Microtone 3D Theremax: Gesture Instrument for Leap Motion

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ABSTRACT
Microtone 3D Theremax is a gesture instrument designed in Max/MSP using the Leap Motion sensor interface. It incorporates a number of unique features such as the ability to play chords and explore different note progressions within three dimensions.

Keywords: Gesture Instrument, Leap Motion, Max/MSP.

1. Introduction

Microtone 3D Theremax, to be written as Theremax from this point on, is a gesture instrument designed to offer expressive control over two dual-oscillator subtractive synthesizers using the Leap Motion sensor interface. At its most complex set-up the user can explore melody in all three dimensions using two hands, create chords with the fingers, bend notes between tempered scales to create micro-tonal music, as well as utilise expressive effects like filter, vibrato and tremolo. At its simplest set-up it offers dual control over its two synthesizers and expression on rotation of the hands with the resultant positioning data filtered by melodic mode so it always sounds musical which is ideal for those with limited musical abilities as well as those with special needs (*Swingler et al 2009*).

Its main focus is on offering as much control over an instrument, which is based on traditional instrument paradigms, through gesture. Meaning that, rather than it being an instrument that seeks to capture natural human expressive gestures and represent them as sounds, it simply maps specific gestures to expressive sound elements in order to create traditional musical works (*Arfib et al 2005*).

2. Gesture Implementation

Arfib et al (*2005*), say that the gestures used in digital musical instruments do not have to be expressive themselves, but should generate expressive sounds. As in acoustic instruments, only the results of the gestures need to be expressive. The contrasting opinion is that traditional instruments lack a level of performer-instrument compatibility that can be addressed by new instrument design which can "stretch the instrument to the needs of the performer instead of stretching the performer to the needs of the instrument" (*Mulder 2009*).

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The Theremax is firmly the former of the two ideas. The gestures used are born from the requirements of how to create expressive sounds, i.e., how best to control the elements within the synthesizer with gesture.

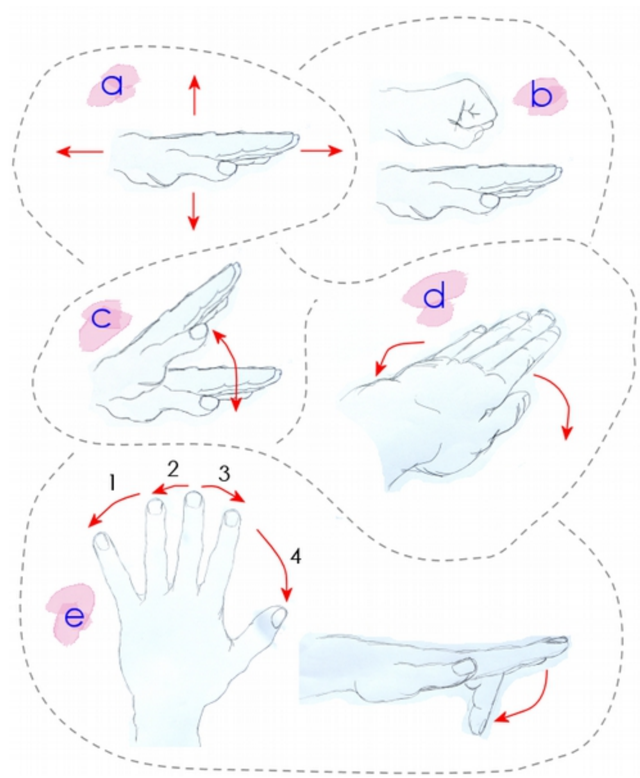

Figure 1. Gestures.

a. Movement of the hand controls pitch. Default pitch control is up and down which gives linear pitch control. When the range sliders are set differently in each of the x/z sectors (discussed later), left and right movement will also change the pitch. Movement from center line of the Leap Motion's field towards the outside (x-axis) can control filter cut-off depending on the settings of the graphical user interface (GUI).

b. Volume of each synthesizer is changed by the size of the hands. Making a fist will result in no volume and a fully opened hand will result in full volume.

c. Rotating the hand from flat to upright will change the filter cut-off position. The gesture is like that of a WahWah pedal rocking back and fourth on its spindle. This motion can be switched to control the filter resonance. In this state the filter cut-off is controlled by movement of the hand along the x-axis.

d. Rotating the hands from side to side will create expressive effects. Outwards will provide vibrato to the note and inwards will provide tremolo.

e. The fingers control the microtones. Spreading each individual finger controls the volume of the individual microtones. Lowering the finger provides a pitch bend to any pre specified interval.

