Performance with an Electronically Excited Didgeridoo

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ABSTRACT

The didgeridoo is a wind instrument composed of a single large tube often used as drone instrument for backing up the mids and lows of an ensemble. A didgeridoo is played by buzzing the lips and blowing air into the didgeridoo. To play a didgeridoo continously one can employ circular breathing but the volume of air required poses a real challenge to novice players. In this paper we replace the expense of circular breathing and lip buzzing with electronic excitation, thus creating an electro-acoustic didgeridoo or electronic didgeridoo. Thus we describe the didgeridoo excitation signal, how to replicate it, and the hardware necessary to make an electro-acoustic didgeridoo driven by speakers and controllable from a computer. To properly drive the didgeridoo we rely upon 4th-order ported bandpass speaker boxes to help guide our excitation signals into an attached acoustic didgeridoo. The results somewhat replicate human didgeridoo playing, enabling a new kind of mid to low electro-acoustic accompaniment without the need for circular breathing.

Author Keywords

Augmented/hyper instruments, Robotic music, diggeriedoo, dijj, didjeridu

ACM Classification

H.5.5 [Signal analysis, synthesis, and processing] Sound and Music Computing

1. INTRODUCTION

The didgeridoo is an ancient instrument heralding from the indigenous Australians, Aboriginal Australians, and Torres Strait Islanders. Originally fashioned from termite-hollowed out branches of trees [3], the didgeridoo is a long low frequency wind instrument that is driven by buzzing one's lips. It can be played continuously by human players if circular breathing is employed. The didgeridoo typically produces long drones, but one can also speak into it and modulate the frequency of buzzing and breath to play various motifs similar to animal sounds found in Australia [4].

Circular breathing [1] is the act of continuously pushing air out of the mouth by the use of lungs, diaphragm, and even cheek muscles. Circular breathers will lock their mouth cavity down, breath through their nose, and push air out of their mouths mechanically with their cheeks. This enables the circular breather to continuously refresh their air supply and not run out of air. The level of skill required to drive a didgeridoo is more than what is required to drive smaller wind instruments. Circular breathing is a difficult skill to learn for many novices, *especially* the authors of this paper.

Thus the main motivation for this work comes from the fact that both of the authors are didgeridoo novices, and they find the large volume of air that a didgeridoo requires to be too much for their weak circular breathing skills. Out of desperation and need to play acoustic long drones, combined with a lack of enthusiasm for skillful training and practice, the authors attempted to automate some forms of didgeridoo playing.

This work has 3 requirements: play a didgeridoo automatically without a human respiratory system; play a didgeridoo acoustically—do not synthesize the resonant chamber of the didgeridoo, rather drive it; and to drive a didgeridoo electronically such that it sounds like a real didgeridoo.

The authors experimented haphazardly to drive a didgeridoo much like a bagpipe, by driving a tube with compressed air, air from balloons, and air from pumps. The authors found that the buzzing lips of the didgeridoo player were not appropriately modelled by these attempts and, consequently, did not sound like a didgeridoo. Thus the authors embarked down a path of electronically exciting didgeridoo with speakers that played a signal that closely replicated the buzzing of a didgeridoo player's lips. Other works [8] have driven wind instruments with speakers, drivers, and tweeters and have had some success, so why not try didgeridoos?

Driving a didgeridoo requires a different approach than driving a clarinet as the frequency of the excitation signal is much lower than that of clarinets and other smaller wind instruments. We employ speaker box design to address this need for low frequency response from excitation signals.

In this paper, we provide the following contributions:

- we present a method of electronically exciting a didgeridoo with speakers;
- we describe the design of speaker boxes necessary to drive a didgeridoo;
- we have performed, tested, refined, and analyzed this design;

2. PRIOR WORK

To drive a didgeridoo with a speaker we need to emulate the noise made by a human player. The didgeridoo excitation signal was described and modelled by Fletcher et al. [3]. This model uses frequency, time, and lip opening as inputs and produces a sound wave that can excite a didgeridoo. We provide a detailed description of this model in Section 3.2.

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The Monochord-Aerophone Robotic Instrument Ensemble [8] used high frequency driver-excited clarinets and wind intstruments during live performances. Their clarinet has solenoid driven "fingers" and can play many pitches, however, unfortunately the tone is robotic. The tweeter drivers used in the instrument make it inappropriate for driving a didgeridoo as they are too high pitched.

