Handheld Acoustic Filter Bank for Musical Control

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ABSTRACT

This paper introduces the design of a handheld musical input device that produces control data by measuring, and analyzing, the resonances of carefully tuned pipes. Inspired by the khaen, a musical instrument from Northeast Thailand and Laos, the controller consists of a row of acoustic tubes, each one having a speaker at one end, creating a *closed end*, and an small fingerhole at the other, creating either an *open* or *closed end* depending on whether the hole is covered. A microphone is strategically placed along the tube so that it measures maximum pressure variation when the user is "playing" a pipe. The microphone data is easily acquired via the computer's line level audio inputs, allowing the device to interface reliably and conveniently to laptop computers, without having to cart a lot of extra gear to the show.

Keywords

khaen, sound synthesis control, mapping, musical acoustics

1. INTRODUCTION

Western "breath-driven" musical instruments [1] typically make use of a mouthpiece and a single bore that can take on a variety of shapes from cylindrical tubes to conical or flared horns, or some piecewise combination thereof. If a player is to change the pitch on such an instrument, some mechanism, such as toneholes or nested sliding tubes, must be in place for changing the bore's effective acoustic length[2]. These mechanisms have served musicians well over the course of western music history, so well in fact, that their ubiquitousness continues to pervade our paradigms for new musical input devices. Though these devices have offered substantial possibilities for controlling tone [5, 2], because they are monophonic they are far less suitable as controllers for more general musical needs.

Following research on the generalized virtual reed model [6], there existed a need for an input device that would allow for the control of an arrangement of multiple pressure-controlled valves. As is the tradition in the development of new music controllers, the author began by looking at existing tried and true control mechanisms that would meet our needs. The *khaen*, a breath-driven instrument from Northeast Thailand and Laos, consisting of two rows tuned acoustic pipes which may be played independently or simultaneously, served as our model.

Many new musical controllers are developed independently from the computer sound synthesis algorithms they control. This disconnect has made it increasingly more difficult to develop mapping strategies for parameter laden physical models, synthesis algorithms for which the input control parameters and the synthesis parameters are very strongly linked. This research therefore also attempts to address the notion of *relinking* acoustics to controller by measuring and analyzing the resonances of carefully tune pipes—rather than using sensors to measure the user's input. The benefits of this approach are twofold: 1) the user isn't forced to interact directly with bulky, often overly wired and flakey electronics which often break, and frequently need replacing from overuse and 2) the controller can directly interface with the audio ports on a laptop computer, without requiring a microcontroller and alot of extra circuitry for data acquisition—returning the concept of portability to musicians who use laptop computers during performance.

2. KHAEN ACOUSTIC DESIGN

The *khaen* is a free reed, mouth-organ style instrument found in the Northeast region of Thailand (Issan) and Laos. Very similar to the Japanese *sho*, or the Chinese *sheng*, it consists of two rows of bamboo tubes with decaying lengths—each row being accessible to one hand, with holes within the fingers reach. The player supports the intrument upright in front of the mouth, with the windchest resting comfortably between the palms of prayer positioned hands. Blowing, or inhaling, through the hole provides a pressure or vacuum inside the air chamber surrounding the reeds [1].

Pipes are inserted into a windchest, called the *tao*, so they form rows of anywhere from 6-10—but usually 8—pipes. The perfect skyline arrangement of the pipes is purely aesthetic; the actual pipe lengths are determined using vent

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[1] The term "breath-driven" is used to distinguish from *wind* or *wind-driven* instruments, which would include organs and accordians, among others.

[2] Some reed driven instruments, such as the digiridoo, rely exclusively on the mechanical resonance of the reed to alter the sounding pitch, though their pitch range is rather limited as a result.

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Figure 1: Mr. Khene, a khaen maker from Roi Et, Northeast Thailand, displays the tuning vents in the pipes.

holes placed a distance L apart, approximately 3/4 L above and approximately 1/4 L below the position of the reed (see Figure 2). The distance L is therefore, the effective acoustic length of the pipe when the fingerhole is covered. An open fingerhole, melted into the bamboo using a heated iron needle, drastically reduces the acoustic length of the pipe, altering its resonance so that it no longer permits vibration of the reed.

