“SQUEAKeys”: a friction idiophone, for physical interaction with mobile devices

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***Abstract*—We present “SqueaKEYS”, a musical instrument application to enhance touch screens on mobile devices. Sound is generated acoustically by the sound of one or more fingers rubbing on the glass surface of a liquid crystal display screen, or the like. In this sense, the instrument is not an electronic instrument, but, rather, a friction idiophone (e.g. in the Hornbostel Sachs musical instrument classification sense). Location sensing on the touch screen is used to frequency-shift the sound onto a musical scale depending on where the screen is rubbed, struck, or touched. In other embodiments the location of the touch is determined with sound localization by way of geophones bonded to a glass substrate, eliminating the need for a touch screen (e.g. to implement the instrument on any glass surface equipped with appropriate listening devices).**

I. Introduction

“SqueaKEYs” is a friction idiophone that uses the sound of fingers rubbing on wet glass or acrylic as a multimedia input device. This can be used as, for example, a musical instrument in which sound originates idiophonically. It is not an electronic musical instrument [1], i.e. it is not merely a user-interface per-se, but, rather, a highly expressive physiphone. A physiphone [2] is a form of physical interaction that is not an electrophone in the Hornbostel Sachs [1] sense. The squeaking sound of rubbing fingers as input provides a high degree of variation over a wide range of highly expressive musical timbres, much like the expressivity possible with a violin. Moreover, a wide range of other forms of interaction are possible, not just rubbing: The screen can be touched, tapped, rubbed, struck, squeezed, or engaged in a many different ways, each of which produces a highly variable acoustic sound source.

Unlike many mobile interfaces that generate sound by triggering sound samples, we sample real-time physical vibration that comes from tactile physical interaction. And unlike many tangible acoustic interfaces [3], [4], [5], [6], [7], we augment the acoustic content with position-derived control signals to modify the content while staying true to the original acoustic source as generated by the user.

II. SqueaKEYs

We’re all familiar with the squeaking sound made by rubbing wet glass. Previously existing musical instruments such as Benjamin Franklin’s armonica [8] (spinning glass disks, one for each note, as shown in Fig 1) or the Cristal Baschet (glass rods, one for each note, as shown in Fig 2) use this effect.

We propose ”SqueaKeys”, a multitouch screen made from one continuous piece of glass or other material, in which the acoustically generated sound made by rubbing it is frequency-shifted in proportion to the location where it is rubbed. In this way, we achieve a highly expressive musical instrument with continuously variable pitch. The instrument also functions as a multitouch screen.

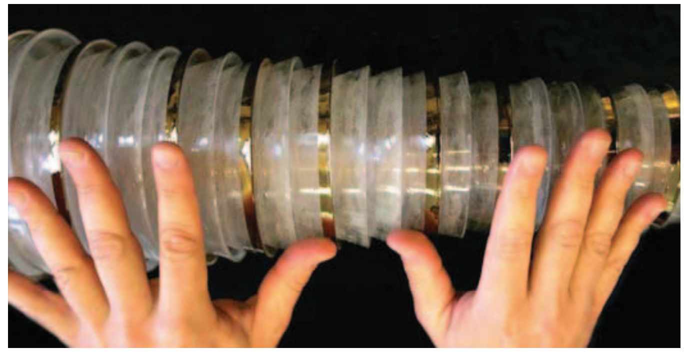

Fig. 1. Franklin’s Armonica, played by classical musician Thomas Bloch. Spinning glass disks are touched by wet fingers, to make sound in a way similar to the sound made by rubbing the rim of a wine glass. Lower notes are produced by touching the larger disks to the left. Higher notes are produced by touching the smaller disks to the right. Picture from Wikimedia Commons.