Not all attempts at driving wind instruments used speakers. Some have tried to drive wind instruments with air pressure control systems that pump air out of robots. The biologically inspired performance robots described by Solis et al. [9] force air into wind instruments like flutes.

Michon et al. [5] developed the hybrid clarinet. It has a human driven mouth piece with an electronically modelled clarinet. They attempted to address the physical need for a clarinet body by using physical modelling in software, yet still rely on the nuanced reed playing of a human performer. Their approach facilitates the generation of virtual clarinets that rely on the existing skills of a clarinet performer. Our work took the opposite approach, we rely on the software driving the excitation signal to be the skilled force that drives a real didgeridoo rather than a skilled performer playing a virtual didgeridoo.

3. DESIGN

To help drive the didgeridoo with low frequency tones we rely heavily on band-pass speaker boxes [2]. These are passive boxes whose architecture act as a bandpass filter on the speakers mounted within the box. We rely on the guidelines for ported bandpass speaker boxes from Vance Dickason [2].

The overview of the design of the electronically driven didgeridoo is a ported bandpass speaker box coupled with a didgeridoo. The intent is to directly couple the speaker ouput to the didgeridoo with a tight seal forcing the acoustic energy through the didgeridoo.

While almost any sub-woofer design would be able to produce the low frequencies required for this application, a 4th order bandpass design combines a sealed woofer chamber with a secondary ported chamber such that all acoustic energy is transmitted via the port. (See Figure 1) This design yields a physical advantage in that the driver is completely enclosed and the output from the enclosure emanates from a port that can be coupled directly to the instrument.

Since the port must be coupled to the tube, the port dimension is an important design criterion that must be chosen in advance. The remainder of the design is then adjusted to facilitate the chosen port opening.

- Acquire a speaker tuned for and capable of producing frequencies in the 60hz to 90hz range.
- Given the port opening, calculate the volumes of the closed box, the ported box, using a 4th order bandpass calculator [7].
- Build the bandpass box and mount the speaker inside.
- Attach a didgeridoo to the port.
- Configure software to play signals through an appropriate amplifier for the mounted speaker.

3.1 Bandpass boxes

The range of the didgeridoo excitation signal, and the output of the didgeridoo are quite low, thus sub-woofers, woofers, and mid-speakers should be used. A professional player's excitation signal contains strong components from about 50Hz up to around 4 kHz. This is a different requirement from Rogers et al.'s [8] clarinet-like instrument which used high frequency drivers. Yet Dickason [2] describes many different kinds of speaker boxes that address low frequency response such as bandpass boxes.

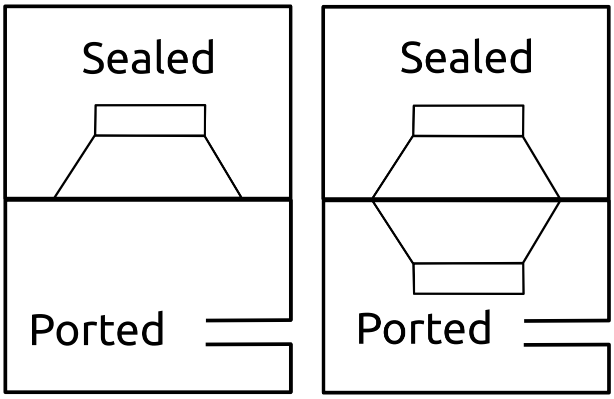


Figure 1: 4th Order Bandpass Designs, sealed and isobaric speaker boxes.

Normal use of bandpass speaker as a sub-woofer requires a crossover to filter out high frequencies. In our case we connect the amplifier directly to the bandpass speaker as we want to reproduce as much of the high frequency content as possible and we are not concerned with the efficiency issues of traditional subwoofer design.

3.1.1 Box 1

The first box is constructed from raw materials and makes use of the leftmost design shown in Figure 1. Box 1 is built from MDF wood and ABS pipe, coupled with an inexpensive didgeridoo. It was used for performance and it used a 8 inch diameter mid-range car speaker that had a free air resonance of 88hz (Pyramid WH8 8-Inch 200 Watt High Power Paper Cone 8 Ohm Subwoofer). The sealed box had an interior volume of 13.3 L with dimensions of 25.4cm by 25.4cm by 20.6cm, (10 x 10 x 8.1 inches), and a ported box with interior volume of 2.5 L with dimensions of 25.4cm by 25.4cm by 3.81cm. (10 x 10 x 1.5 inches). The port was 5cm (2 inches) in internal diameter and 26.78cm (10.5 inches) long, cut from 5cm (2 inch) diameter ABS pipe. The port is longer than all dimensions of the box, thus it was placed externally to the ported box, like a stovepipe. Theoretically the box output frequencies were tuned between 51hz and 153hz centered around 88hz.