To derive at this gesture scheme required lots of testing and subtle changes to get right. Compromises had to be made in order to be able to control enough of the expressive elements of the sound. For instance it was possible to control tremolo, vibrato, filter cut-off, and filter resonance all from a hand's rotation in four directions. However, on certain mappings it was impossible to use specific combinations of expressions as desired.

Forward	**Backwards**	**Outwards**	**Inwards**
Cut-off	Resonance	Tremolo	Vibrato

Cut-off and Resonance are not possible together as is the case for Tremolo and Vibrato.

Forward	**Backwards**	**Outwards**	**Inwards**
Cut-off	Tremolo	Resonance	Vibrato

This allows both Cut-off and Resonance to work together. However it would be useful to allow filter effects as well as modulation effects at the same time which is not possible here.

Forward	**Backwards**	**Outwards**	**Inwards**
Cut-off		Tremolo	Vibrato

Removing the Resonance and creating a larger sweep for Cut-off allows a working filter and modulation effects to be used at the same time. Two compromises had to be made here. Tremolo and Vibrato can not be used together and filter resonance has to be pre-set by the GUI.

Experiments were done to control some effects with hand movements but with the addition of the 3D Note Matrix, all effects were moved to hand rotations as there was a large conflict.

The various gestures used in the Theremax was largely determined by the Max external object used. This project used semdd.leapmotion (*Hochschule fuer Musik Carl Maria von Weber*). This is an external written in Java which is severely lacking in terms of utilising Leap Motion's built in gestures such as point & click and circular movements. The external has only had the basic movement, rotation and velocity information implemented. Because of this it was necessary to create some newer gestures from the information available. The microtone controls were created by using the positions of the fingers and subtracting the values of two neighbouring fingers to get a small range of values which could then be mapped and scaled to control the volumes of the microtones.

Even though the need to control specific aspects of the sound came first, there was an attempt to make the gestures used natural to their use. Filter cut-off as a WahWah gesture and volume as an opening and closing of the hand are both natural and easy to do. Even though gestures were pre-defined new expressive gestures did emerge simply from testing the instrument. For instance using the instrument with the microtones on allowed for gestures that were not considered when implementing the feature.

Because the individual volumes of the microtones are determined by the spread of the fingers on the x-axis, a gesture of rotating the hand on the y-axis changes the relative distances of the fingers which results in varying levels of microtones which changes the overall timbre of the sound. This was an unexpected gesture to emerge. Much like any real instrument there are things to be discovered and things that can be added to the performer's musical vocabulary.

Developments to the Theremax will look at ways to implement more gestures. With time it can be possible to update the Java external to incorporate more from the Leap Motion SDK. Gestures like circular movements and point & click can be used to control some of the GUI elements as well as adding more musical expression.

3. Mode Filtering on a Fretless Instrument

Adding mode filters to an instrument that has no frets and has no ability to skip notes offered a unique challenge that needed some compromise to work.

The entirety of the y-axis covers the MIDI range from 0 to 127. To get these numbers the data from the Leap Motion (0. to 200.) is scaled to 0 to 127. These numbers are then converted to frequency values by the Max object 'mtof~'. This 0 to 127 range translates to the western tempered scale. This is simple enough and makes the entire range of the y-axis give 128 discrete musical notes.

If a float delimiter is used after the numbers, any frequency value between the tempered scale can be created via hand position on the y-axis. This results in a "fretless" scale of frequencies from 20Hz to 20kHz. It would be easy to leave out the decimal place to filter out anything that does not correspond to the tempered scale, however this would rule out being able to set the pitch axis to a "fretless" mode which is desirable for a Theremin like instrument.