Fingerholes in the khaen do not function as toneholes in single bore instruments. Though the small hole alters the effective acoustic length of the pipe if left uncovered, it also destroys the pipe resonance and prevents the reed from vibrating. Therefore it is possible to blow into the instrument and not produce any sound. The player needs only to cover the holes for the pipes that should sound and can therefore play several notes simultaneously.A rubbery material called *kisoot*, which seals the pipes and the *tao*, may also be used to close finger holes, creating a fuller sound with drones or pedal notes.

The arrangement of the pipes and the proximity of their fingerholes make it relatively easy to play notes in rapid succession (with a little practice). Since very little finger pressure is needed to play a pipe, it is fairly easy to flutter the fingers over the holes and, again with practive, to play with speed and virtuosity. This is an aspect of the khaen that would be very difficult to capture using force sensing resistors. Khaen players will also say that the texture of the hole oulines beneath their fingers provides important information for locating their positions (which are not visible while playing), and this is information that should not be removed from a controller.

3. ACOUSTIC FILTER BANK FOR INPUT PARAMETERS

The design of a controller for a parallel arrangement of generalized reed synthesis models, is based on, and inspired by, the acoustics of the Khaen. Clearly the arrangement of pipes, one for each sounding pitch, is a particulary useful paradigm for controlling several virtual reeds [4]. But this input device also incorporates its use of resonance as a mechanism for control.

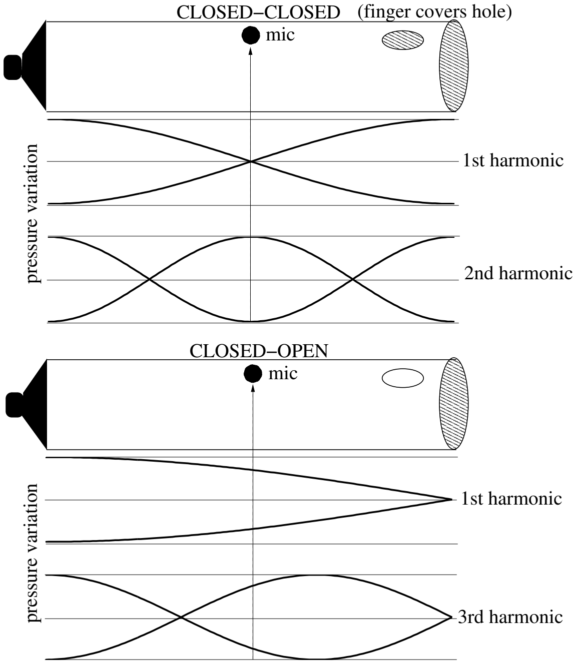

Figure 2: First two modes of vibration showing pressure variation maxima and minima for closed-closed and closed open acoustic tubes.

Like the khaen, the controller consists of a bank of carefully tuned pipes with fingerholes placed within the reach of the player's hands, and a mouthpiece supplying pressure variations—though this research focuses on capturing the fingering of the player rather than his/her blowing technique.

Each tube is cut so that it has an effective acoustic length L when the hole is covered. A microphone is placed on one of the tube, effective sealing and closing that end, and the hole is place at the other end, which is otherwise also sealed and effective closed (see Figure). Closing the fingerhole therefore changes the configuration of the pipe from a closed-open acoustic tube, to one that is closed-closed.

Notice from Figure 3 that though displacement of air is greatest at an *open end*, the pressure variation is maximum at a *closed end*. For the first harmonic of a closed-closed tube, there are maximum pressure maximum at either end, with a pressure null in the center. For the second harmonic of the same tube, adding a node and antinode produces a standing wave pattern with a pressure maximum in the center of the tube. Driving the tube with a sinusoid at a frequency equal to the sencond harmonic for the closed-closed configuration and placing a microphone a the center of the tube, will allow for measuring the maximum pressure variation when the hole is covered. Uncovering the hole reverts the configuration back to a close-open tube with an altogether different (lower) resonance (see Table 3, [3] or any acoustics text for calculating tube resonant frequencies), and as a result there is a considerable drop in the sound pressure level of the signal recorded by the microphone.

