audio. Nevertheless, the implementation of network capability via OSC suggests a number of more elaborated forms of networked and immersive sound exploration. In particular, we were interested on the possibility of connecting sonically augmented outdoor urban spaces, with the more traditional concert hall or museum experience, proposing a creative framework for composers and sonic artists to construct a dual interlinked event.

3.1. SonicMaps + MAX
An interesting sound installation, Kinesthesia (Ivica Ico Bukvic, 2012), exploring these ideas, was presented during an Immersive Audio-game Showcase in the University of Manchester. The piece analyzes the human geospatial motion of multiple participants, whose cumulative actions form a subconsciously collaborative data stream devoid of time and space. The ensuing data stream was broadcast from Blacksburg (United States) to Manchester (United Kingdom) where it is reconstructed inside an autonomous meta-instrument and presented to an audience as a persistent spatially-aware installation. Up to eight people with mobile devices running SonicMaps were asked to walk across the Virginia Tech Campus, experiencing a custom soundwalk. Meanwhile, the OSC node was sending their positions to a remote computer in Manchester running a MAX patch that used the incoming geolocated data to feed several sound objects and shape a multichannel musical output.

3.2. SonicMaps + Game Engine (Unity3D)
It is also possible to connect a physical real space and a computer-generated virtual representation of that space for a sonic-centric networked installation. For example, the piece Alive: Elegy to the Memory of an Unequall Lady (Ignacio Pecino, 2012), uses a Unity3D virtual model of Whitworth Park (Manchester) to display the current position of a remote user walking on the real physical park. This virtual environment is then presented to an audience in a concert hall so it is possible to experience, in a synchronized way, the same sounds the remote performer is triggering as he walks outdoor using the SonicMaps mobile application.

Figure 8. SonicMaps + Unity3D visualization (Aliace).

DEVELOPING A CHROMATIC INTERFACE FOR REAL-TIME DIGITAL HARMONISATION OF SAXOPHONE PERFORMANCE
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ABSTRACT
A new interface for musical expression, the Harmonic Table Pitch Shifter (HTPS) is presented. It is a harmonisation system that allows free selection of intervallic voicings to harmonise live saxophone performance in real-time, resulting in homophonic harmony in up to five-parts. Pitch-shifting software developed in Max/MSP reacts to MIDI messages to produce the desired harmonisation and features an envelope-based mixer to give the added voices a dynamic contour over time. A custom MIDI footpedal based on the isomorphic note arrangement known as the ‘harmonic table’ places the most consonant intervals nearest one another and also exhibits transpositional invariance, allowing chordal (‘shapes’) to be freely moved within the array without affecting their intervallic relationship. Microswitches mounted on the saxophone thumb rest give quick access to a piano pedal-like effect allowing drones or chords to be sustained beneath melodic playing or improvisation.

1. INTRODUCTION
My experience playing the guitar, piano and as an orchestrator in the jazz idiom deeply ingrained in me the notion that two notes in harmony are somehow greater than the sum of their parts, but the aforementioned musical outlets have never rewarded me with the feeling of expressive freedom I experience when improvising on the saxophone. In my capacity as a single-line instrumentalist, a continuing base to produce harmony leads me to experiment with technology as an extension of my saxophone playing.

Sound-on-sound looping, for example, allows me to slowly create harmonised passages through a process of layering. Pitch-shifters and diatonic harmonisers deliver a means of producing harmony in real-time, and to a reasonable extent offer real-time control over density, dynamics and timbre. In this case the quality has to be predetermined - a simple pitch-shifter will only produce a fixed-interval voicing, and a diatonic harmoniser will only produce consonant harmony within a particular key/interval.

The aim of this research is to develop a chromatic interface for real-time harmonisation, and this paper will detail the process behind the development of one possible solution, the ‘Harmonic Table Pitch Shifter’ (HTPS), which consists of a custom MIDI footpedal and pitch-shifting audio plugin. It was important for the control hardware to be reliable in live performance, have a logical and easily navigable layout and allow a wide range of chordal voicings to be selected with one or two feet. The processed audio output was to be capable of blending with the live instrument performance or contrasting as a distinct voice. Through a process of experimentation, improvisation and composition I offer conclusions regarding the viability, potential and limitations inherent to this approach.

