effect of this action adds fluctuation to the grain stream, effectively increasing the variation between grains – depending on the sound source used.
- Palm position Z-axis to Oscillator level: Moving the hand along the depth axis increases the volume of all oscillators linearly.

A second variant applied a more complex set of mappings between gestural controller and synthesis engine, with the aim of exploring mapping strategies that go beyond a 1-1 approach. An additional 8-channel filterbank and 8-channel convolution reverb were added to the system as effects.

The following mappings were made:

- Palm Position X-axis to Grain Start Position (as in 3.1)
- Palm Position Y-axis to Grain Start Position Variation Amount (as in 3.2)
- Palm Position Z-axis to Volume and Reverb Mix
- Hand Rotation to Filtering

Additional effects included:

- Palm position Z-axis to Volume and Reverb Mix: This combination replicates a common technique used in audio production to move sounds backwards in the sound stage. The process increases the wet mix of reverb, whilst also reducing the overall volume.
- Wrist rotation to Filtering: This implemented a combined filter that sweeps from 20hz – 20khz as lowpass through the first half of the

range, then 20hz – 20khz highpass for the second half of the range with adjustable resonance. The effect of the combined control is to tilt the equalisation from a stronger bass response to treble response.

- Grab strength to Volume: Using gesture recognition within the Leap API, this parameter reduces volume when the grabstrength value increases. The effect allows the user to effectively make a fist with their hand to lower the volume to zero.

Example output of this stage of development [14]

### *Gestural Control of Timbre and Panning*

Many conventional instruments divide physical input between different limbs of the body, eg pitch and rhythm with the bass guitar, or position and mix source with turntables and mixer. Hunt and Kirk (2000) describe this as the user "injecting energy" into the system (that is the instrument). The example of the violin is shown in Figure 10. This concept formed the basis for the next step in implementation, with three-dimensional panning mapped to one hand, and timbral controls mapped to the other.

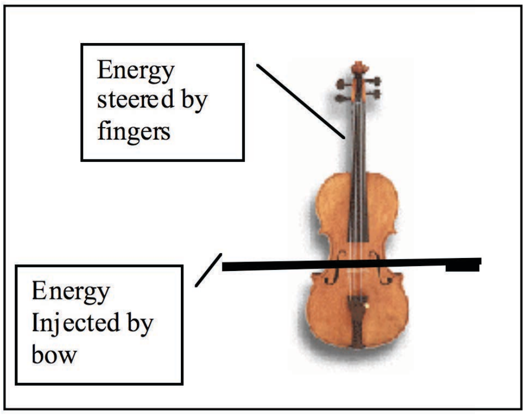


*Fig 10: "Human energy input and control" (Hunt and Kirk: 2000).*

The resulting implementation takes XYZ position data from the five fingertip positions on the user's left hand, then maps these to the XYZ position data inputs to the Ambimonitor object. Figure 11 shows the approach taken within Max/MSP, here thumb position data (as an X,Y,Z list) is split, scaled and mapped to the inputs of Ambimonitor. Figure 12 further demonstrates the result of the approach: with an illustration of two separate gestures through a photograph of actual hand position, the interpreted hand position by the Leapmotion object, and finally the resulting panning position in Ambimonitor.

