On the Use of Flute Air Jet as A Musical Control Variable

Andrey R. da Silva, Marcelo M. Wanderley and Gary Scavone
Sound Processing and Control Laboratory - Computational Acoustic Modeling Laboratory
Music Technology - McGill University
Montreal, Canada
andrey.dasilva@mail.mcgill.ca

ABSTRACT

This paper aims to present some perspectives on mapping embouchure gestures of flute players and their use as control variables. For this purpose, we have analyzed several types of sensors, in terms of sensitivity, dimension, accuracy and price, which can be used to implement a system capable of mapping embouchure parameters such as air jet velocity and air jet direction. Finally, we describe the implementation of a sensor system used to map embouchure gestures of a classical Boehm flute.

Keywords

Embouchure, air pressure sensors, hot wires, mapping, augmented flute.

1. INTRODUCTION

The extension of the musical possibilities based on the concept of augmented instruments has long been applied to flutes. However, the idea of using embouchure gestures as a way to control real-time digital audio effects has not yet been considered.

The embouchure technique is one of the most important skills developed by a flutist. This is because embouchure parameters play a significant role on the sound production mechanism of the flute. In fact, the style of flute schools is strongly defined by the way the embouchure technique is taught [9].

In the case of the Boehm flute, the most relevant parameters controlled by the embouchure are the air jet velocity and the air jet direction along the instrument axis [10]. The air jet velocity basically controls the roughness of the sound. Higher jet velocities produce more turbulence and, therefore, higher contribution of noise in the sound content, as reported by [8] and [7]. The direction of the air jet along the flute axis acts to change its acoustics characteristics in several ways. The most important characteristic is the variation of the input impedance[6].

The coming sections of this paper comment on previous works on augmented flutes, then on the possibilities of tracking embouchure variables.

For that we analyze several options of sensors that can be used to track velocity and direction of air jets in terms of sensitivity, dimension, accuracy and price. Finally, we present a detailed implementation of a sensor system that maps the embouchure parameters of the traditional Boehm flute and controls digital audio effects.

1.1 Previous Work

Some early examples of digital flutes were built not to act as extended versions of the traditional instrument but, instead, to merely act as digital controllers. One example, developed by Yunik et al. [12], implemented a microprocessor to scan ten keys (on/off switches) in order to produce single tones through the use of timing loops. The keying arrangement could be adjusted by the player. The attack, sustain and decay were controlled by the sound captured by a small microphone positioned inside the instrument's mouthpiece.

More recent works on digital flutes were done in a way to preserve the traditional characteristics of the instrument in terms of acoustics and, in the same time, to track musical gestures by the use of sensors mounted along the instrument body. The flute developed at IRCAM [4] is an example. It was implemented to track the fingering positions which were output through MIDI protocol. Another example within the same category is the The Virtually Real Flute by [11] . In fact, this was the attempt that most approached the purpose of using embouchure variables as interesting control parameters. In this case, a sense of the embouchure gestures could be indirectly derived from the pressure variations captured by a microphone placed inside the flute, precisely at the cork. The approach of using a microphone as a way to control variables by the embouchure had been previously implemented by Yunik [12], as already mentioned, although in a different context. Nevertheless, a more precise embouchure tracking, considering variables such as air jet velocity and particularly air jet direction, could not be done. One more example is the Hyper-Flute [3] which added to a classical Boehm flute a myriad of sound effects controlled by magnetic field sensors, ultrasound transducers, mercury tilt switches, FRSs, a light sensor and a microphone. In this case, however, the embouchure gestures were completely neglected as control variables, in that the microphone was used to simply acquire the flute sound.

2. TRACKING EMBOUCHURE

As previously mentioned, the most important variables controlled by the embouchure technique, in the case of the Boehm flute, are the jet velocity and the jet direction.

A number of methods can be used to estimate the velocity of confined air flows with a reasonable accuracy (flows completely bounded by solid surfaces). Nevertheless, such measurements become extremely tricky when the velocity is to be estimated from an open air jet, which is the condition of a flutist playing a flute. In this case, there is no velocity profile due to the absence of boundaries around the flow. Hence, the velocity can be only estimated in isolated points. Moreover, the velocity estimation becomes extremely sensitive to the position of measurement especially when the flow is highly turbulent.

