Musical Control of a Pipe Based on Acoustic Resonance

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ABSTRACT

In this paper, we introduce a pipe interface that recognizes touch on tone holes by the resonances in the pipe instead of a touch sensor. This work was based on the acoustic principles of woodwind instruments without complex sensors and electronic circuits to develop a simple and durable interface. The measured signals were analyzed to show that different fingerings generate various sounds. The audible resonance signal in the pipe interface can be used as a sonic event for musical expression by itself and also as an input parameter for mapping different sounds.

Keywords

resonance, mapping, pipe

1. INTRODUCTION

Electronic wind controllers have been designed to show the high expressiveness through the generation of various sounds. Fingering information is used in most of the controllers. However, breathing, which is an essential technique for traditional wind instruments, is an optional input parameter. Epipe[1] is an electronic woodwind interface that synthesizes sounds based on tone hole coverage information. The T-Stick[2] has the pipe like shape of a woodwind instrument. A performer can hold, shake, and turn the interface without breath. In The Pipe[3], breath pressure was considered to be a control input for musical expression by using a pressure sensor.

These digital wind controllers detect touch by a number of sensors such as force sensing resistor (FSR). Thus, a complex electronic circuit that controls the sensors needs to be placed in the controller. This makes the controller fragile. Moreover, the many sensors needed result in high development costs and always requires a computer to process the signals from the sensors.

To reduce cost and complexity, we proposed a musical interface that recognizes touches on a pipe by measuring resonance. The original purpose of this work was to develop an interface that creates sonic events by hanging clothes on a clothes airer. However, this paper only focuses on the detection of touches on a pipe without sensors.

This approach is theoretically based on Smyth's design of a musical input device based on the resonances of tuned parallel pipes[4]. In her design, a hole was pierced at one end of the pipe and a microphone was placed in the middle to determine whether the hole was closed or not.

Since the purpose of our work was to recognize the touch/ fingering pattern on multiple holes on a pipe, several holes were drilled along the pipe and two microphones were placed, one on each end of the pipe, to measure variations of the resonance.

The biggest advantage of this design is that only microphones are used. Since no sensors are used, the interface is a simple, durable, and not attached to electronics. Additionally, the signal from the microphone can be easily used on a computer as discussed in [4].

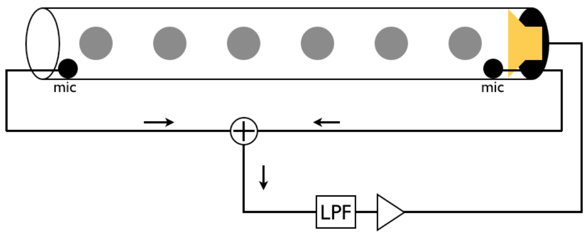

Figure 1: Design of the interface in which the measured sound signal is low-pass filtered, amplified, and played by a speaker unit to amplify the resonance in the pipe

2. DESIGN

Figure 1 shows the design concept of the interface. It included two microphones installed at both ends of the pipe. Signals from the microphones were mixed, low-pass filtered, and amplified. The reason for placing two microphones, one on each end of the pipe, was that the coverage of a hole on the opposite side of a microphone does not significantly change the resonance measured by the microphone. A low-pass filter was used to avoid unwanted excessive howling. The amplified signal was played through a speaker unit placed at one end of the pipe.

Based on the design concept, the interface was developed as shown in Fig. 2. On a PVC pipe of two meters in length, six tone holes (3 centimeters in diameter) were made along the pipe at 30 centimeter intervals. On each ends of the pipe, two pin microphones were installed. The signals from the two microphones were transmitted to a Mackie Onyx 1220 mixer, low-pass filtered by a mixer, amplified by a Pioneer M-1500 power amplifier, and played by a small speaker unit in the pipe.

Figure 2: Prototype of the interface

3. MEASUREMENT

When we started to operate the interface, we could hear the resonant sound. This sound changed as different tone holes were closed and continuously played. However, the generated sound was the same when closing the same tone holes. To demonstrate how the resonance signal is changed when closing different tone holes, the signals were measured and analyzed. Sounds from various tone hole fingering patterns were recorded (one second per each pattern) and analyzed by the fast Fourier transform (FFT). Figure 3 shows the magnitude spectrum when no holes were closed. In the figure, the lowest partial of 311Hz exists and multiples of the frequency were added to the partials of 690Hz and 622Hz. In particular, the partial of 1623Hz, which is the addition of the partial of 690Hz and the third multiple of the lowest frequency, is apparent in the graph, which has a magnitude of -20dB.