In the context of this research, the term ‘chromatic’ is used as an identifier to convey the possibility of connecting sonically augmented outdoor parks to allow the performer to produce all possible voicings (limited only by range and number of voices), irrespective of their degree of consonance or dissonance. While extended saxophone techniques such as multiphonics allow a performer to produce multiple pitches at once, this research is limited to digital techniques for producing harmony based on twelve-tone equal temperament. The word ‘harmonisation’ is used throughout the paper to encompass all instances where multiple notes are sounded at once, including unisons and octaves. The harmonisation discussed is usually homophonic in nature, but in certain instances incorporating horizontal displacement or independent movement of parts I describe the effect produced as being polyphonic.

2. PITCH SHIFTERS AND HARMONISERS
2.1. Commercially available products
Digital pitch shifters have been commercially available since 1972, when Lexicon released their speech pathology-focused ‘Varispeech’ processor [1]. Another early harmoniser was Eventide’s H910 unit, released in 1975 - possibly the first device marketed specifically for creating “musical harmonies” [2]. Harmonisation products can be grouped into three main categories, with some fitting into more than one category, depending on their feature sets.

The simplest variety is the fixed-voicing pitch shifter. It is capable of producing one or more additional voices shifted at fixed intervals with respect to a live input signal, resulting in a static voicing. These kinds of devices generally limit the performer to utilising a single interval type or voicing at a time, making it impossible control harmonised voices on-the-fly while performing. Contemporary examples usually include features from...
the following categories in addition to a fixed-voicing mode.

The second category, 'smart harmoniser' allows the user to specify a diatonic scale and voicing (ie adding a simple diatonic third above, or both a fourth and sixth below input pitch) and will produce the pertinent major/minor/augmented/diminished intervals that are diatonic to the nominated scale. Chromatic input pitches and Max for Live would allow for additional varying functionalities depending on the individual product. The Boss PS-6 effect pedal, Eventide H8000 and audio plugins such as Antares Harmony Engine Evo offer this kind of functionality.

Effects in the third and final category are program-reactive, meaning they accept the live instrument input plus an additional 'program' input (generally a keyboard or guitar playing chordally) from which it infers the appropriate interval choices to again produce diatonic harmony. The Boss VE-20 and TC Electronic Voicelive series are prominent hardware examples.

From the perspective of an improvising musician, the more advanced models of commercially available pitch shifter could be considered to restrict the ability to improvise freely. The need for a predetermined key centre or scale/mono/poly is inescapable in itself, but beside this remains the simple fact that an improvisatory musical language may not be strictly diatonic. Fixed-voicing pitch shifters have the opposite effect, in that they immediately restrict the performer's ability to produce diatonically harmonised passages at will, at times the harsh reality of a fixed interval voicing becomes less prominent than the more generalised timbral effect that results from its consistent quality.

3. DESIGN OF THE CONTROL MECHANISM AND SOFTWARE

3.1. Control Mechanism

The use of the pitch shifter on brass and windwind instruments is by no means unheard of; Don Burrows' Octavider clarinet on LP's recorded with George Golla, Randy Brecker's octave-up and perfect fourth effects, and Jon Hassell's stark thirds and parallel triads are clear examples in the jazz and fusion idioms. These effects relied on single or multiple presets of the pitch shifter without necessarily requiring complete real-time control over voicing and density.

My concept for a pitch-shifting harmonisation effect for saxophone evolved from my existing usage of a MIDI foot controller with multiple footswitches, and it was partially inspired by an organism's bass-pedalling, partially by the bass and chord buttons actuated by an accordionist's left hand.

As both hands are generally required for saxophone playing, I envisaged including a foot controller in the earliest stage of development. I focussed on readily available MIDI foot control products from Roland, Line 6 and Behringer as possible means by which I could select predetermined voicings based around major/minor/diminished/augmented triads and inversions. I soon realised that the net effect of this implementation would be limited to the production of simplistic material rather than adding an expressive frequency, which varied harmonic language I wished to draw upon in a solo setting. Ideally, a broad range of chordal possibilities, including cluster chords, would be assigned perfect fourths or fifths as well as octaves, unisons and simple thirds or sixths needed to be available on demand. As the permutations of these voicings rose exponentially, it became necessary to consider an interval-array approach which allowed free selection of voicing using multiple footswitches at a time, where each footswitch would be assigned a set interval in relation to the live performance pitch.