2.1 Sensor Systems to Measure Embouchure

The specifications of a sensor system used to measure embouchure parameters, such as jet velocity and jet direction, will highly depend on the application of the measuring.

In the case of a musical controller, the level of accuracy is not considered to be a priority, because a reasonable amount of the system's inaccuracy can be compensated by the mapping strategy. Conversely, the sensor system used for this task has other, but not less important, requirements. In the first place, the sensor should be small enough not to disturb the air flow into the embouchure hole and hence, not affect the mechanism of sound production. Secondly, the sensor should be sensitive enough to measure small flow velocities or, equivalently, small stagnation pressures. In the case of the flute, the maximum velocity of a jet can vary between 15 and 20 meters per second[1]. Robustness is also a very important requirement of a sensor, especially when it is submitted to mechanical loads or conditions different of those of a laboratory, as is usually the case of musical controllers. Finally, the latency of the sensor should be smaller than 5 ms, which means that the sensor is able to track embouchure gestures up to 100 Hz [2].

In the other hand, the specifications of the system become very different when it is intended to be used in a laboratory, where the accuracy is usually the most relevant requirement.

A description of two families of sensors that can be used to measure embouchure parameters is presented below.

2.1.1 Hot Wire Sensors

Hot wire sensors are by far the most accurate class to measure air jet velocity. Their operation is based on the idea that the velocity of a flow can be estimated by the rate of cooling of a very thin wire due to the flow of fluid around it. The wire, of which the diameter is not greater than $5\mu m$, can be found in many configurations. Most commonly, the wire is embedded into a thin film (hot-film) to protect it against mechanical and chemical damage. Even so, hot wires are extremely fragile devices.

Although these sensors are very small and accurate, their application on musical controllers is limited for many reasons. First, hot wires are very expensive compared to other options (see Tab. 1), remembering that high accuracy is not a priority in this case. Secondly, because controllers are generally subjected to rough conditions and, in such a circumstance, a hot wire would not last long. More over, hot wires usually work connected to a huge electronic device that is used to continuously calibrate the temperature of the sensor. This issue could jeopardize the mobility required by a controller.

2.1.2 Pressure-Based Sensors

Pressure sensors are based on the idea that the velocity of a fluid at one point can be obtained by a relation between its stagnation pressure and its static pressure. Considering the flow to be incompressible, the Bernoulli equation can be written as:

$$\frac{p_0}{\rho} = \frac{p}{\rho} + \frac{V^2}{2} \tag{1}$$

where p, V, p_0, ρ are the static pressure, the velocity, the stagnation pressure and the density of the air, respectively.

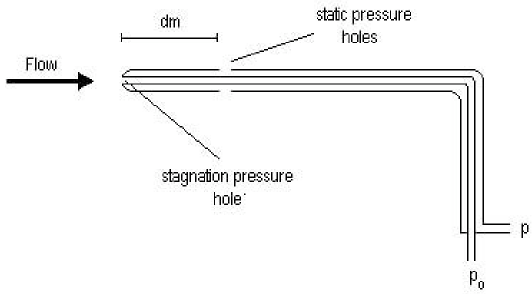

Figure 1: Scheme of a Pitot tube

The static pressure p is the pressure that would be measured by an instrument moving with the flow. One easy way to measure that is to attach a thin closed end probe to the pressure sensor input. The probe should have small holes on its side and should be positioned in a way that the cross section of the holes remain parallel to the flow. The stagnation pressure p_0 is obtained when a flowing fluid is decelerated to zero by a frictionless process. This can be measured by another probe with a single hole that faces directly the flow upstream (open end).

The Pitot tube (Fig. 2) aggregates both probes in one system. The probe terminations can be attached to a dual input pressure sensor, the sensitivity of which is chosen depending on the type of flow that has to be measured (see Table 1). However, Pitot tubes usually have a minimum size defined by the distance, dm (Fig. 2), in order to avoid turbulence around the static pressure holes caused by the stagnation tip.