Fig. 2. Cristal Baschet, played by Thomas Bloch. Glass rods are arranged with the low notes on the left and the high notes on right. But unlike the Armonica, all 54 glass rods are exactly the same size and length. The mechanical contraption they are connected to shifts the frequencies, so, for example, the rods to the left produce low notes and the rods to the right produce high notes, by way of a mechanical filterbank. Each mechanical filter is a resonant mechancial “circuit” that sits above the corresponding glass rod, such that, for example, the leftmost is tuned to a low frequency and the rightmost is tuned to a high frequency. Picture from Wikimedia Commons.

III. THE LIQUID CRYSTAL BASCHET

Whereas the Armonica (Fig 1) uses a different sized glass disk (bowl) for each note (bigger bowls for lower notes and smaller bowls for higher notes), all of the glass pieces in the Baschet are of identical size. This makes it much easier to play the Baschet in many ways. An array of mechanical resonant "circuits" causes the production of low notes when the leftmost rods are rubbed, and high notes when the rightmost rods are rubbed.

Our SqueaKEYs system performs a similar action, but through the use of a bank of computational filters [9], instead of the mechanical filters that are used in the Cristal Baschet.

Whereas the Baschet has a discrete (i.e. integer) number of filters, our SqueaKEYs system uses a continuous filterfield, so that the pitch can vary continuously across the fingerboard.

Because the sound produced by SqueaKEYs originates accoustically, the device is not merely an input device to a sound synthesizer. Instead SqueaKEYs is a friction idiophone, and it is in the same Horbostel Sachs classification category as Franklin's armonica and the Cristal Baschet. But SqueaKEYs can also produce vibrato, pitch-bend, and play microtonally, which the Armonica and Baschet cannot do (because of their pitch quantization that arises from an integer number of discrete bowls or rods).

Additionally, the use of the iPhone's multitouch screen allows for the tracking of different regions and combinations of regions, in various ways.

A. Various embodiments of SqueaKEYs

SqueaKEYs is a continuous Cristal-Baschett-like musical instrument and user-interface based on the use of acoustic disturbances on a multi-touch screen.

Several different embodiments were constructed. One, which we called "Liquid Cristal Baschet", consisted of an LCD (Liquid Crystal Display) multitouch television screen equipped with geophones to listen to sounds of its screen being rubbed. The actual acoustic sounds generated by the rubbing, along with acoustic phenomena of the liquid crystal itself, were used in the initial sound production that was frequency-shifted based on locations determined by the multitouch screen itself.

In another embodiment we used a piece of glass or acrylic with geophones bonded to it. See Fig 3.

Any multitouch screen with suitable glass and acoustic pickups can be used. After much experimentation we built a number of embodiments of our own multitouch screen with geophones bonded to it.

In some embodiments only localization by sound was used. In other embodiments, cameras were used to track location and then the geophones used to get the sound that was frequency-shifted.

We also used a combined system with tracking by both acoustic sound localization (arrays of geophones) and vision. See Fig 4.