Using a commercially available twelve footswitch MIDI controller it would be possible to assign one octave of chromatic intervals below (or above) the live input to the footswitches and create various voicings using these in combination. For example, to produce a simple D minor seventh voicing consisting of the notes D, F, A and C (lowest to highest) I could play the C C and then depress the footswitches representing, respectively, intervals of 3, 7 and 10 semitones below this note.

I began to foresee how certain musical and physical barriers could hinder success in this approach. Firstly, only closed voicings (ie those within a range of one octave) would be available without introducing further mechanisms to spread the transposition range effectively. Secondly, giving the MIDI maximum range of eight octaves, a mechanism to prescribe 'drop 2' and 'drop 2, drop 4' voicings depending on the current state of a dedicated switch or potentiometer). This would add an additional layer of complexity to another limb/finger/gesture would have to be responsible for changing between closed and open voicing schema, given that both feet are utilised for note selection.

Furthermore, the allocation of intervals to the physical arrangement of the footswitches on existing MIDI hardware posed another problem. Products featuring at least two rows of six or three rows of four footswitches were ostensibly suitable, but a pedal technique required became difficult when two feet were required to depress multiple footswitches simultaneously. In a simple paper-based analysis where I drew diagrams representing common 3 and 4 note voicings on templates representing the layout of the MIDI foot controllers in question, systems that arranged the array of intervals in whole tone rows, or in perfect fourths/fifths (as in the bass notes of an accordion) proved equally unwieldy.

3.2. Hardware Interface

Considering the above evidence, I accepted the reality that a customised hardware solution would be necessary for the success of this project. The design of existing foot control products did not mesh well with the interval-array concept I had developed. Ideally, intervals that were often played together needed to be closely situated, and the entire unit needed a logical and easily navigable platform.

I was aware of C-Thru Music’s ‘Axis 49’ and ‘Axis 64’ MIDI keyboard controllers, which make use of an unusual note arrangement based on a ‘harmonic table’ pitch organisation scheme. C-Thru music credit Peter Davies, builder of custom ‘Opal’ MIDI controllers as the inventor of the harmonic table layout although an earlier instrument, Hohner’s ‘Harmonetta’ chord harmonica used this layout in a different orientation. All of these instruments are closely related to the ‘Tontenna’; two-dimensional pitch grids designed by mathematician Leonhard Euler [3].

A major advantage of this scheme is that the most consonant intervals become the most closely located, as opposed to piano keyboard layouts, which place the notes closest in pitch nearest one another.

![Figure 1. Portion of harmonic table note field](image)

a. Moving vertically (North/South axis), adjacent notes are a perfect fifth apart b. Moving diagonally (NW/SE axis), adjacent notes are a minor third apart c. Moving horizontally (NE/SW axis), adjacent notes are a major third apart d. Moving horizontally (East/West axis), adjacent notes are a semitone apart

These intervalic traits simplify the production and transposition of even complex voicings. For example, major and minor triads form triangles and can each be produced with a single digit, which can potentially be then utilised in the upper structure of a larger chord voicing. In addition, any geometrically similar note collection has the same intervalic relationship when moved to another location on the keyboard; a quality best described as transpositional invariance [4].

I envisaged a foot controlled button array with the harmonic table pitch arrangement, however instead of fixed MIDI notes (as in the Axis-49), each button would represent a fixed positive or negative interval in relation to the centre of the array which would be considered ‘zero’. Provided that it would be possible for each of the foot pedals to depress 2 buttons at once, I could produce five part harmony in real-time.

To strike a balance between range and navigability, I settled on an array with an array of 29 buttons; enough to cover a range of two octaves plus a major third. When distributed evenly above and below the centre (zero) position, the maximum shift interval in either direction was a major ninth.

Using C74 (an iOS app which allows custom user interfaces to communicate with a Max/MSP external over a wifi network) I developed simple touch interface using the aforementioned design which could experiment with the above mentioned design while working on the audio processing side of the system.

3.3. A custom software pitch-shifter

The hardware pitch-shifting units mentioned in section two could offer advantages of low latency, high sound quality and steadfast reliability. Software plugins were more affordable, had attractive user interfaces and could be more easily integrated into the existing signal chain of my performance software (especially as I was already using software plugins for microphone input channel conditioning and general effect processing). MIDI control over voicing would be possible for many hardware and software products on the market.