This problem can be overcome if we assume that the static pressure p is equal to zero (see Eq. 1). That allows us to simply use stagnation probes to derive velocity values instead of using the whole Pitot system[3].

[1]The velocity values were derived by the Bernoulli equation by measuring the pressure values around the mouthpiece using a dual pressure sensor (All Sensor 1inchD4V)

[2]There is a controversy around the frequency threshold of embouchure gestures. It is claimed that some techniques, like multiphonics and extended range playing, may have higher spectral contents. More information can be found in [5]

[3]In fact, in the case of open flows, $p \ll p_0$. Thus p can be neglected from equation 1.

Although pressure sensors are not as accurate as hot wires, their application to musical controllers become more interesting for obvious reasons: pressure sensors are much cheaper (see Tab. 1); they are robust enough to support the mechanical loads of a controller; finally, they can also track direction of the air jet by correlating velocities measured with two stagnation probes placed in different regions.

2.2 What is Available?

A great number of sensors are available on the market. Table 1 summarizes some characteristics of the most common sensors in terms of price and sensitivity.

Table 1: Sensor spaecifications

type	manufacturer	sensitivity V/Pa	price aprox.
pressure	Fujikura	0.0005	US 20
pressure	Fujikura	0.0001	US 17
pressure	Motorola	0,0003	US 22
pressure	Motorola	0.00001	US 21
pressure	All Sensors	0.004	US 65
hotwire	TSI	-	US 413

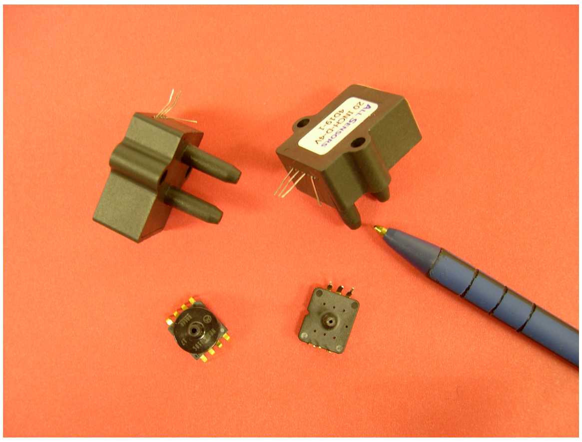

Figure 2: Some examples of pressure sensors

3. THE PROTOTYPE IMPLEMENTATION

Based on the descriptions previously presented, some simplifications of the controller were taken into account. In the first simplification we assumed the static pressure p to be equal to zero (see Eq. 1).

The simplification permitted us to use simple stagnation probes instead of using a Pitot tube. That allowed the sensor system to be less invasive, avoiding disturbance on the flow around the mouthpiece and, consequently, preserving the original sound of the instrument.

Two stagnation probes were connected to the pressure sensor (All Sensor 1inchD4V) whose sensitivity is 0.004 V/Pa. The sensitivity was chosen in order to allow the system to track jet velocities within the whole range (0 to 20 m/s). The open ends of the probes were then placed at the two extremes of the mouthpiece (Fig. 3) so that, besides measuring the stagnation pressure, it was also possible to track the orientation of the air jet in the flute axis direction by means of difference of pressure in each input. Such a measurement could not be achieved if we instead used a microphone.

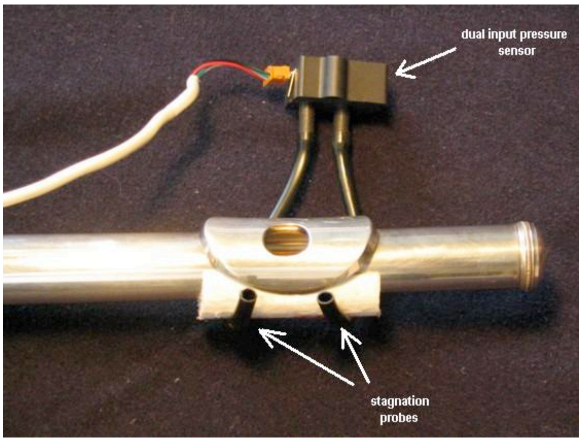

Figure 3: Preasure sensor and probes mounted around the mouthpiece

3.1 The System Setup

The system was implemented using a G4 Macintosh computer for the digital processing, an analog/digital MIDI converter (Atomic Pro), the double input pressure sensor, a force sensitive resistor (FSR), the feedback actuator and a microphone (Figure 4).