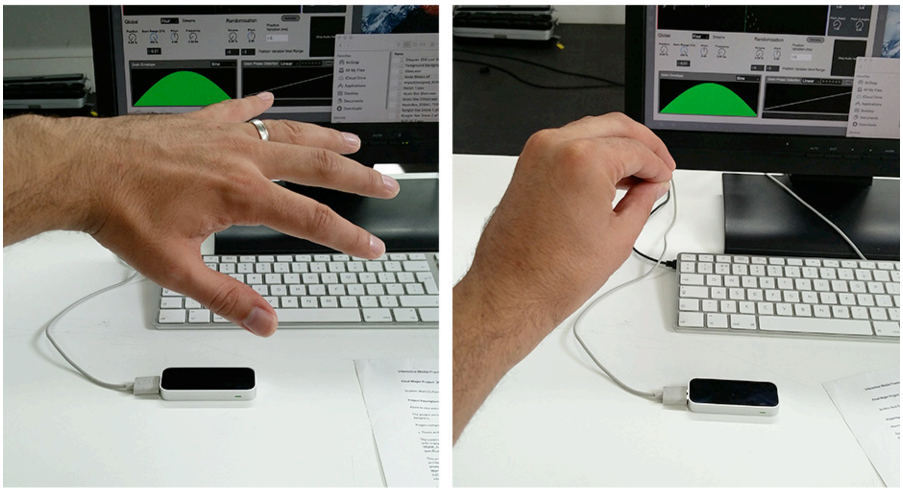

*Fig 11: Finger position data scaling.*

As the Leap Motion is capable of sensing two hands, a logical progression for including both timbral and position control would be to split the two duties between hands, mapping data from a single Leap to each target area. This option was avoided to preserve the intuitive 1-1 mapping approach around the Leap Motion controller (as described in 5.1: Ambisonic Panning). As an alternative, the next arrangement uses the left hand for panning position and the right hand for timbral control using the Myo controller. Orientation from the Myo for Max object was converted into Euler angles, and gyroscope data was summed to create a parameter that measured acceleration in any direction.

In terms of mapping, the approach builds on the previous implementations, with data from the Myo X-axis position mapped to the grain start position in the sample. This approach provided a direct connection between horizontal arm position and the area of the sample being granulated, effectively allowing the user to 'scan' over the sample with left to right arm movements. To provide further control over the sound, an additional destination control was added to control the pitch of the grain streams independently of the grain position. This parameter was then mapped to the Y-axis output from the Myo armband, effectively allowing the user to raise and lower their arm to set the pitch of the instrument. Data from rotation along the Z-axis was mapped to the reverb mix, effectively allowing the user to move from fully dry to fully wet reverb mix by rotating their hand clockwise.

Example output using Leap Motion with Myo [15].

As an alternative to using two ‘open-air’ controllers such as the Leap Motion and Myo combination, a third alternative controller, a MacBook Pro trackpad, was added to the system to allow for additional evaluation. The implementation used the Fingerpinger Max/MSP external [10], to capture data for use within Max/MSP. The parameters used for control are X-axis position, Y-axis position and size of finger (effectively similar to pressure). The X-Axis trackpad position is mapped to grain start position, effectively allowing the user to ‘scan’ over the sound using positional movements on the trackpad. Y-axis trackpad position is mapped to global pitch, effectively allowing vertical movements up and down the trackpad to control pitch accordingly. The trackpad is incapable of reading finger pressure, but can read finger size on the its surface. As pushing the finger harder into the trackpad increases the size due to compression of the fingertip, this functions in a similar way to a pressure or a Z-axis parameter. In this way finger size was mapped to volume, allowing the user to press on the trackpad and raise the sound level, whilst releasing the finger fades the level down to zero.

