Excited Sounds Augmented by Gestural Control

Clemens Wegener
Bauhaus-Universität Weimar
Interface Design
clemens.wegener@uni-weimar.de

Max Neupert
The Center for Haptic
Audio Interaction Research
max@chair.audio

ABSTRACT

An acoustic interface to create excitation signals for digital resonators (waveguides, lumped models, modal synthesis and sample convolution) in synchronicity with augmenting control signals is presented. It is described how a direct acoustic excitation creates an intimate and intuitive interaction. Multiple prototypes and the lessons learned from them are documented in this paper.

1. INTRODUCTION

In the heyday of physical modeling synthesis, typical excitation signals were static noise bursts or clicks. When using a MIDI keyboard as an interface, the advantages of physical models compared to playing back samples are negligible, so manufacturers began to implement samples in their instruments as memory became cheap. With the right *acoustic interface* which allows audio signals to continuously excite these models in real time the strengths of physical models easily outperform what is possible with a keyboard and sampling. Acoustic excitation enables us to create rich sounds with intuitive interaction and intimate control. In a previous publication we presented the *Tickle* instrument and concepts of its driver architecture [1], this publication expands on the research that led us to its current form.

1.1 Exciting audio

Using live audio as excitation signal for physical models allows for a dynamic and continuous stream, but even more importantly, through its spectral information it carries rich potential for expressive play. Commercial products trying to harness this power are surprisingly rare: *Korg's Wavedrum* (1994), Zamborlin's *Mogees* [2] (2014) and the ATV *aframe* [3] (2017) are the only products which are feeding the excitation signal into a digital resonator. On the other hand researchers have proposed many simple and affordable interfaces such as ceramic tiles [4], to acrylic sheets instead of guitar strings [5], [6] or intricate prototypes with vibration insulated pads for eight fingers [7]. In this category the distinction between interface and instrument (or controller and synthesizer) becomes blurry. You could argue to define it as an instrument, as the source waveform for the synthesis is generated by the musician interacting with the surface of the instrument. You could likewise argue it is "only" a controller or interface because the synthesis happens on a connected computer or synthesizer. Therefore we also call the Tickle an *acoustic interface* (to an analog or digital synthesis).

1.2 Augmenting control

Miller's tiles [4] and Momeni's *Caress* [7] consider the processing of the contact microphone as sufficiently expressive. Cook's *Nukelele* [8] combines two sensors, one at audio rate and one at control rate, to create the affordance of an Ukulele which is played with both hands on different positions of the instrument. Like with a guitar, one hand controls the parameters, the other provides an excitation signal. Former is the control rate input and later the audio rate input.

We want to augment the sound signal with additional parameters, so we simultaneously get the **position** of touch on the surface. This way we eliminate the need for a second hand. Our implementation creates a percussive instrument which can be hit, but also can be played melodic and continuous by rubbing, scratching or bowing on its edge.

2. THE TICKLE

2.1 Prototypes

In the development stage we produced about a dozen prototypes to evaluate the idea and different realizations thereof.

We started prototyping with multiple piezo mics attached to 3d printed (Figure 1) – or wooden (Figure 2) bars resembling what could perhaps be recognized as an electronic marimba. Each bar (key?) had its own piezo microphone attached, resulting in the use of eight channels of the audio interface to digitize and excite the physical models in software. We started using soft polyurethane foam as a sound insulator underneath the bars as a starting point but noticed soon, that this insulation was not sufficient. The next iteration was aimed at improving the insulation by using a 3D printed, free hanging rubber construction and at the same time speeding up the fabrication process by designing a laser cut enclosure.

However using eight audio channels, patching them into the audio interface and then patching the software channels inside the DAW was a very uncomfortable workflow. Additionally all the interface channels are then blocked, of course. In a new approach we wanted to use a single audio channel and use it in combination with positional data to alter the pitch of the digital resonators. This is where we investigated capacitive- and force sensing interfaces.

Figure 1. *3D printed keys with individual microphones*

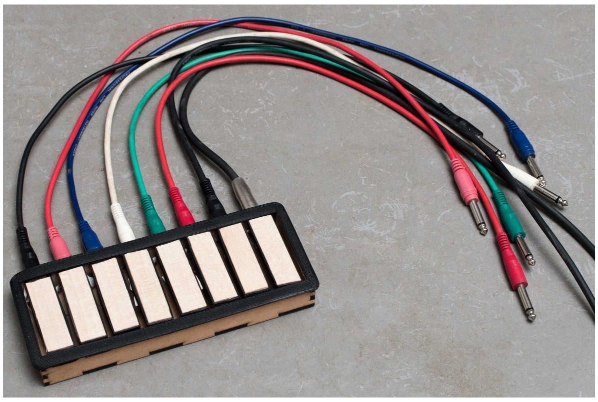

Figure 2. *Laser cut and 3D printed rubber for individual wooden keys*

Most notably is a touch-pad with integrated piezoelectric sensor and a load-cell in each corner, similar to the *Nuance*[9]. It was made by taking a 7 Euro kitchen scale from a supermarket and replacing the electronics by a custom made circuit board (Figure 3), reading the four sensors separately instead of summing up their readings.