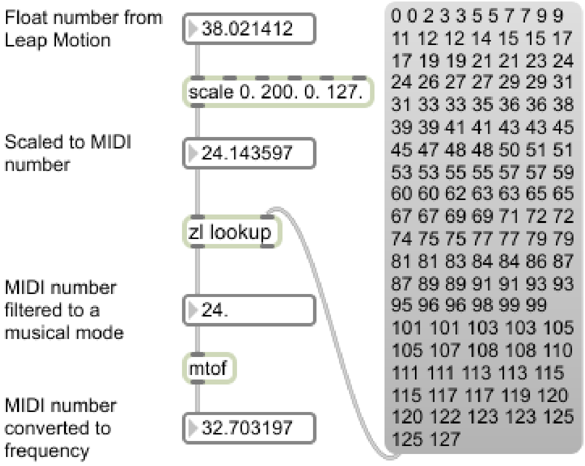

Figure 2. Simplified Max Patch Showing Mode Filtering.

To achieve both aims, look-up tables were created for every scale and mode. To get a tempered scale the look-up table simply looked up 0 to 127 values and gave out the corresponding number which in the case of the tempered scale was an exact 1 for 1 number.

Input	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	etc., to 127.
Output	0	1	2	3	4	5	6	7	8	9	10	etc., to 127

However the look-up table does not contain a decimal place so the output is always restricted to the tempered scale. Every input float value from 1.000000 to 1.999999 as given by the Leap Motion data will correspond to a single 1 integer, 2.000000 to 2.999999 will be 2, etc. To get a "fretless" mode the look-up table can then be bypassed.

To create mode filters there was two options.

Input	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	etc., to 127.
Output	0	2	3	5	7	9	11	12	14	15	17	etc., to 127

This removes the MIDI number of the notes that do not belong in the scale. The result of this is that a relatively small range of hand movement on the y-axis moves through more octaves of notes than when not using a mode. This restricts the ease at which the notes can be "plucked from the air".

It also meant that when a mode is selected the notes, as compared to the tempered setting, will be located in different places on the y-axis.

The second option and the one used was to pad the output of the look-up table.

Input	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	etc., to 127.
Output	0	0	2	3	3	5	5	7	7	9	9	etc., to 127

Now a good playing resolution is retained and the memorisation of note placement can still happen easier. However when moving the hand slowly along the y-axis the note changes happen at uneven positions. This is a compromise. The best method for achieving mode filters in this type of instrument is still to be determined, but this method provides enough usability with only a small drawback.

4. Three-Dimensional Note Matrix

The 3D note matrix allows a set-up where moving the hand along the x and z axes sends the y-axis Leap Motion data to different note range sliders. These note range sliders can be set anywhere from 1 note to all 127 notes and at any start and end note. This means that there can be 72 areas where the notes that can be performed will be different.

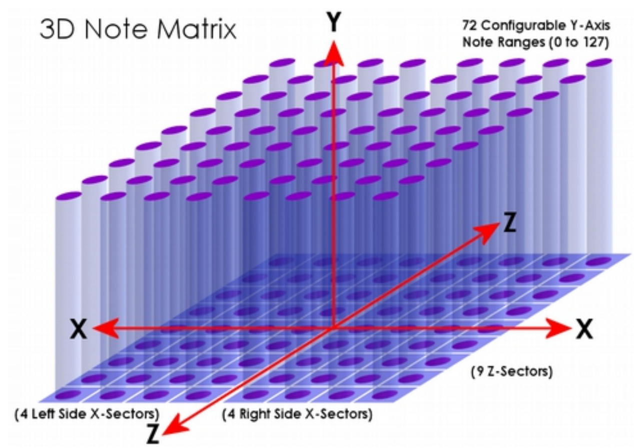

Figure 3. Three-Dimensional Note Matrix.

It works by a simple scaling of the x and z axes to trigger the opening of a gate which elegantly sends the y-axis pitch data to one of the 36 note range sliders.