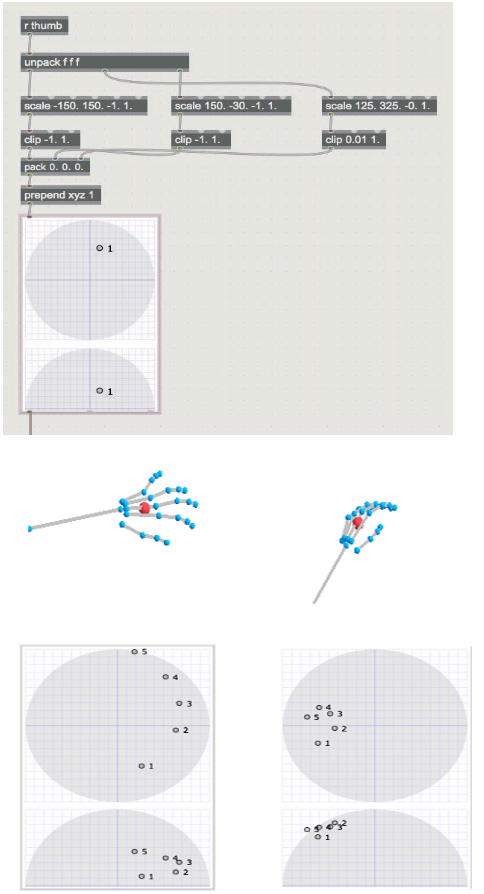


*Fig 12 (a,b&c): Position mapping comparison - These images demonstrate the mapping between hand and sound position. Photograph (top), 3D rendering (middle) and Ambisonic soundfield position (bottom).*

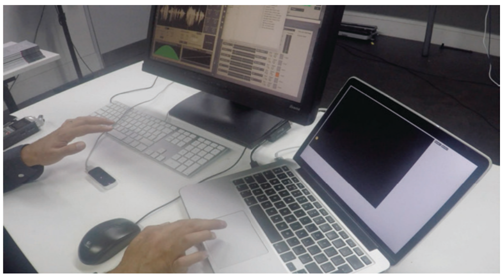

*Fig 13: Using Leap in combination with the MacBook trackpad.*

## *Conclusions and further work*

The granular sound generator is capable of producing Ambisonic soundfields that are spatially active and constantly fluctuating. This is especially true when adjustments are made to individual oscillator pitch controls and grain start position randomisation. A spatial phenomenon is created by the effect of the individual oscillators running simultaneously and at different pitches; rhythmic cycles across the spatial soundfield vary between noticeably periodic to seemingly random and imperceptible. Source material with percussive attacks provide more clues for the listener to localise sources in this way. At lower grain rates sounds are perceived as coming from their panning location, but at faster rates the sound is perceived as one mass, positioned perceptually by fluctuating interaural time delays (ITDs) and interaural level differences (ILDs) as described by Goldstein (2010).

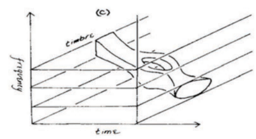

*Fig 14: "A complex sound object moving through the continuum" (Wishart: 2002, p.26).*

The combination of gestural controller and flexible mapping system provides a range of control for the user over the sound output. Poepel (2005) suggests musical expression can be coded into performance using "tempo, sound level, timing, intonation, articulation, timbre, vibrato, tone attacks, tone decays and pauses" (Poepel: 2005, p.229). Of these parameters sound level, slow vibrato and tempo (through grain rate) are controllable through the instrument, alongside pitch. Timbral changes can also be programmed into the instrument, due to the way the granular engine handles position within the soundfile. By first designing a performable sound object that moves through the desired timbral range, a sound designer can create a morph that approaches a parametisation of the sonic continuum introduced by Wishart (2002).

The development process of the instrument included informal demonstrations of the system to a set of sound designers, whose feedback was assimilated into the development process. Much of the positive feedback of the system centred around overall ease of use, with all participants able to understand the connection between gesture and sound output after a short introduction to the control system. There was also a consensus that the controls were intuitive and playful, and that the combinations of mappings encouraged rapid development of sounds through use and experimenta-

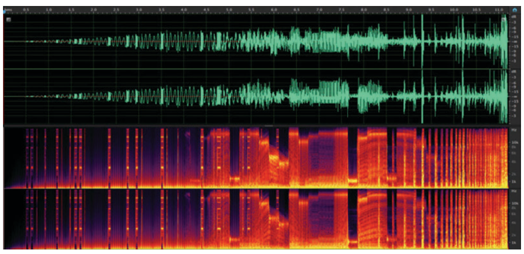

*Fig 15: Example timbral morph: a sound file composed of three sounds crossfaded together.*

tion.