While the existing pitch-shifting hardware or software could be leveraged or modified to fit the emerging requirements of my project, specific considerations lead me to the conclusion that a customised solution in Max/MSP would offer the best possible fit. I decided that the additional cabling, bulk and complexity of integrating a hardware pitch shifter negated any potential benefits. Software plugins, while ostensibly suitable were generally not designed for live performance, and adding any form of envelope control (discussed in section 3.5) would add an unacceptable degree of latency to MIDI mappings. To its merit, a Max/MSP-based solution could have a native mapping to the foot control interface, its UI could display whatever information seemed most appropriate and the system could allow for almost seamless integration with my existing performance software platform.

3.4. Software Development

The first harmonisation mechanism I developed in Max/MSP relied on pitch-to-MIDI conversion and output of harmonised MIDI voicings using tone generators. When it became apparent that this approach was burdened with significant limitations, I began to create a pitch-shifting software environment more closely related to existing harmonisation products. This approach had less potential for timbral variation than one leveraging the diverse world of MIDI-based products, but to its merit a more uniform blend of live and harmonised sound could result as the tonal characteristics of the harmonisation would closely mirror those of the live playing.

3.5. Pitch-shifting approach

The most important Max/MSP object in achieving this aim, ‘gizmo~’, implements a “floating formant” transposition method. Once transposed, this method more closely reproduces the timbral characteristics of an instrument’s timbre than the typical ‘fixed formant’ approaches, which are successful in vocal applications. In broad terms, the lower portion of an instrument’s
the following categories in addition to a fixed-voicing mode.

The second category, ‘smart harmoniser’ allows the user to specify a diatonic scale and voicing (ie adding a single diatonic third above, or both a fourth and sixth below input pitch) and will produce the pertinant major/minor/augmented/diminished intervals that are diatonic to the nominated scale. Chromatic input pitches around this scale in differing ways depending on the individual product. The Boss PS-6 effect pedal, Eventide H8000 and audio plugins such as Antares Harmony Engine Evo offer this kind of functionality.

Effects in the third and final category are program-reactive, meaning they accept the live instrument input plus an additional ‘program’ input (generally a keyboard or guitar chordedly!) from which it infers the appropriate interval choices to again produce diatonic harmony. The Boss VE-20 and TC Electronic Voicelive series are prominent hardware examples.

From the perspective of an improvising musician, the more advanced models of commercially available pitch shifter could be considered to restrict the ability to improvise freely. The need for a predetermined key centre or scale/mode is prescriptive in itself, but besides this remains the simple fact that an improvisatory musical language may not be strictly diatonic. Fixed-voicing pitch shifters have the opposite effect, in that they immediately restrict the performer’s ability to produce diatonically harmonised passages at will, at times the harmonial functionality of a fixed interval voicing becomes less than the more generalised timbral effect that results from its consistent quality.

3. DESIGN OF THE CONTROL MECHANISM AND SOFTWARE

3.1. Control Mechanism

The use of the pitch shifter on brass and woodwind instruments is by no means unheard of; Dom Burrows’ Octovider clarinet on LPs recorded with George Golla, Randy Brecker’s octave-up and perfect fourth effects on the earliest stage of development for the small diatonic third above, or both a fourth and sixth below input pitch) and will produce the pertinant major/minor/augmented/diminished intervals that are diatonic to the nominated scale. Chromatic input pitches around this scale in differing ways depending on the individual product. The Boss PS-6 effect pedal, Eventide H8000 and audio plugins such as Antares Harmony Engine Evo offer this kind of functionality.

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range will contain richer harmonic content, and this richness will become less pronounced higher in the range [5]. Gizmo− achieves a similar effect through non−linear association of transposed notes, a parameter which strongly influences our perception of timbre [5]. To minimise processor load, the Max patch uses poly−to−process audio in up to 4 instances of a processor containing the gizmo− object. The patchers also contain mixer elements to provide volume and pan control of the individual voices within a stereo field and an envelope generator to control the dynamic contour of the voice. Different ADSR settings allow the manner in which voices are brought in and out of the mix to be best suit the musical situation. For example, if gradual swelling of volume is appropriate, longer attack and release times can be selected. A more percussive quality is achieved by setting short attack and decay times, coupled with low sustain values.

4. FIRST HARDWARE PROTOTYPE

Having completed software development, I set about creating the first physical prototype of the control pedal MIDI hardware.