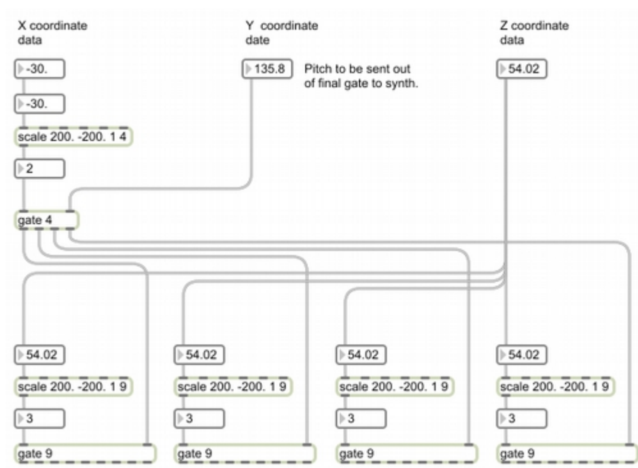

Figure 4. Max Patch Simplified Routing matrix.

The various ways in which this can be set are numerous and the potential for melodic exploration is high. It can be possible given time to make the settings, of making each axis of movement play through a different musical mode of notes.

This is the most powerful feature of the Theremax and one that has potential to be explored and experimented with.

Currently it has been split down the center with different sides corresponding to the two hands offering 36 areas each. This should have been made to allow both hands to travel into any one of the 72 areas. The areas can be overlaid on top of each other so both hands get 72. This would allow for better set-ups of various modal schemes with more range of travel in the x-axis. This will be a simple update. It will then stop the Theremax being restricted to one hand per side and allow for greater flexibility of movement matching its flexibility in other areas.

It can be possible at some point to even allow each area to be filtered separately for modal scale offering even more versatility and exploration by the end user. Currently the mode filter is universal. This area has potential for development.

5. Microtones and Microtonality

Microtones are extra notes which can be controlled by the movement of fingers. They can be switched between two modes, either intervals within the universal mode filter to make up chords, or as multiples of the hand's fundamental note, i.e., partials. Both are limited to 4 per hand.

To create a microtone the fingers of the hand can be spread as per *'Figure 1' (image e)*. Varying degrees of volume can be attained by the distance of the spread.

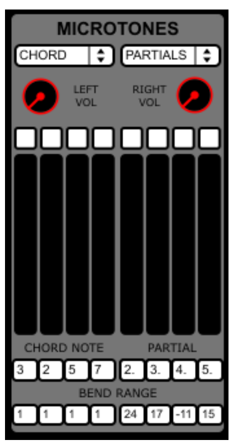

Figure 5. Microtone Control.

The idea of adding this feature was to allow microtonal playing. Microtonal is any music or scales which utilises the range between the notes of the western tempered scale. This was attempted by creating a bend range control for each of the microtones. By lowering the finger that is spread the microtone will bend in pitch up to a predefined amount which can be anything between +/- 2 octaves. Set to 1 semi-tone it is possible to hold the note anywhere within that small range. This can add microtonal notes to the performance or create "beats" with the fundamental.

However focus then moved towards allowing chords to be played on this instrument. It is possible to set the four microtones to intervals which allow the performer to create four different chords whilst playing. Adding a 3rd as the first microtone, a flattened 3rd as the second microtone, a 5th as the third microtone, and a 7th as the fourth, then varying the spread of fingers will allow Major, Minor, Major 7th, and Minor 7th chords to be played by one hand.

This whole microtone system is relatively under-developed. There could be further development of the microtonal element such as making fingers bend the hand's fundamental or a microtone to predefined microtonal notes such as 0.25, 0.5, and 0.75 of a semitone. This idea could then be extended to the mode filters to allow microtonal modes. As it currently stands it only allows a microtone to be bent to anywhere between the notes of the selected mode.

There is one aspect of this microtone feature that can and should be explored in more detail as it has only been flirted with in its current implementation. This is the partial setting of the microtone system (discussed later).

6. Project Development

The project development was not as smooth as it should have been. This was mainly down to time management, but once the project had finally started it was developing fast and resulted in something which is unique.

The development went in a number of stages as discussed below.

1	Research Practice paper on gesture instruments, sensors and controllers.			
2	Meeting. Talked about the idea for multi-channel performance software based on the idea of the no-input mixer using the Leap Motion.			
3	Research into multi-channel performance and spectral diffusion. Attempts to solidify an idea.			
4	Unofficially dropped out.			
5	Research into Leap Motion and Leap Motion instruments as part of a late proposal.			
6	Leap Motion test patches.			
7	Floating Piano	Theremin like instrument	Generative Sound Box	Balancing Game
8	Piano Chandelier plus External Interface.		External Interface for other applications.	
9	Meeting.			
10	Microtonal Theremin like instrument.		Balancing Game.	
11	Theremin like instrument with 3D note matrix, microtonal elements and chord creator.			
12	Future development on controlling the spectral make-up of the sound via gestures.			