To cut out this box with 1.9cm (3/4 inch) thick MDF we recommend cutting out 2 30.48cm (12 inch) by 25.4cm (10 inch) inner side pieces, and 2 30.48cm (12 inch) by 30.48cm (12 inch) side pieces, 2 30.48cm (12 inch) by 30.48cm (12 inch) end pieces, and 1 25.4cm (10 inch) inner speaker mount piece. A hole of appropriate size must be cut out of the inner speaker mount piece to mount the speaker. The box volumes were calculated using a calculator made by Raymond et al. [7].

This box was driven by a 1970s solid state Kenwood KA-4002 stereo amplifier with 18W per channel, as it was freely available. The box and the attached didgeridoo are depicted in Figure 4 in Section 4.

3.1.2 Box 2

Box 2 is an isobaric speaker box made from two modified commercial speaker enclosures, in our case, the Alesis Monitor 1. Many commercial speakers can be adapted to this design which is a simple method for quickly building a ported bandpass enclosure.

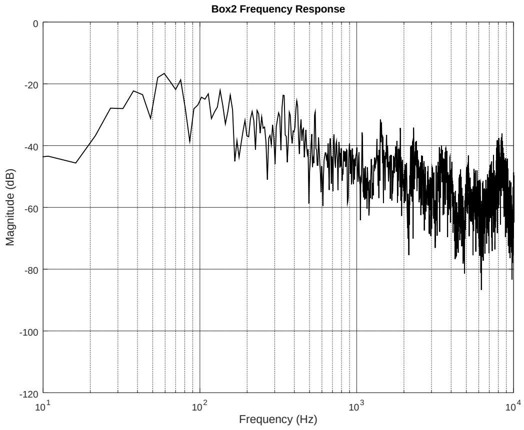


Figure 2: Box 2 Response

The Monitor 1 has a frequency response down to 45 Hz and uses a 16.5cm woofer which has several properties that facilitate our design. The woofers are perfectly centered in the box in its shortest dimension and have a rubber mounting ring that protrudes slightly from the face. Consequently, when the two speakers are placed face to face, the woofers are perfectly aligned and the space between them is sealed in an airtight gap. In order to realize an adequate seal, one of the two tweeters must be removed. The resulting opening, however, is sufficiently sealed by the face of the opposing tweeter which is left in place to provide a barrier between the two cabinets. We disconnected the wiring of both tweeters as they are not used in this design.

Each speaker has a rear facing port hole that is slightly larger than 3.81cm (1.5 inch) PVC pipe. One of these two ports is sealed shut and the other is coupled to the PVC pipe via an adapter. The two speakers are then placed face to face and coupled tightly together using clamps. The didgeridoo, a PVC pipe of similar bore, is coupled to the port PVC pipe.

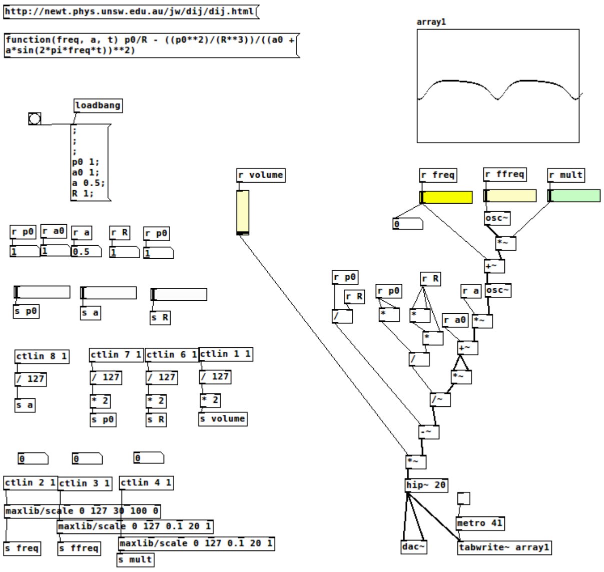
This construction yields an isobaric 4th order bandpass enclosure. An isobaric enclosure uses two drivers working in concert as a single driver as shown in the rightmost diagram of Figure 1. When one driver moves outward, the other moves inward. To achieve proper operation the two speakers are wired in opposite polarity and without crossover networks. An isobaric configuration behaves as a single driver with a motor that is twice as powerful. This configuration, however, requires twice the power to produce the same output [2]. Each speaker is capable of handling 120 Watts at 8 ohms. We power this with a bridged Mackie 1400i capable of producing 1400 Watts at 4 Ohms.