Figure 4 shows the magnitude spectrums while each hole was closed. Some signals that were recorded while the third, fourth, fifth, or sixth hole from the right side was closed (Figs. 4c, 4d, 4e, and 4f) have different timbres compared with the signal that was recorded when no holes were closed (Fig. 3). When comparing the magnitudes of the peaks around 311Hz, 1623Hz, and 4850Hz, the differences became apparent (Table 1). Other signals had partials of different frequencies. When closing the first hole, the one closest to the speaker unit, the lowest frequency was 265Hz (Fig. 4a). When closing the second hole, the lowest frequency was 327Hz (Fig. 4b).

Using these characteristics, a simple algorithm can be implemented to classify which hole is closed. At first, the frequency of the highest peak needs to be estimated from the magnitude spectrum. If the frequency is about 265Hz or 327Hz, the first or second hole is closed. If it is about 311Hz, then the second high peak needs to be estimated. If the magnitude of the peak is larger than -20dB, then the fourth hole is closed when the magnitude of the peak around 4850Hz is larger than -40dB and the fifth hole is closed when the magnitude of the peak around 4850Hz is less than -40dB. If the magnitude of the second peak is less than -20dB, then it is regarded that no hole is closed when the magnitude of the peak around 4850Hz is larger than -60dB, the sixth hole is closed when it is less than -90dB, and the third peak is closed when it is between -60dB and -90dB. This algorithm can be implemented using real-time FFT spectrum analyzer software.

Data was also gathered for more than one hole closed. When closing more than one hole, the signals showed clear distinctions in timbre and partial frequencies, as shown in Fig. 5. These sound samples are available at **http://aimlab.kaist.ac.kr/~asuramk88/pipe**.

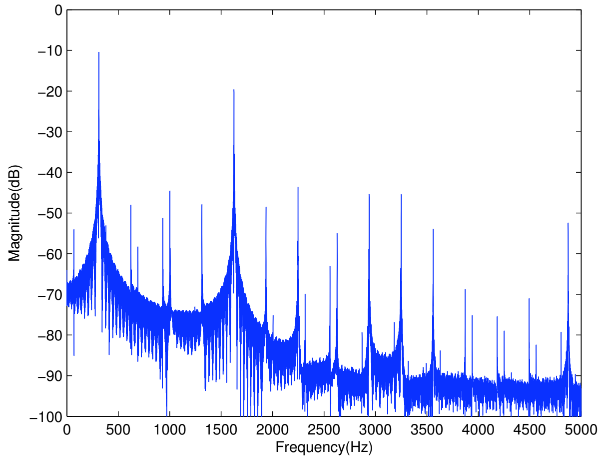

Figure 3: Magnitude spectrum of the resonance in the pipe when no hole is covered

4. APPLICATIONS

A characteristic of this work is that the users can hear sound without any mapping strategies in a computer. Moreover, the sound changes when closing the tone holes in different patterns. Thus, this work can be a musical interface by itself.

The original purpose of this work was to develop a musical interface by detecting clothes hung on the pipe interface. Based on the design, the interface was developed and exhibited in Incheon Digital Art Festival (INDAF), as shown in Fig. 6. It consisted of four pipe interfaces that worked as an interactive clothes airer installation. We used only one microphone in each pipe because the clothes covered more than two holes and changed the sounds audibly with only a single microphone whenever the closed holes were changed. For the audience to hear the resonant sounds clearly, four loudspeakers were also installed in front of the interface.

Information about the resonant sounds may be used for the source of mapping strategies to generate different sounds. The magnitude of each partial can be used as a parameter in how the holes are closed.

5. CONCLUSION

This work presents a musical interface based on the acoustic principle of woodwind instruments. Tone hole coverage of the pipe creates a resonance, and this system amplifies the resonance to generate audible sounds through a speaker unit in the pipe. The sound changes depending on how the tone holes are closed, so this system can be used as a musical interface by itself without any mapping algorithm.