30 mm diameter arcade machine buttons, which encase a momentary microswitch in a plastic plunger, were my choice for the button array as they are strong, accurate and inexpensive. As I wanted the ability to hold multiple buttons with either foot, but also to be able to select individual buttons cleanly I measured the distance between the ball of my foot and the centre of my heel and used this measurement to determine the button spacing. Using a distance of 60 mm between centres, my foot could depress one, two or a line of three adjacent buttons on the vertical or diagonal axes. If slightly arched, one foot could press the outer two buttons in a row of three, spanning the one in between.

I toughed out a chassis for the first prototype, drilling holes and inserting the twenty−nine arcade buttons along with six 10k rotary potentiometers (pots) to provide physical control of parameters such as volume. Four pots were mounted on the top−mounted rotary pots meant they were frequently knocked by accident. More free space was needed in general, as one foot would often require a resting place while another traversed the board’s surface. I also found the buttons themselves had an unfortunate tendency to stick, although white lithium grease proved an effective treatment which also served to reduce the acoustic ‘click’ of the plunger mechanism.

4.1. Testing and impressions of the first hardware prototype

Once the functionality of the hardware was established, I was finally able to test the playability of the harmonisation system as a whole. The setup included microphones for the saxophone, an audio interface, a laptop computer, the prototype control pedal and a speaker to output the harmonised sound.

My initial impression of the tone quality of the pitch−shifted notes was that they were somewhat ‘raw’ sounding, but equalisation, compression and the addition of sufficient reverb to give the impression of an acoustic space transformed this into a palatable and usable sound. It was pleasing to note how closely the transposed notes followed the dynamics and tonal variation in my live playing, and how the formant of the shifted notes appeared to coherently follow the degree of transposition. For instance, soprano saxophone notes shifted down an octave seemed timbrally reminiscent of tenor saxophone.

The chassis was unfortunately too fragile to place much weight upon (despite playing seated), and the location of the top−mounted rotary pots meant they were frequently knocked by accident. More free space was needed in general, as one foot would often require a resting place while another traversed the board’s surface. I also found the buttons themselves had an unfortunate tendency to stick, although white lithium grease proved an effective treatment which also served to reduce the acoustic ‘click’ of the plunger mechanism.

4.2. Second hardware prototype

Testing of the initial prototype had revealed several shortcomings, some of which limited my ability to fully explore the potential of the interface. A sturdier and more rigid overall construction was a priority, along with the relocation of certain control elements away from the board’s surface. Using CAD software, I was able to draft and edit an updated three−dimensional design with a cleaner, broader surface, more potentiometers (this time all located on the side panels), and inputs for up to four expression pedals.

I collaborated with my brother Benjamin Savage to create an Arduino firmware, which would translate the physical input data to the desired MIDI messages. His expertise in computer programming languages cut the onerous task of coding down to a simple case of compiling requirements, uploading a firmware, testing and revising until a stable code was achieved.

The firmware we settled upon accepts the input of 32 physical switches and 12 potentiometers and outputs MIDI Control Change messages on MIDI channel 1 at the Arduino Mega’s transmit (TX) pin. This pin is connected to a disassembled Roland UM−1x USB MIDI interface, to which a female USB Type B connector on the prototype’s chassis providing power to both the Arduino and UM−1x, and carrying the USB−MIDI data from the UM−1x to a connected computer.

4.3. Testing and impressions of the second hardware prototype

The superior construction of the second prototype made an immediate difference to the playing experience. The board easily held weight when I needed to shift balance from one foot to another or place both feet down in unison, and the inflexibility greatly aided accuracy of button presses in the middle region of the array. I was able to play the button array with a satisfying vigour and could confidently try rhythmic gestures, sliding ‘glissando’ effects and generally employ a more kinetic foot technique that resulted in a greater level of physical engagement with the instrument.

I experimented with parallel and diatonic voicing techniques, but also with deliberately dissonant effects, such as quickly engaging minor second, tritone or major seventh intervals to emphasise certain notes or phrases in my live performance. The increased number of expression pedals and potentiometers provided refined control over the sound produced by the pitch−shifting software, and their positioning eliminated unintentional actuations. Unused controllers could be assigned to additional effect plugin parameters in Ableton Live if required.

4.4. Additional controls

As I developed familiarity with my harmonisation interface I discovered that if I wished to toggle effect parameters, trigger samples or record loops in a live performance environment but my feet were occupied with button pushing, actuation of further controls would have to happen elsewhere.