Areas where usability could be improved centred around response rate and control complexity with some mappings. Improving responsiveness could potentially be achieved through an increase in computer processing power, further optimisations in the Max/MSP patch or by moving to a complete signal driven panning system as an alternative to the ICST Ambisonics implementation used.

*Acknowledgements*

The Max/MSP objects *Leapmotion* and *Myo* were created by Jules Francoise [8, 9]. The *Fingerpinger* external was created by Michael and Max/MSP Egger [10]. The ICST Ambisonics externals are by Jan C. Schacher (2010).

I would like to thank Mike Exarchos and Savraj Matharu, whose time, support and guidance has been invaluable throughout this project. This work would not have been possible without the generous support of Ravensbourne University London.

*Notes*

[1] "Dolby Atmos Cinema Sound." (2013) *Dolby Atmos in the Cinema*, www.dolby.com/us/en/technologies/cinema/dolby-atmos.html. (Accessed January 2018)
[2] "Auro-3D For Cinema." *Auro-3D*, www.auro-3d.com/professional/industries/cinema. (Accessed January 2018)
[3] "4DSound." *4DSound*, www.4dsound.net/. (Accessed January 2018)
[4] "Envelop." *Envelop*, www.envelop.us/. (Accessed January 2018)
[5] "Harpex X Plugin." *Harpex Ltd*, www.harpex.net/. (Accessed January 2018)
[6] "Leap Motion Controller." *Leap Motion,* www.leapmotion.com (Accessed January 2018)
[7] "Myo Controller." *Thalmic Labs*, www.thalmic.com (Accessed January 2018)
[8] Francoise, Jules. *Leapmotion Max External*. Computer software. Nov. 2014. Available at: http://ismm.ircam.fr/leapmotion/ (Accessed January 2018)
[9] Francoise, Jules. *Myo For Max*. 2015. Avaliable at: https://www.julesfrancoise.com/myo (Accessed January 2018)
[10] Egger, M. & Egger, M. (2009) *Fingerpinger*. Computer software. [ A N Y M A ]. Available at: www.anyma.ch/2009/research/multitouch-external-for-maxmsp
[11] Fonseca, Nuno. "Sound Particles." www.soundparticles.com. (Accessed January 2018)
[12] Dolby® Atmos® Next-Generation Audio for Cinema [White Paper]. (2014). San Francisco. Available at: https://www.dolby.com/us/en/technologies/dolby-atmos/dolby-atmos-next-generation-audio-for-cinema-white-paper.pdf (Accessed January 2018)
[13] 1st order Ambisonic analysis of sound output. Available at: https://youtu.be/H4xxws61ujo
[14] Example output of Leap Motion control. Available at: https://youtu.be/u02h9aNHV30
[15] Example of position and timbre control using Leap Motion and Myo: https://youtu.be/zkIgkii9wRI
[16] Example of position and timbre control using Leap Motion and a MacBook Pro trackpad: https://youtu.be/HmLdJ7m-gYg
[17] "Max/MSP", *Cycling '74,* https://cycling74.com/ (Accessed January 2018)

## References

Cannon, S. & Favilla, J. (2010) 'Expression and Spatial Motion: Playable Ambisonics.' *New Interfaces for Musical Expression*.

Coppola, Francis Ford, director. *Apocalypse Now*. Universal pictures, 1979.

Di Donato, B., & Bullock, J. (2015). 'GSPAT: Live Sound Spatialisation Using Gestural Control.' Available from http://www.balandinodidonato.com/gspat-live-sound-spatialisation-using-gestural-control-paper/ (Accessed January 2018)

Dobrian, C., & Koppleman, D. (2006) 'The "E" in NIME: musical expression with new computer interfaces.' *Proceedings of the 2006 International conference on new interfaces for musical expression*.

Goldstein, E. B. (2010) *Encyclopedia of perception*. Thousand Oaks: Sage.