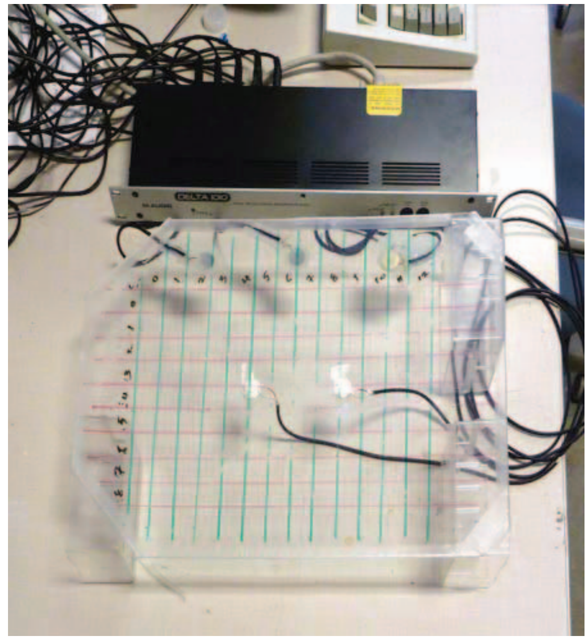

Fig. 3. "SqueaKEYs" system prototype consisting of a raised acrylic sheet with geophones bonded to the underside of it. For testing and algorithm training purposes, it has been marked (ruled) in 1-inch (approx. 25mm by 25mm) squares. Five geophones have been waterproofed for use with this setup. The two in the middle were potted separately so they could be moved around, whereas the three at the top were bonded with sealant glue right to the multitouch surface, and are therefore immovable but give better acoustic pickup. Sound travels through the sheet from anywhere it is touched or struck. Rubbing it with wet fingers results in a squeaking sound that is frequency-shifted continuously no matter where it is rubbed in any of the 140 zones or in-between zones, as an essentially continuous input space.

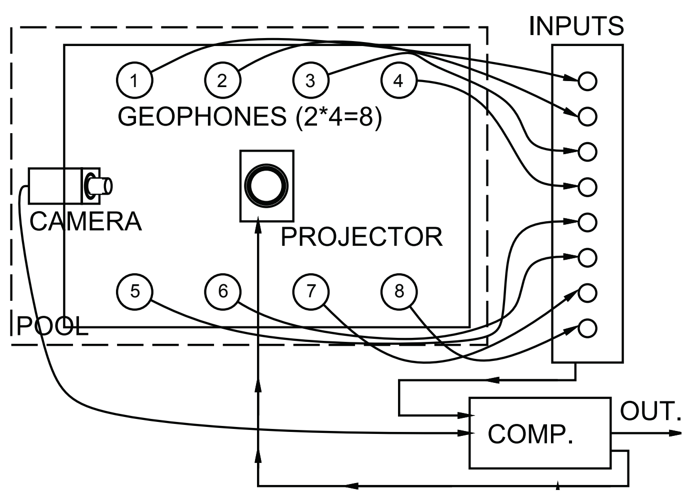

Fig. 4. SqueaKEYs: A continuous friction idiophone as a user-interface. Two linear arrays, each comprising of 4 geophones bonded to the glass surface perform sound localization. A camera provides additional localization, and, though not essential, helps improve the accuracy. A projector completes the touch screen.

Sounds were frequency-shifted to notes on a musical scale to simulate a Crystal Beschet effect. Thus rubbing the touch-screen on the left side made a very low note (the sound was shifted down), and rubbing it on the right side made a high note (the sound was shifted up). Rubbing it in the middle left the sound close to its original frequency.

IV. Implementation on the Apple iPhone

The use of a multitouch screen such as the Apple iPad or iPhone allows the localization to be performed by the touch screen itself. Initially we used the iPhone's built-in microphone to capture the sound of the touch, and then frequency-shifted based on location. A major problem with this method is the fact that the microphone picked up a lot of ambient sound, such as people talking in the room.

Microphones are actually designed to avoid picking up handling noise such as touching the housing of the iPhone. But in our case, this so-called handling "noise" is our signal-of-interest.

Moreover, sounds of speech in the room, which would normally be "signal" for a phone conversation on the iPhone are, in our case, noise.

There four specific classes of transducers that are each optimized for "listening" to vibrations in a particular state-of-matter:

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1. solid       geophone
2. liquid      hydrophone
3. gas         microphone
4. plasma      ionophone
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Selecting a geophone allows us to respond primarily to the mechanical disturbances that occur in solid matter rather than in the surrounding air.

Since the iPhone touch screen provides location, the input can be simply done with only one geophone rather than an array of geophones. The single geophone was used to capture the sound which was then frequency-shifted.

Our final implementation uses a single geophone acoustically coupled to the surface of the iPhone.

See Fig 5.

V. Frequency shifting algorithm

Depending on what region(s) are touched on the screen, the acoustically generated input sound is frequency-shifted to one or more corresponding musical note pitches.

In much the same manner that a singer's voice is pitch-corrected, our instrument corrects the pitch of the actual sound produced by a finger squeak or tap or rubbing sound.