In order to achieve satisfactory response an equalization curve was applied manually to Box 2. A high shelf boost of $12dB$ at $2kHz$ increased the high frequency response and a sharp notch filter at $1.5kHz$ was required to null a resonant peak. Figure 2 shows the corrected response of Box 2 when driven with a white noise signal. While it is hardly flat across the spectrum, it gives usable response between $40Hz$ and $4kHz$.

3.2 Software driven excitation

We implemented the excitation signal generator in Pure Data (Figure 3) and Reaktor (Figure 5) using a function from Fletcher et al. [3] given by:

$$dijj(f, a, t) = p_0/R - \frac{(p_0^2)/(R^3)}{(a_0 + asin(2\pi ft))^2} \tag{1}$$



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http://newt.phys.unsw.edu.au/jw/dij/dij.html
```

```
function(freq, a, t) p0/R - ((p0**2)/(R**3))/((a0 +
a*sin(2*pi*freq*t))**2)
```

```
;
;
;
p0 1;
a0 1;
a 0.5;
R 1;
```

Figure 3: Pure Data didgeridoo exciter

where f is frequency of lips, a is size of lip opening where $0 \leq a < a_0$, and t is time. Pressure is p_0, and R is the acoustic resistance of the instrument tube at the resonant frequency. We keep p_0, R, and a_0 constant while we can vary f and a over t. The output across t is a waveform of a didgeridoo excitation signal. Note that this does not replicate vocalization. Vocalization can be added to the $dijj(f, a, t)$ signal.

3.3 Software interface

During the public performance of the didgeridoo we used a webservice UI that mapped a 2D Hilbert curve to a 2D scratch-pad. When the scratch-pad was touched or clicked a didgeridoo tone was initiated, when it was released the didgeridoo tone was released. The didgeridoo used an ADSR envelope for triggering with a long release so that any drone could be sustained or its parameters changed via mouse or touchscreen control.

Points on the 2D Hilbert curve were mapped to back to a 1D scalar value and which was then mapped to a N dimensional Hilbert curve across the parameters of the synthesizer. This effectively maps 2D inputs to N-D inputs. In our case we used dimensions such as lip opening (a), lip frequency (f), amplitude, frequency modulation, and the constant value for p_0. This meant that areas on the scratch-pad existed that sounded like other areas, but short local movements would not change the synthesizer parameters drastically. This enabled a performer to modulate the didgeridoo synth parameters simply by dragging the cursor. This helped create more complicated and natural didgeridoo expressions, as without variation the didgeridoo excitation is very mechanical, exact, and robotic. This scratch-pad is inspired by the Sonic Zoom interface proposed by Tubb et al. [10].

4. LIVE PERFORMANCE

The didgeridoo driven by Box 1 was used in a live performance in January 2017 at Art's Birthday (celebrating the birth of the concept of art) in Edmonton, Canada. The didgeridoo was driven by live improvisation to accompany a pre-recorded piece of music by Philippe Neau. It was well received although the didgeridoo had to be micro-phoned

Figure 4: Art's Birthday Performance using Box 1 with a wooden didgeridoo

to amplify its signal in the large room. Figure 4 shows the performer sitting down controlling the didgeridoo attached to Box 1 sitting beside him. The performer utilized a 2D scratch-pad, described in Section 3.3.