Hunt, A., Wanderley, M. & Kirk, R. (2000) 'Towards a model for instrumental mapping
in expert musical interaction.' *Proceedings of the International computer music conference,* ICMA.

Kostadinov, D., Reiss, J., & Mladenov, V. (2010) 'Evaluation of Distance Based Amplituse Panning for Spatial Audio', *International Conference on Acoustics, Speech, and Signal*. Available at: http://citeseerx.ist.psu.edu/viewdoc/citations;jsessionid=9B07FDAD10DCEBA4A560E0A31872E151?doi=10.1.1.725.6393 (Accessed January 2018)

Lossius, T, & J Anderson. (2014) 'ATK Reaper: The Ambisonic Toolkit as JSFX' *40th International Computer Music Conference & 11th Sound and Music Computing Conference.* Available at: trond-lossius.no/pages/text. (Accessed January 2018)

Lossius, T. & Anderson, J., (2014) 'ATK Reaper: The Ambisonic Toolkit as JSFX plugins' *40th International Computer Music Conference & 11th Sound and Music Computing Conference*. Available at: http://trondlossius.no/pages/text (Accessed January 2018)

Mariette, N. (2009) 'AmbiGrainer - A Higher Order Ambisonic Granulator in Pd' *Ambisonics Symposium*. Graz, Austria, Available at: https://ambisonics.iem.at/symposium2009/authors/ambigrainer-a-higher-order-ambisonic-granulator-in-pd (Accessed January 2018)

Nymoen, K., Haugen, M.R, & Refsum Jensenius, A. (2015) 'MuMYO — Evaluating and Exploring the MYO Armband for Musical Interaction.' *International conference on new interfaces for musical expression*, USA, Baton Rouge

Poepel, C. (2005) 'On interface expressivity: a player-based study.' *Proceedings of*

Pulkki, V. & Hirvonen, T. (2005) 'Localization of Virtual Sources in Multichannel Audio
Reproduction', *IEEE Transactions on Speech and Audio Processing*, Vol 13, No. 1.

Roads, C. (2004) *Microsound*. Cambridge: MIT Press.

Rovan, J., Wanderley, M. and Dubnov, S. (1997) 'Instrumental Gestural Mapping Strategies as Expressivity Determinants in Computer Music Performance.' *Kansei - The Technology of Emotion,* Genova/Italy.

Satongar, D., Dunn, C., Lam, Y., & Li, F. (2013). 'Localisation Performance of Higher- Order Ambisonics for Pff-Centre Listening', *BBC White Paper*. Available at: http://www.bbc.co.uk/rd/publications/whitepaper254 (Accessed January 2018)

Schacher, J.(2010) 'Seven Years of ICST Ambisonics Tools for Max/MSP – A Brief Report' *2nd International Symposium on Ambisonics and Spherical Acoustics*.

Schacher, J.C (2007) 'Gesture Control of Sounds in 3D Space' in: Proceedings of the 2007 Conference on New Interfaces for Musical Expression (NIME07), New York, NY, USA *the international conference on new interfaces for musical expression*, Vancouver

Wanderley, M. (2001) 'Gestural Control of Music' International Workshop - *Human Supervision and Control in Engineering and Music - Kassel, Germany Sept 21-24, 2001.* Available from: http://recherche.ircam.fr/equipes/analyse-synthese/wanderle/pub/kassel/ (Accessed January 2018)

Wanderley, M. & Battier, M. editors. (2000) *Trends in Gestural Control of Music*. Ircam - Centre Pompidou.

Wanderley, M., & Depalle, P. (2004). 'Gestural Control of Sound Synthesis'. *Proceedings of the IEEE*.

Wilson, S. (2008) 'Spatial Swarm Granulation'. In: *Proceedings of 2008 International Computer Music Conference*. SARC, ICMA, Belfast. Available at: http://eprints.bham.ac.uk/237/ (Accessed January 2018)

Wishart, T. & Emmerson, S. (2002) *On Sonic Art*. London: Routledge.