This pitch correction was attained, firstly, by a frequency modulation or pitch shift. However, since much of the input sound is broadband, at least when the finger strikes the surface, it was found that putting the signal into a bandpass filter also produced a desired result. The bandpass filter passband was varied depending on where the screen was tapped, so as to land in the correct frequency bin for the pitch desired for a particular note.

In actuality we found that mixing these two frequency shifting approaches produced a more natural sound, having components in bandpass filtering and pitch correction.

Finally, we added a third component to each frequency shift, namely by way of envelope detection and frequency shift from DC. Our final chosen frequency shifter algorithm

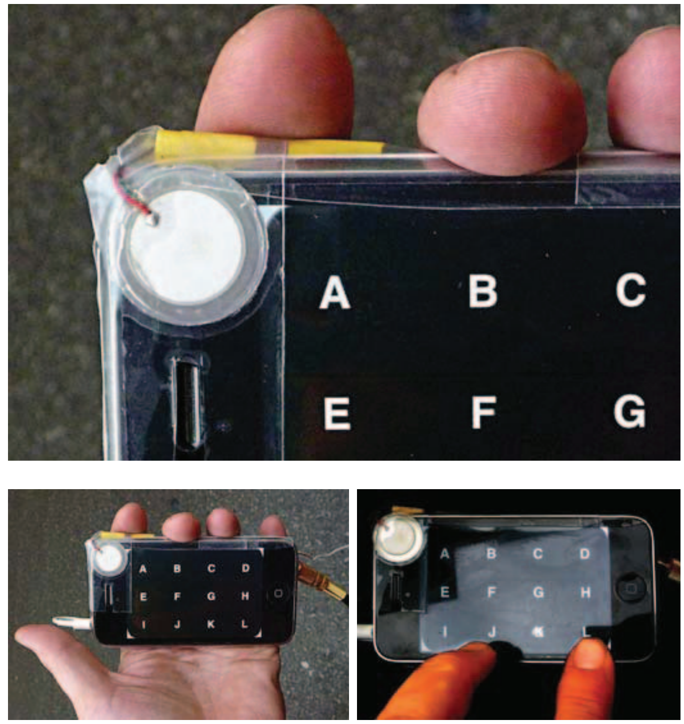

Fig. 5. SqueaKEYs running on an iPhone 3GS. A geophone picks up mechanical vibrations in the solid matter of the screen. There are 12 regions on the screen that can be touched, rubbed, tapped on, or squeezed in various ways. Tapping, rubbing, or the like, on region A results in having whatever acoustic disturbance is created being shifted to 220Hz. Interacting in region "B" shifts to 246.94Hz, in region "C" to 261.63Hz, and so on.

consisted of combining all three of these processes, each serving a purpose similar to the Proportional, Integral, and Derivative (P.I.D.) components of a PID controller.

1) harmonic expansion (analogous to "P");
2) bandpass filtering (analogous to ("I"); and
3) a frequency-shifting system based on envelope detection (analogous to "D").

Heisenberg uncertainty is a familiar concept both in quantum mechanics and electronic filter design. The more selective a filter is, the more delay there is in actuating a note. Whereas a guitar responds quickly versus a flute or violin or pipe organ, the guitar's pitch is less precise. In some sense a guitar favors the time domain whereas a flute favors the frequency domain.

To get the best of both worlds, we often hear a quick instrument such as a piano playing alongside a more tonal instrument like a flute.

We propose a shifterbank that combines these components of quick and slow response, to obtain an instrument that initially sounds like a guitar or piano, but settles over time to sounding like a strings ensemble of violins and cellos. We might call this a "guiolin" or "pianorgan" or the like, having quick attack but when sustained, having definite pitch. See Fig 6.