The saxophone mechanism itself utilises nine of these potential functions to operate the keywork. While not all of these are in constant use, I decided to focus on the tenth digit, being the right thumb. I experimented with attaching a small lever microswitch to the saxophone body within reach of the last joint of my right thumb. It was possible to actuate this with a comparatively subtle movement albeit at the expense of some stability. I decided to address the issue of stability directly by building a much larger aluminium thumb rest - two microswitches were attached to the new thumb rest and interfaced with the hardware prototype’s Arduino board via a two−pin cable.

One thumb switch application was to trigger an audio freeze effect, which instantly captured and indefinitely sustained any sound present at the input of the pitch−shifting plugin. This provided piano sustain pedal−like functionality but also allowed me to play the button array independently of the saxophone. For example, drums or chord voicings produced from a captured saxophone note could then be used to accompany an improvised solo.

4.5. Making music

While developing HTS repertoire I have adopted two primary modes of operation, the first of which is “improvisation feeding composition”, where I identify specific techniques and principles developed in improvisatory explorations and utilise them to create short etudes or to form the basis of a composed piece. One such piece, “Rinibanna” revolved around consonant parallel harmonisations that can be exploited within symmetrical modes such as the half−whole tone diminished scale.

5. CONCLUSION

The second is “composition feeding improvisation”, where I solve a compositional problem, such as the harmonisation of a melody in 2 or 3 parts on paper, then learn to perform the resultant piece using HTS, hopefully discovering techniques or patterns to then reuse in an improvisatory setting. In one instance, a 24−bar melodic line harmonised with a variety of two and three note voicings through a set of non−diatonic chord changes necessitated a new sliding, pivoting foot technique for tenuto transitions due to the constantly changing nature of the harmony (and therefore footswitch selection).

The HTS is better suited to some applications than others. For instance, fast diatonic passages can be
range will contain richer harmonic content, and this richness will become less pronounced higher in the range [5]. Gizmo- achieves a similar effect through non-linear control of transposed notes, a parameter which strongly influences our perception of timbre [5].

To minimise processor load, the Max patch uses poly- to process audio in up to 4 instances of a patch containing the gizmo- object. The patches also contain mixer elements to provide volume and pan control of the individual voices within a stereo field and an envelope generator to control the dynamic contour of the voice. Different ADSR settings allow the manner in which voices are brought in and out of the mix to be determined by the musical situation. For example, if gradual swelling of volume is appropriate, longer attack and release times can be selected. A more percussive quality is achieved by setting short attack and decay times, coupled with low sustain values.

4. 1st HARDWARE PROTOTYPE

Having completed software development, I set about creating the first physical prototype of the control pedal MIDI hardware. 30 mm diameter arcade machine buttons, which encase a momentary microswitch in a plastic plunger, were my choice for the button array as they are strong, accurate and inexpensive. As I wanted the ability to hold multiple buttons with either foot, but also to be able to select individual buttons cleanly I measured the distance between the ball of my foot and the centre of my heel and used this measurement to determine the button spacing. Using a distance of 60 mm between centres, my foot could depress one, two or a line of three adjacent buttons on the vertical or diagonal axes. If slightly arched, one foot could press the outer two buttons in a row of three, spanning the one in between.

Iroughed out a chassis for the first prototype, drilling holes and inserting the twenty-nine arcade buttons along with six 10k rotary potentiometers (pots) to provide physical control of parameters such as volume and ADSR. Four pots were mounted on the surface of the chassis at the top left of the button array, while the remaining two were mounted to the sides. Provision was also made for an expression pedal to be connected via a 6.5mm socket. All components were then connected to the appropriate inputs of an Arduino Mega 2560 board using stripboard PCBs to route pull- down resistors for each digital input and IDC cabling and connectors to minimise loose wiring and allow easy disassembly if required.

I collaborated with my brother Benjamin Savage to create an Arduino firmware, which would translate the physical input data to the desired MIDI messages. His existing expertise in computer programming languages cut the onerous task of coding down to a simple case of configuration requirements, uploading a firmware, testing and revising until a stable code was achieved.

The firmware we settled upon accepts the input of 32 physical switches and 12 potentiometers and outputs MIDI Control Change messages on MIDI channel 1 at the Arduino Mega’s transmit (TX) pin. This pin is connected to a disassembled Roland UM-1x USB MIDI interface, near a female USB Type B connector on the prototype’s chassis providing power to both the Arduino and UM-1x, and carrying the USB-MIDI data from the UM-1x to a connected computer.