One audience member, a didgeridoo player, suggested employing more vocalizations and attaching a microphone to the device. Possible improvements in performance could be attained by using a more powerful amplifier to drive the speaker, as well as employing lip opening envelopes rather than straight ADSR envelopes. One concern was with how simple or robotic the didgeridoo sounded. We concluded that adding low amplitude noise to many of the parameters such as frequency f and lip opening a would improve the naturalness of the didgeridoo sound.

5. IMPROVED EXCITER

In an effort to combat robotic performances we acted upon feedback from the performance to modify Fletcher's [3] exciter to produce signals closer to real didgeridoo players.

Fletcher et al. describe their model as a simplified model of a lip valve [3]. We compare its spectrum with the specturm of our normalized version of the simplified model. When the parameter a is close to zero, the output of the exciter has few harmonics. As the parameter approaches 1 the harmonic content increases dramatically. Although the intensity of the harmonics increases with parameter a, this model replicates very little of the higher formants typical of human didgeridoo players.

We also observe that the basic exciter implementation has far less variation than the exciter of the human didgeridoo player. Moreover, the high frequencies roll off sharply after $1kHz$.

5.1 Improved exciter design

To improve the realism of the simulated didgeridoo we extended the original exciter model. This second exciter was implemented in Reaktor [6], as seen in Figure 5. Our first improvement was to simplify the exciter for fixed pressure and tube impedance and to normalize the output somewhat.

Since we are holding p_0, R, and a_0 constant we make some simplifications. We observe that this function will have a DC offset that must be removed with a high-pass filter, consequently, the value of these constants when fixed is arbitrary and, setting $\alpha = -1$, we can simplify the exciter as follows.

$$dijj(f, a, t) = \frac{\alpha}{(1 + asin(2\pi ft))^2} \qquad (2)$$

However, we also find that the output level varies considerably over the range of useful values of a. Consequently, we make some attempt to normalize the exciter function by setting $\alpha = (1-a)^2$. This scaling factor yields roughly constant amplitude for a large range of the a parameter. As the additional harmonics are introduced the overall amplitude is reduced to compensate for the increased spectral content.

5.2 Robotic sound

In the Pure Data implementation we modulated the exciter function with a sine wave *low frequency oscillator* (LFO), in order to modulate the drone frequency. While this allowed some variation in frequency and tone it was insufficient to avoid a robotic sound.

We observe that real players do not maintain a constant frequency or amplitude but have small perturbations in these parameters while playing. In our improved exciter we use two random waveform LFOs to simulate the variation expected in a human player's lip opening while playing. The two LFOs operate at frequencies $0.1 \cdot f$ and $0.01 \cdot f$ labelled fast and slow respectively. Each has player controlled amplitudes. These LFOs output a random waveform that simulates Brownian motion.

5.3 Vowel like sounds

In addition to variation in the lip movement, the tongue and throat contribute significantly to the sound of the didgeridoo. While modelling the tongue and throat accurately is beyond the scope of this work, we added a third LFO to add some harmonic colour.

This LFO primarily modulates the frequency of the exciter and thus,in addition to providing additional harmonic content, it also replaces the function of the LFO in the Pure Data implementation.