The presence of an input sound such as a squeaking sound or tapping sound is buffered in frames of 512 samples each. Each frame of samples is convolved with an n-section bi-quad filter which achieves 40 Hz of pass-band, centred at the note

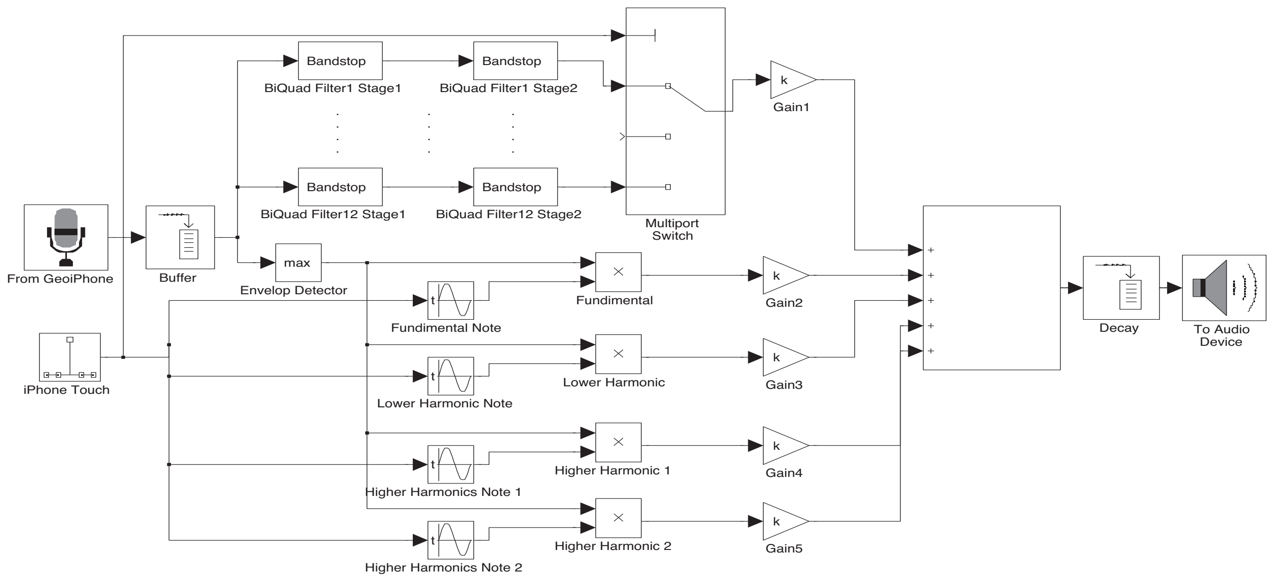

Fig. 6. Frequency shifting algorithm, modifying acoustic content from vibrations of physical tactile interaction. Position-derived control signals allow more control, and act on the original sound simply like an effects processor. This implementation was designed in MathWorks Simulink.

center frequency, f_c. The n-section bi-quad filter is a common cascaded Infinite Impulse Response (IIR) filter design that allows stage based filtering. Each successive filtering stage can be triggered at particular time unit within the same frame so that expressions of input sound (e.g. finger squeak or the like) is gradually fine tuned to a nearly pure tone.

An envelope detector captures the peak amplitude of samples within a frame. The envelope of the signal is shifted with a pure tone sinusoid at f_c. Together, two band-pass filtered and shifted envelope signals provide an audible output that is richly expressive from the user's input. To further enrich the timbre of the sound, a group of harmonic frequencies is combined with the output, in the harmonics blocks as shown. In the current configuration, the harmonic components shape the output to sound like an organ pipe. The final processed signal goes through a decay block. The exponential decay effect contributes a variable parameter to silence the note, and increase the effective dynamic range accessible to the user.

VI. Conclusions

We implemented and demonstrated "SqueaKEYs," a friction idiophone that makes sound from touching, tapping, or rubbing a touch screen surface.

Our aim is to create "open science"[1] devices for teaching and research by designing open-source algorithms and flexibly-reconfigurable hardware, which pays tribute to seminal early inventions while allowing others to build, extend and improve.

VII. Video Demo

For more information and a video demo, see:
http://eyetap.org/hyperacoustic

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[1] The term "open science" was coined by Mann (1999). openscience.com was sold to degruyter.com in 2011.