A signal is therefore generated from the computer which combines the appropriate driving frequencies (see frequencies from Table 3), output via the speakers on the tube ends,

Boundary	Harmonic k	Wavelength λ	Frequency $f_k = c/\lambda$
Closed-Closed	1	$2L$	$f_1 = 425$ Hz
	2	L	$f_2 = 850$ Hz $= 2f_1$
Closed-Open	1	$4(L + 0.61a)$	$f_1 \approx 206$ Hz
	3	$\frac{4}{3}(L + 0.61a)$	$f_3 \approx 618$ Hz $= 3f_1$

Table 1: Modes of vibration for a closed-closed and closed-open pipe of length $L = 40$ cm and radius $a = 2$ cm, computed using speed of sound, $c = 340$. In an actual pipe, pressure variations drop to zero slightly beyond an open end, effectively increasing the acoustic length for this condition by approximately $0.61a$, where a is the radius of the pipe.

		Closed-Closed		Closed-Open	
pipe	L (cm)	f_1 (Hz)	f_2 (Hz)	f_1 (Hz)	f_3 (Hz)
1	20	1700.0	**3400.0**	0757.6	2272.7
2	12	1416.7	**2833.3**	0643.0	1928.9
3	14	1214.3	**2428.6**	0558.5	1675.4
4	18	0944.4	**1888.9**	0442.2	1326.7
5	20	0850.0	**1700.0**	0400.6	1201.7
6	22	0772.7	**1545.5**	0366.1	1098.2
7	30	0566.7	**1133.3**	0272.3	0816.8
8	35	0485.7	**0971.4**	0234.7	0704.0

Table 2: Tube lengths L (in centimeters), closed-closed (Cl) or closed-open (Op) and frequencies f_0 and f_1 (in Hz) for 8 pipes.

and is effectively filtered via a bank of acoustic filters—that is, each pipe acts as bandbass filter, resonating only at its corresponding resonant frequency. The output from each of the microphones is added together using the very simple mixing circuit (see Appendix), and the sum is input back into the computer via the line level audio inputs, scanned and analyzed to determine which pipes have been selected.

The sound produced by the tubes must be within the audible range (not exceeding the Nyquist limit) so that the input and output can be done using the computer's audio ports. The closed-closed configuration was chosen to limit sound radiation to the player's when resonating, as the user will be holding the instrument at the mouth, in close proximity to the ears.

4. CONCLUSIONS

With the surfacing of new controllers and computer sound synthesis algorithms, there has been a clear disconnect between the device that produces the sound and the device with which the player/musician interacts. Various sensors may be used to capture human input that has very little, if anything, to do with the mechanism or acoustics of the produced sound. Though this would seemingly increase the possibilities for the design and developement of new controllers unfettered by the demands of the acoustic systems they control, in actual practice it seems to have been more of a hindrance in the developement of quality musical instruments with intuitive mapping.

Figure 3: Mr. Samong plays a Khaen using "extended" techniques.

This work has presented the design of an instrument that tries to use the acoustic information from the controller, and remap it for parameter control of a computer synthesis model—effectively preserving, but without be limited or restrained, by the acoustics on which it is based.

5. ACKNOWLEDGMENTS

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APPENDIX

A. MIXER DESIGN

The microphone signals must be added together before connecting them to the line level input of the laptop. Simpling placing the speaker outputs in parallel will overload the outputs and likely increase the distortion in the sound. A better approach is to create a very simple mixer circuit, which involves simply inserting the appropriate resistor (see Figure A.1) at the output before arranging in parallel.

Since the computer's line level audio input is stereo, two mixers can be used to sum the microphone signals from each row, and then input into the computer via the left and right channel.

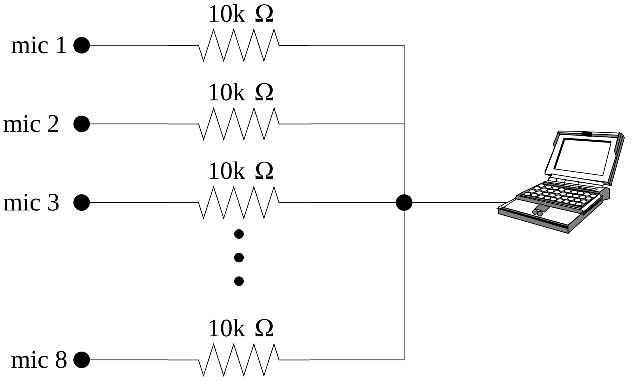

Figure 4: A simple mixing circuit for up to 8 input channels.