The microphone was used in this case to capture the flute's sound and send it directly to the computer via the audio port using a sample rate of 44.1 kHz.

The audio output channels were used as feedback conveyers. One of them was used for ordinary audio feedback (through a loudspeaker) and the other one to control the mechanical actuator (haptic feedback).

3.1.1 *Mapping*

At this stage, our intention was to evaluate the way the player would interact with the implemented system. The goal was to evaluate how difficult it was for the player to control the system and to perceive its feedback. The mapping strategy was developed using Max/MSP.

The idea was to create an interaction looping where each sensor should control only one digital audio effect (one-to-one)[2]. In this case, the breath sensor was set to control the frequency sweep of a comb filter, through which the input audio from the flute was passed. One of the breath sensor

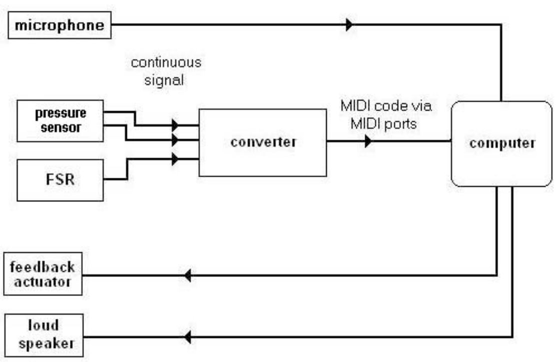

Figure 4: Scheme of the system implementation

input was set to sweep the frequency up and the other input was set to sweep it down. The rate in which the frequency was swept up and down was controlled by the jet velocity driven by the player.

This way, the player could control the flanger effect by simply changing the orientation of the air jet. The signal from the comb filter was passed through a delay line in which the number of delay samples was controlled by the FSR, mounted on the flute at the position of the right hand thumb.

3.2 Musical Considerations

One difficulty faced by our volunteer flutist while playing with the embouchure controller was to correlate her gestures with the sound feedback from the implemented system.

This usually happens when a musician is challenged to play an augmented version of his traditional instrument. The usual correlation made by the musician between gestures and auditory feedback becomes blurry.

For this purpose, we have implemented a haptic feedback system [1] which consisted on an electro 3.0 volts DC motor, commonly found in children toys. The motor was controlled by one of the audio channels output.

The audio channel used to control the actuator is fed with a pulse train signal whose peaks have enough amplitude to cross the threshold of photo-interrupter device composed of a diode and a light-sensitive transistor.

This setup also prevents any current flow back into the audio channel which could cause serious damage to the hardware.

The frequency of the pulse train is controlled by the breath sensor. By varying the frequency it is possible to control the power driven into the motor and, therefore, the intensity of its vibration. In other words, the energy put into the pressure sensor is fed back by the actuator (motor) in terms of vibration amplitude.

4. CONCLUSIONS

The idea of controlling digital audio effects by embouchure gestures was found to be a very interesting approach for gestural controllers, especially when dealing with the air-jet family of instruments.

As new control approach, many possibilities can still be explored, mainly related to the development of multiple and less invasive sensors to be placed around the mouthpiece.

The main difficulty for the player involved the correlation of control and feedback. The subsequent implementation of the feedback actuator, as previously mentioned, proved to significantly help in this regard.

In fact, this problem could be better overcome if the mechanical feedback system could be placed around the mouthpiece region.

Again, the requirement of a sufficiently small device is mandatory not to disturb the air flow and therefore, not to cause any effect on the flute's sound generation mechanism.

5. ACKNOWLEDGMENT

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