1. Research into gesture instruments with the intent that it would feed into a project to develop a gesture instrument.

2. The idea of creating a gesture instrument had been dropped as it was believed it would be too difficult. The idea to look at multi-channel and surround set-ups was thought up as it would cover an area of knowledge yet to be explored. At the meeting at the beginning of the semester the idea was talked about, however the idea was still sparse.

3. Reading commenced around multi-channel performance. Looking at spectral diffusion as part of multi-channel performance was also suggested. This was added to the research. Papers were sourced via Google scholar, the university library and the NIME website. A Leap Motion was bought.

4. The idea never solidified and the project came to a complete halt. During this time a proposal/work in progress presentation was missed and communication was ignored to the detriment of the project and prospects of successfully completing the degree.

5. Over a month later exploration of the Leap Motion was started. A proposal was created with contextual research into the Leap Motion and Leap Motion instruments. The proposal outlined four gesture/sound applications making use of the Leap Motion which would have shared a single GUI called LeapSuite.

Floating Piano was based on examples created by others such as Andrija Stepic's (*2014*) Leap Motion piano built in Unity 3D. The others were thought up to cover a wide range of gesture application types, such as a SountToy, generative music creator, a Theremin like instrument, and an electro-acoustic continuous controller where a ball is balanced and rolled around a virtual world similar to Andy Dolphin's SpiralSet (*2009*).

6. Before commencing building the applications. A number of test patches were created in Max as both proof of concepts and as a way to understand and implement gestures from the Leap Motion.

7. Work commenced starting with the floating piano. Although it was based on the previous example, the intention was to expand and develop the idea as far as it would go through experimentation. The Theremin like instrument was also started. Currently this was an undeveloped idea with a starting point of simply copying a real Theremin, going as far as wanting to try emulate the sound.

8. After work had commenced and the floating piano had been tested. It seemed there was a need for an external element to allow the user to gauge where they were in relation to the virtual piano. This idea developed into wanting to create a set of external interfaces from wood and perspex. Additional applications were thought up such as the Piano Chandelier which was going to be a piano keyboard arranged in an upright cylindrical tube. The external element would have then been the perspex rolled into a tube. The two would be aligned so touching the physical tube in certain places would trigger sound in the virtual world. The idea was based on Norman Schlüter (*2013*) LEAP Hang which uses an upturned bowl as a drum interfaces for a Leap Motion application.

9. Second meeting with tutors in which the ideas were discussed. This is the turning point for the project as a number of ideas were brought up. Rather than the project being general, it became more focused on two of the gesture applications. The two were the Piano which was going to now incorporate exploration into creating microtonal sounds, and the Balancing Game as it provided a much more interesting idea for experimentation. The external interfaces were rightfully dropped.

10. Once the work had been started it became clear that the Theremin was a better conduit for the microtonal developments. This then became the focus before hoping to move on to the balancing game. However after the project started to grow and ideas started to emerge from experimentation and testing, it was decided that this singular project should now be the focus.

To recap. The project started as a very general set of gesture applications which were going to be part of a larger application called LeapSuite. The idea then developed into having an additional application as well as a number of external wood/perspex interfaces. The project was then narrowed down to focus on two of the most interesting ideas of a continuous controlled electro-acoustic SoundToy and a micro-tonal Piano, later changed to the Theremin. Then just the Theremin was focused on.

11. As this Theremin project commenced and the first testing video was produced and shown for feedback (*Leap Motion - Dual Theremin - Progress 1, and Progress 2)* it was suggested that a second dimension of pitch control could be added which spurred on the projects development along these lines but instead of implementing just one extra dimension, a way to utilize the entire 3D area of the Leap Motion was worked out and then implemented over the next few days. The development was now including experimentation in 3D pitch area as well as the original microtonal element which was developing further into a way to play chords with the fingers.