4.1. Testing and impressions of the first hardware prototype

Once the functionality of the hardware was established, I was finally able to test the playability of the construction of the synthesizer system as a whole. The environment included microphones for the saxophone, an audio interface, a laptop computer, the prototype control pedal and a speaker to output the generated sound.

My initial impression of the tone quality of the pitch-shifted notes was that they were somewhat ‘raw’ sounding, but equalisation, compression and the addition of sufficient reverb to give the impression of an acoustic space transformed this into a palatable and usable sound. It was pleasing to note how closely the transposed notes followed the dynamics and tonal variation in my live playing, and how the formant of the shifted notes appeared to coherently follow the degree of transposition - for instance, soprano saxophone note one was transformed down an octave seem unharmonious and inharmonic.

The chasis was unfortunately too fragile to place much weight upon (despite playing seated), and the location of the top-mounted rotary potentiometer means they were frequently knocked by accident. More free space was needed in general, as one foot would often require a resting place while another traversed the board’s surface. I also found the buttons themselves had an unfortunate tendency to stick, although white lithium grease proved an effective treatment which also served to reduce the acoustic ‘click’ of the plunger mechanism.

4.2. Second hardware prototype

Testing of the initial prototype had revealed several shortcomings, some of which limited my ability to fully explore the potential of the interface. A sturdier and more rigid overall construction was a priority, along with the relocation of a female USB type B connector from the board’s surface. Using CAD software, I was able to draft and edit an updated three-dimensional design with a cleaner, broader surface, more potentiometers (this time in side panels), and inputs for up to four expression pedals.

The superior construction of the second prototype made an immediate difference to the playing experience. The board easily held weight when I needed to shift balance from one foot to another or place both feet down in unison, and the inflexibility greatly aided accuracy of button presses in the middle region of the array. I was able to play the button array with a satisfying vigour and could confidently try kinetic gestures, sliding ‘glissando’ effects and generally employ a more kinetic foot technique that resulted in a greater level of physical engagement with the instrument.

I experimented with parallel and diatonic voicing techniques, but also with deliberately dissonant effects, such as quickly engaging minor second, tritone or major seventh intervals to emphasise certain notes or phrases in my live performance. The increased number of expression pedals and potentiometers provided refined control over the sound produced by the pitch-shifting software, and their positioning eliminated unintentional actuations. Unused controllers could be assigned to additional effect plugin parameters in Ableton Live if required.

4.4. Additional controls

As I developed familiarity with my harmonisation interface I discovered that if I wished to toggle effect parameters, trigger samples or record loops in a live performance environment but my feet were occupied with button pressing, actuation of further controls would have to happen elsewhere.

The saxophone mechanism itself utilises nine of these additional potentiometers as per the updated design. Additional 6.5 mm jacks for expression pedals and two additional potentiometers as per the updated design.

5. CONCLUSION

The harmonic table pitch shifter represents just one possible implementation of a chromatic interface for real-time digital harmonisation of saxophone performance. The HTPS is better suited to some applications than others. For instance, fast diatonic passages can be building a much larger aluminium thumb rest - two microswitches were attached to the new thumb rest and interfaced with the hardware prototype’s Arduino board via a piece of cable.

One thumb switch application was to trigger an audio freeze effect, which instantly captured and indefinitely sustained any sound present at the input of the pitch-shifting plugin. This provided piano sustain pedal-like functionality but also allowed me to play the button array independently of the saxophone. For example, drones or chord voicings produced from a captured saxophone note could be used to accompany an improvised solo.

4.5. Making music

While developing HTPS repertoire I have adopted two primary modes of operation, the first of which is ‘improvisation feeding composition’, where I identify specific techniques and principles developed in improvisatory explorations and utilise them to create short etudes or to form the basis of a composed piece. One such piece, “Rihinbana” revolved around consonant parallel harmonisations that can be exploited within symmetrical modes such as the half-whole tone diminished scale.
difficult to execute whereas extreme changes in density and voicing structure are comparatively easy. Spontaneous production of a wide variety of fixed-interval voicings for parallel harmonisation has been a strong feature of many of my HTPS improvisations to date, and the ability to use a rhythmic pedal technique or play polyphonically sets the device apart from other pitch shifters and harmonisers.