Re-using and appropriating a mass produced product allowed it to be extremely cheap. For a continuous calibration of the readings a fifth load-cell is necessary as a reference, so buying five scales will allow for making four interfaces.

The touch point on the surface is calculated by a simple center-of-mass formula and it allows to detect force and position simultaneously. The USB user space driver for getting the position had an update rate of 200Hz with a dynamic range of detecting the force on each sensor of 60dB, allowing to read forces with a resolution of five grams. Additional shielding could even improve this. The class compliant USB audio interface sent the audio signal from the attached piezo mic with 44.1 Khz. The approach of calculating the center of mass to detect the touch point has very interesting physical side effects: it is possible to do a vibrato by applying a shear force to the surface (you don't have to slide the finger, you can push and pull on a single point in all directions and measure the resulting force continuously).

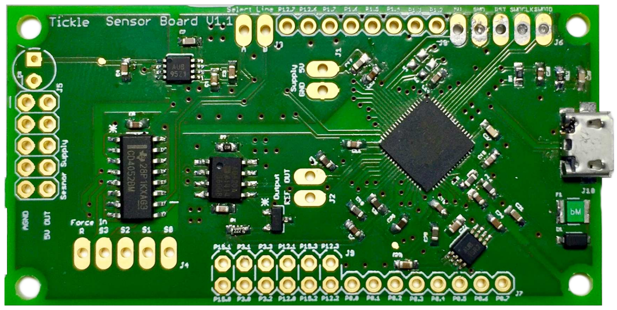

Figure 3. *This custom PCB turns a kitchen scale into a sensor board*

The hijacked kitchen scale (Figure 4) approach was very appealing to us, mostly because it is possible to measure force and position at the same time using very accessible technology. The disadvantage of this approach is the measurement inaccuracy that results from the physical properties of the setup.

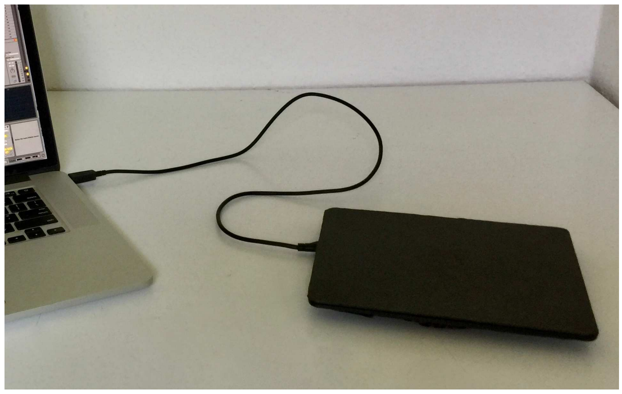

Figure 4. *Kitchen scale based prototype*

One problem is the momentum of the surface that results from its own weight. Because of the momentum, the surface will physically vibrate on the springs of the strain gauges and cause sensor misreadings.

A second problem is the strong susceptibility to shearing forces when applying only little total force. The measurement setup can be more sensitive to shearing forces than the actual position of the center of mass (your finger) on the surface. This causes the position measurement to be much more inaccurate when little force is applied. The limitation is in the sensor design, since it actually measures both: weight and shearing forces as a linear combination.

Finally we opted for capacitive sensing technology because of manufacturability and reliability. The *Monoitch* (Figure 5) and the *Pocketickle* [sic!] (Figure 6) are direct predecessors of the *Tickle*.

2.2 Hardware

The case is made of bent steel with wooden side panels. It's top surface is a printed circuit board and has a capacitive X-Y sensor, three endless rotary encoders with associated RGB LED and two buttons (for transposition or other parameters). On the back are six ports which allow it to be

Figure 5. *Capacitive sensing surface with piezoelectric microphone*

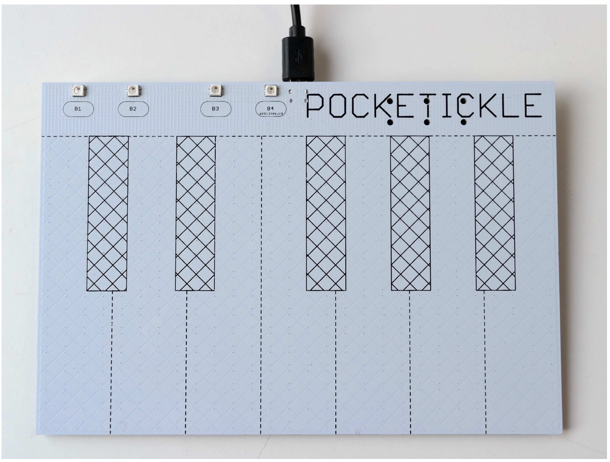

Figure 6. *The "pocketickle", a direct predecessor of the Tickle has a piano keys print*

connected to a modular synthesizer.