Rather than a straightforward sine wave oscillator, we use a formant oscillator which allows the formant frequency of the oscillator to be adjusted independently of the base frequency. This LFO also modulates the a parameter thus simulating that a change in frequency will also cause the lip opening to change. The base frequency is fixed as a multiple of the fundamental frequency. The formant frequencies are user controllable and add a simulation of vowel-like sounds to the basic sound of the exciter.

5.4 Spit sounds

A small amount of coloured noise is added to the output to simulate the wind and spit sounds that a real didgeridoo player will produce. The noise amplitude is modulated by the output of the exciter to simulate the motorboat like properties of a didgeridoo player's lips. The user is able to control the noise colour and the level of noise added to the output.

6. FUTURE WORK

While our improved exciter addressed many of the issues of a robotic sounding performance, more can be done. Adding noise worked well for the improved exciter, thus perhaps adding reverb could help simulate a didgeridoo born of a termite infested branch. This reverb could simulate a less than smooth bore.

Another area of improvement is to address the model of the human player. We did not have good measures of lip opening, pressure, or frequency of excitation, furthermore much of our aim was emulate didgeridoo playing and thus all of the sounds one can make with a didgeridoo. Future work can involve searching a space of parameters that change across time in order to find the parameter timeseries that could produce other characteristic didgeridoo sounds

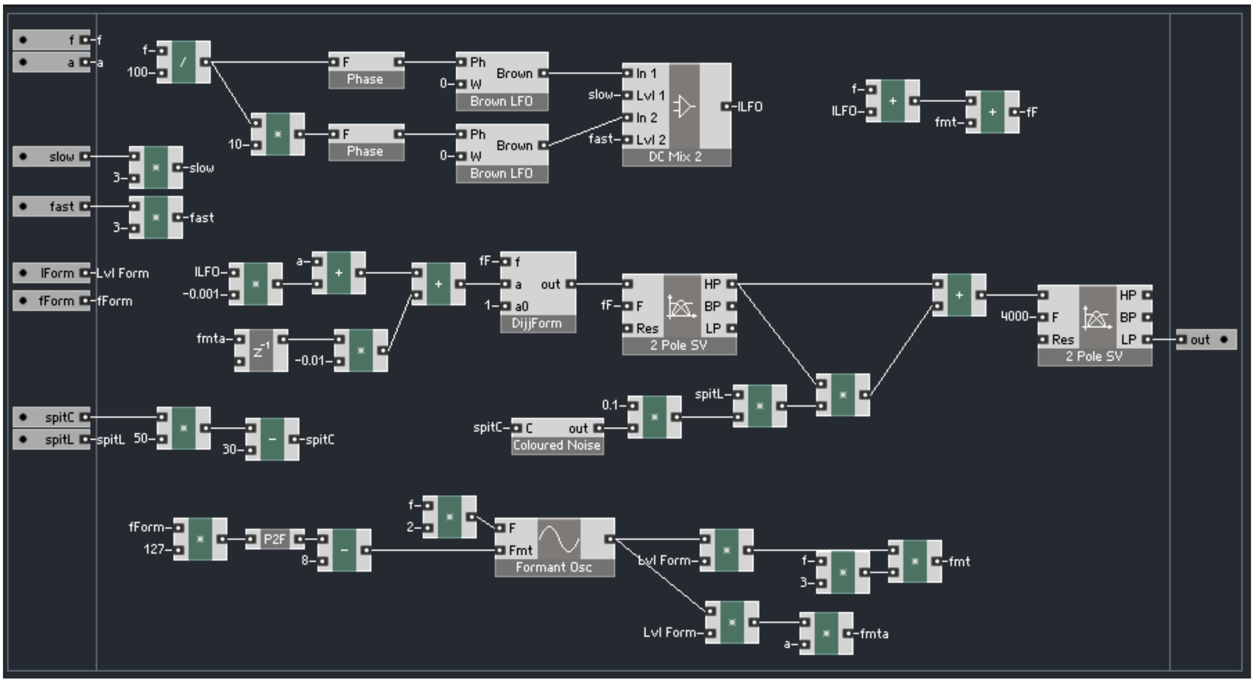

Figure 5: Reaktor didgeridoo exciter. Inputs are on left, output is on the right. Frequencies are specified directly in Hz. All other inputs are normalized to a 0..1 range.

such as dingo barks [4]. Rather than manually reverse engineer how a didgeridoo sound is made we could use search algorithms to tune the parameters of our exciter to find series of parameters that would produce didgeridoo sounds.

Alternatively we can use a microphone to simulate driving a didgeridoo with our own mouth whether by enveloping the excitation signal or by layering microphone vocals into the excitation signal to simulate vocalizing with a didgeridoo. Fletcher [3] has shown that many vocalizations are not from the lips but from the vocal chords and are overlaid on the lip buzzing signal.

7. CONCLUSIONS

We have described a method of utilizing ported bandpass speaker boxes to electronically drive didgeridoos, effectively making an electro-acoustic didgeridoo. This kind of didgeridoo faces serious energy/amplification constraints that other electronically excited wind instruments do not as lower frequency response requires larger speakers driven by powerful amplifiers—similar to speakers and amplifiers used in hobbyist car stereos. Using the work of Fletcher et al. [3], the speakers produce a didgeridoo excitation signal meant to mimic the buzzing of a performer's lips. This signal drives a didgeridoo and produces sounds similar to a didgeridoo performer's music.

We found that if frequency, and lip opening are not carefully modulated, whether manually or by Brownian motion, the didgeridoo will sound robotic. Adding further modulation and noise can produce more natural didgeridoo sounds, yet it is clear there is a lot of future work to be done in intentionally emulating many forms of didgeridoo expressions as well as finding appropriate user interfaces to control the didgeridoo. [1]

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[1] didgeridoo patches can be found here `https://github.com/abramhindle/diggeridoo`