While convenient and cheaper than using multiple sen-

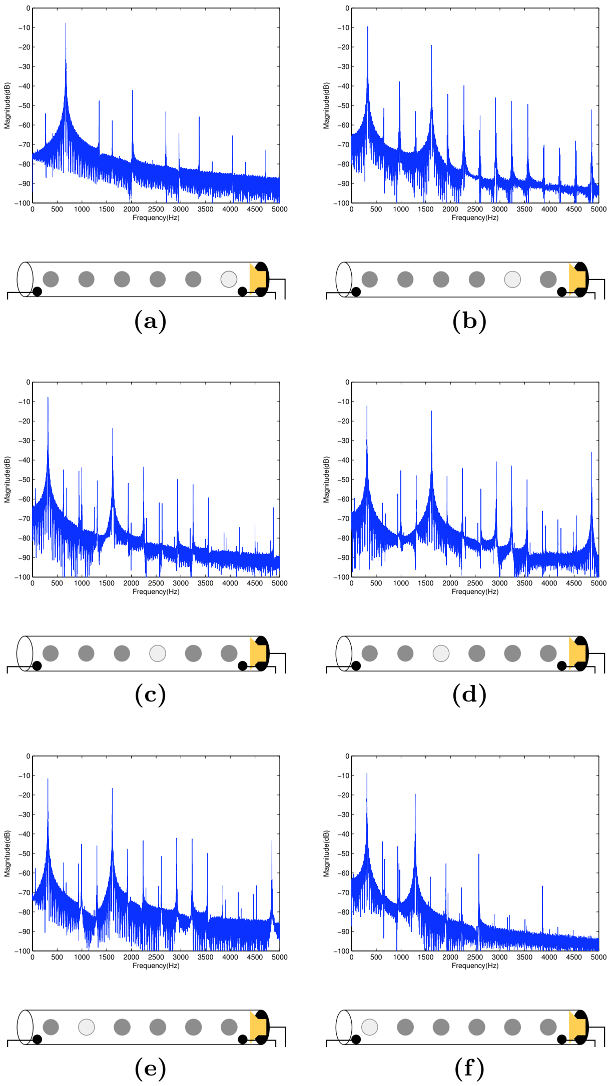

Figure 4: Magnitude spectrums of the signals that close each hole from right to left side

	311Hz	1623Hz	4850Hz
Fig 3	-10.48	-20.36	-52.42
Fig 4c	-7.78	-23.67	-64.29
Fig 4d	-12.14	-14.78	-36.02
Fig 4e	-11.61	-16.53	-43.03
Fig 4f	-8.81	-62.08	-93.22

Table 1: Comparison of dB magnitude of the peaks around 311Hz, 1623Hz, and 4850Hz among the signals having different timbre

sors, this interface has some limitations. One limitation is that the sound plays continuously without manual control of the amplifier. Thus, a computer is required to control the sound volume automatically using software. In addition, the mathematical principle of this work was not explained in full. Smyth[4] presented basic features, but we did not investigate phenomenon in depth once the resonant sound became more complex with two microphones. Further research is needed to determine the mathematics involved.

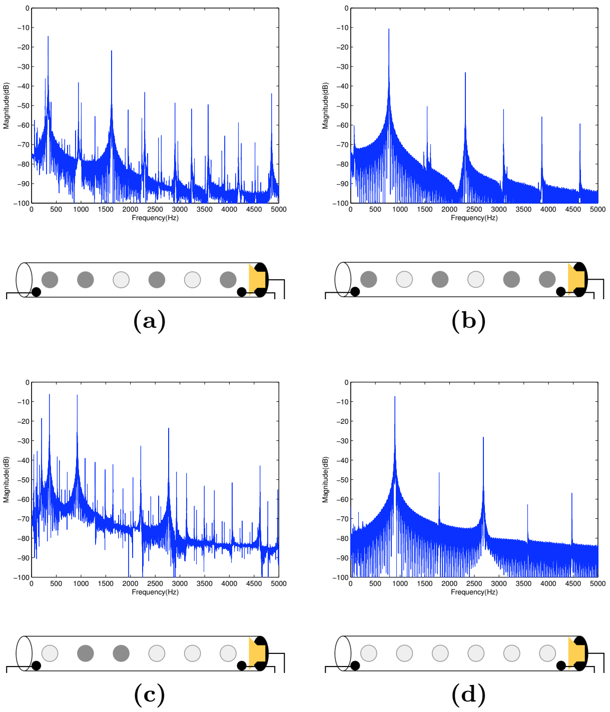

Figure 5: Magnitude spectrums of the signals that close the (a) second and fourth holes, (b) third and fifth holes, (c) first, second, third, and sixth holes, (d) all holes

Figure 6: The interface exhibited in Incheon Digital Art Festrival (INDAF)

6. REFERENCES

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