A great deal of the potential that the harmonic table pitch shifter has to offer can only be unlocked through discovery and exploration of new techniques, and diligent practice. An ongoing aim of my research is the development of performance pieces typifying a refined idiomatic musical language and performance aesthetic for HTPS.

6. REFERENCES

THE FUZZINESS OF ‘EXPRESSIVENESS’ IN RELATION TO ALGORITHMIC MUSIC.

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ABSTRACT
All sorts of music expresses all sorts of ideas. Yet algorithmic music is often critiqued for its lack of expression. This raises questions about what makes any music ‘expressive’. This in turn leads to addressing notions of expression itself. A logical approach reveals that the concept of expression in music discourse is very vague. This fuzziness arises from three sources. Firstly, the idiomatics of English is inherently confusing and builds specific expectations about music and expression in general. Secondly, the accepted ways of listening to Western art music identified by Becker [3] cause difficulties in identifying the substantial meaning of the word ‘expression’. Thirdly, the conflation of composition and performance into the umbrella term ‘music’ such as the article ‘Expression’ in Grove’s Music Online [24] generates its own confusion. Revealing these sources of confusion, places the alleged deficiency in the expressiveness of algorithmic music into the logical deficiencies of music discourse, rather than locating it in algorithmic music.

1. INTRODUCTION

“Music is a powerful, pervasive and crucial form of human communication and expression” is a proud assertion made on the website for a recent musicological conference [22]. Algorithmic music has been critiqued for being ‘un-expressive’. This may be because this music is not capable of being expressive, or because algorithmic music is so badly composed that the ideas are not articulated coherently, or because the fuzziness of ‘expression’ is highlighted by the intrinsic nature of algorithmic music. The last possibility returns the original problem to the logic of music discourse, rather than a deficiency in algorithmic music. This paper is primarily concerned with addressing this question.

There are difficulties in articulating the concept of expression in an intangible, abstract art form such as music. Nancy Baker, an American musicologist, highlights the paradoxical use of the word in relation to performance and in music criticism [1]. While addressing this paradox, Scruton’s philosophical linguistic approach leads him to conclude that it is logically impossible for music to be ‘expressive’, while acknowledging the reality that music does indeed have a strong emotional resonance [24].

Unpacking Scruton’s reasoning shows that his apparent paradoxical outcome about music and expression arises from several causes. Firstly, various linguistic conventions lead to differing meanings and logical implications despite the use of identical words. Secondly, his automatic elision of ‘expression’ and ‘emotion’, is a result of what Becker [3] describes as the ‘habitus of listening’ adopted in analysis and criticism of Western art music. This elision immediately excludes the possibility that music may be composed to express ideas other than emotional transcendence. Algorithmic music, as a genre, may be designed to address other ideas through the medium of music. Thirdly, Scruton’s implicit assumptions result in faulty logic. This compounds the difficulties presented by the subtleties of English grammar, in clearly articulating the concept of ‘expression’ in the intangible abstract art form which is music.

This paper shows that an explicit understanding of expression through music clearly points to algorithmic music as a means of human expression of a broad range of ideas.

2. IDIOSYNCRASIES IN USE OF ENGLISH LANGUAGE

The concept of ‘expression’ in music discourse is very messy. The words ‘expression’ or ‘expressive’ are regularly used in a wide range of diverse contexts. For example Jacobson writing in the CD liner notes of Beethoven’s string quartets manages to make 'expression' quite meaningless in his comment that a particular movement is “the smoother and more sustained expression” [18], or the CD liner notes to music by German algorithmic composer Barbara Heller says that her work is “…in search of new forms of expression, of possibilities of articulation…for her musical language” [27].

Similarly, some musicologists are quite free in their use of the terminology of expression. “The public quartet made possible an increase in expressive depth in the slow movement because an ensemble can say things which would be embarrassing or ridiculous if vouchedsafe by individuals…” Griffith goes on to say in an analysis of a Haydn quartet “…that the prominence of Major and minor in a single movement, can be used to achieve expressive extremes…” [13]. Yet there are no clearly articulated ideas about what this word means, or consistent evidence which could provide insight into an implied meaning. The end result is that, rather than helpfully clarifying the attributes of ‘expressive music’, the use of the term seems to reflect some type of indefinable, subjective experience.