2.3 Surface

After a brief evaluation of piano key layouts and variations thereof [10] it was concluded, that a piano key layout is contradictory to the intended interaction with the instrument. A hexagon pattern was chosen to have equal sized [1] surfaces without empty spaces on the surface. It is also found in other electronic instruments and controllers, for example the *Synderphonics Manta* [11]. From the 8-Bit resolution in X and Y axis we can calculate in which of the 14 hexagons printed on the surface a touch occurred. The capacitive touch sensing is single-touch, so polyphony can not be achieved by simultaneous touches. However, with voice allocation we can let one touch resonate while a new touch gets its own resonator, so subsequent touch events may have overlapping resonances.

2.4 Material and Texture

To create an acoustic excitation signal we rely on a hard material that captures the spectra of different gestures. In addition to the rigidity of the material, a textured surface is essential to create enough noise when rubbed and scratched. Silicone surfaces are not suitable for our application since they absorb too much of the subtle interaction.

2.5 Residual and Resonance

Generally we want the physical surface of the instrument to resonate as little as possible, so that we can feed the dry residual signal of the touch gesture (rub, scratch, hit, flick, bow, etc.) into a digital resonator (See also [4]). This way the full power of physical modeling synthesis algorithms may be accessed. The practice of sending generated noise-bursts or clicks into digital resonators – which can be found in literature for physical modeling and which is still the standard in many soft- and hardware implementations – is crippling the true potential of such algorithms.

2.6 Synthesis

Our synthesis algorithms are implemented as Pure Data patches and are available through our Git repository. [2]

For the sound synthesis we employ techniques of digital reverbrators. They can be understood as modeled simulations (waveguides and mass-spring models) of the physics happening in real instruments as described by Smith [12]. These models can be generated with Berdahl and Smith's Synth-A-Modeler Compiler [13]. Synth-A-Modeler generates FAUST code which can be compiled in a variety of other formats such as a Pure Data external. With the Pure Data object `pmpd~` from Henry's PMPD [14] library which can create static mass and spring models we achieved nice sounding string, plate and gong topologies. Drawback of PMPD is that the topographies and properties of the model can't be interactively modified while sound is processed.

We are not aiming for perfect re-creations of orchestral instruments, our interest lies in the exploration of synthetic sounds with an acoustic and intimate level of control. Algorithms like a nested comb filter delay as described by Ahn and Dudas [15] prove interesting and fun to interpret with our instrument while being surprisingly cheap to compute. We can employ our acoustic interface to excite *extended, hybrid* and *abstract cyberinstruments* as described by Kojs et al. [16]. Convolution methods with samples can be useful to digital Foley artists to articulate a sample in a plenitude of variations.

2.7 Architecture and Driver

Our hardware is based on a Cypress PSoC 5 microprocessor and runs a firmware which is digitizing the capacitive sensing surface and the signal from the piezoelectric sensor. It communicates to the computer as a USB Class Compliant Audio and MIDI device and as such is available without further software interfaces to user-space software like Pure Data or Ableton Live. After consideration of many different protocols for communication [1], we have opted to implement the Tickle as a Class Compliant Audio and MIDI device. Our legacy Kernel driver for Linux as well as the Pure Data external are published under a free license. A repository of the source code can be found on our aforementioned gitlab/github.

[1] except for the hexagons at the edges

[2] gitlab.chair.audio mirror: github.com/chairaudio

Figure 7. *The current Tickle instrument*

3. FUTURE WORK

Future research may be conducted to implement the following features:

- multi-touch (and thus real polyphony)
- pressure sensing [17]
- haptic feedback
- analog circuitry for sound synthesis
- embedded computing for digital synthesis, for example implemented on the Bela board [18]
- playful interfaces to manipulate mass-spring models in real-time as seen in Allen's Ruratae [19]
- parallelization of processes using GPU power to compute models in real time as in [20]

4. CONCLUSIONS

With our implementation of an acoustic interface we have proven that physical modeling still has huge dormant potential which are needing rediscovery and have been inaccessible due to inadequate interfaces.

Our instrument *Tickle* combines several well-known techniques and technologies which on their own are not new. Touch pad, contact-microphone and physical modeling synthesis have been around for a while. However, in their combination they synergize to a powerful intuitive instrument which allows for a natural and intimate [21] interaction with precise and reproducible control over sound. *Exciting sound* means we can feed an analog excitation signal into a (digital) resonator and thus create familiar as well as alien sounds. Sounds which either behave like instruments we know: Violin, guitar, snare drum, cymbal, gong, marimba, etc. or sounds which are distinctly synthetic but have an analog touch to it.

The development is ongoing and the list of possible future work shows that there are a plenitude of improvements and further research potential.

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