So the two main areas of development which are the microtone control and the 3D pitch matrix were both suggested but they both exceeded the suggestions through experiment and natural progression the development. From a suggestion of working with microtonal aspects came the microtones system and through the suggestion of adding another dimension of pitch came the 3D note matrix. Both of these systems took the instrument form being something that was like a Theremin to something that is unique.

7. The next logical path of experimentation and research?

It emerged at the end of the project that there was a great avenue to further explore and if the project had been started a week earlier it would have certainly been included in the final project.

It was mentioned that control over the waveform via gesture would be a good inclusion so the user does not have to stop playing and use a mouse to change the waveform. Various ways to control the waveform menu were thought about but not implemented as it would have required much more time than was left. But on pondering this, in a shower of all places, within hours of the idea being mentioned in email, an idea emerged for greater depth of research and experimentation which would have lead to greater depth of control over the sound.

A way to control the spectral make-up of the waveform was flirted with already. The microtone control when set to partials allows the user to build up a more complex sound from simple sine waves. However this only goes up to 4 partials and much more are needed to create the level of spectral control that would be desirable. However this system is the start of this further development as it can be easily expanded and experimented on further to create a system where full control over the waveform's spectral make-up is possible.

As is currently implemented, a run of frequencies which are multiples of the fundamental can be set by the number box, the addition of setting the volume of each would be included also. This sequence would then repeat to give a full complex waveform such as a triangle wave. Instead of the first four being controlled by individual fingers as in the current implementation, the individual fingers could be used to control the repeating partial sequence in a way that would allow it to go from the simplest sine wave to a complex square wave. Moving the fingers would then continuously change the spectral quality of the sound. The waveform selection menu can then be completely removed, or at least switched off when in this specific mode of operation.

This is the most logical avenue of exploration following on from how the project has progressed over its development. There was no reason this could not have been part of this project given better time management throughout the project. This is regrettable.

Further development along these lines would have removed it even further from being seen as a Theremin like instrument and more towards being its own unique instrument.

Imagine being able to control the sound of an instrument spectrally from simple to complex with just the fingers and then allow all the hand movements to control a musical performance expressively. This is the next step for this project.

REFERENCES

1. Arfib, D., Couturier, J., Kessous, L., 2005. *Expressiveness and Digital Musical Instrument Design.* Journal of New Music Research. Mar 2005, Vol. 34 Issue 1, p125-136.
2. Dolphin, A., 2009. '*SpiralSet : A Sound Toy Utilizing Game Engine Technologies*', Proceedings of the International Conference on New Interfaces for Musical Expression, pp. 56–57, 2009.
3. Hochschule fuer Musik Carl Maria von Weber. *Max Leap Motion external.* [internet]. Available from: <http://www.hfmdd.de/hochschule/institute/institut-fuer-neue-musik/studio-fuer-elektronische-musik/projekte/leapmotion-mxj/leapmotion-mxj/>
4. Mulder, A., 1996. *Getting a Grip on Alternate Controllers: Addressing the Variability of Gestural Expression in Musical Instrument Design.* Leonardo Music Journal. 1996, Vol. 6, p33-40, 8p. The MIT Press.
5. Schlüter, N., 2013. *LEAP Hang Musical Instrument.* [internet]. Available from: <https://www.youtube.com/watch?v=hJf4c17ngK4#t=29>
6. Sprint, J., 2014. *Leap Motion - Dual Theremin - Progress 1.* [internet]. Available from: <https://www.youtube.com/watch?list=PLE-qauBqVR8HwYcyCL3TFZcwKRjaEJ49d&v=r_nXMLK2yvo>
7. Stepic, A., 2014. *Leap Motion piano in Unity 3D.* [internet]. Available from: <https://www.youtube.com/watch?v=hJf4c17ngK4#t=29>
8. Swingler, T., Brockhouse, J., 2009. *Getting Better All the Time: Using Music Technology for Learners with Special Needs.* Australian Journal of Music Education, n2 p49-57 2009. 9 pp.
9. Wanderley, M., Depalle, P., 2004. *Gestural Control of Sound Synthesis.* Proceedings of the IEEE; Apr2004, Vol. 92 Issue 4, p632-644, 13p. Fig. 1. A symbolic representation of a DMI.