Developing experimental techniques and physical modeling for ethnomusicology project on Ouldémé flutes.

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Abstract

This paper is part of an ethnomusicology study of the Ouldémé flute players that was carried out by an interdisciplinary group. A virtual flute based on physical modeling and controlled by the flutists through a dedicated midi control interface has been developed. A description of the project and the physical model is presented together with preliminary experimental results on the Ouldémé flute functioning.

1 Introduction

A virtual flute based on a physical model and controlled in real-time by MIDI sensors has been implemented as part of a collaboration project with ethnomusicologists. The aim of the project is to better understand musical scales used by Ouldémé flutists from North Cameroon (Fernando 2000). Ouldémé culture is essentially oral, and the concept of musical analysis doesn't exist. Therefore, experiments with musicians are essential to better understand the underlying musical structure, including musical scales and more precisely the tunning strategy.

A typical female flute band is made by four or five women. Each one plays two flutes and sings one note before each blowing. Fine tuning is of crucial importance and each player spends a lot of time choosing the right flute among a lot of nearly similar ones.

1.1 Experimental protocol

From preliminary experiments carried out by ethnomusicologists, it was not possible to find a precise strategy concerning the tuning since no reliable scale could be extracted from successive frequency measurements. The idea of ethnomusicologists was then to use synthesis models of flutes, with precisely adjustable pitch so that they could both record player's pitch adjustment and test their reaction to an imposed detuning, in the spirit of the work done for xylophones from Central Africa (Arom and Voisin 1998).

Within this scope, we proposed to build a physical model of the Ouldémé flute to use for time domain sound synthesis. In order to avoid changing too much their habits of playing, we decided to create a controller for the physical model through gestural interfaces very close to real Ouldémé flutes and provide a synthesized sound as close as possible to the real one.

A description of the flutes functioning and some considerations on the model are described in section 2. Then , we focus on the real-time implementation of the model: the physical model, its implementation and the adjustment and control of the parameters are described in section 3 and section 4.

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2 Investigation on Ouldémé Flute Functioning

2.1 Description of the way of playing

The Ouldémé flute is a simple piece of cylindrical bamboo closed at one end, without toneholes, similar to the Latin American pan pipes or zampoñas. There is no particular cut for the mouthpiece. The length of each flute is chosen to match the desired playing frequency. For our set of flutes, the length varies from $14cm$ to $42cm$.

Placing the tongue outside of the mouth, the player shapes the air stream between her tongue and her upper lip, directed toward the edge of the cane, as shown in figure 1

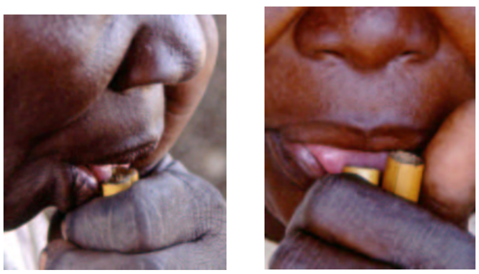

Figure 1: Ouldémé flutists.

Before playing, the inside of the flute is moistened creating a thin film of water. Its effect on the flute functioning is studied in section 2.2.

The Reynolds estimated from mouth pressure measurement together with lip opening evaluation was found to be of the order of $Re \simeq 6000$. This value together with the noisy sound produced by the flutes make us assume the presence of a turbulent jet. An experimental study aimed to characterize the behavior of the turbulent jet submitted to a transverse acoustical field has been initiated, and preliminary results are presented in section 2.3.

2.2 Adding water

Three effects of the addition of water have been considered.

First, like in many other bamboo instruments, the inner surface has to be moisturized in order to prevent air leakage due to the porosity of bamboo.

A second effect is the fine tuning of the flute. In addition to the frequency shift due to the decrease of the inner volume, the thin film of water in the inner surface produces a non-negligible effect. Indeed, impedance measurements made with wet and dry flutes show that the first resonance frequency (close to $300Hz$) is increased by 1.5% ($1/8$ of a tone, i.e. 25 cents) when they are wet. The third effect is the amplitude increment of the resonance peak by 9% for wet flutes. Therefore adding water on inner surface makes playing easier; effect that is well known among musicians.

2.3 Turbulent jet

Flue instruments like other sustained instruments, can be described as an excitation coupled to a resonator. The excitation consists of an intrinsically unstable jet which is directed toward a sharp edge, known as labium.

Instruments operating with a laminar jet have been widely studied and the literature on recorder-like instruments is important (see for example (Verge 1995) and (Fabre and Hirschberg 2000)).

However, this is not the case for instruments, like the Ouldémé flute and some other flutes used in traditional or popular music, which can be suspected to operate with a turbulent jet.

The behavior of turbulent jet and their coupling with the transverse acoustic field coming from the resonator is less understood than the laminar one. For that reason, an experimental study has been initiated (Lamoine 2001) oriented to better describe turbulent jets and its implications in the Ouldémé flute functioning.

2.3.1 Experimental setup

The aim of the experiment is to characterize the behavior of a turbulent free jet submitted to a transverse acoustic field. The jet is created by blowing compressed gas through a channel with rectangular cross section (Ségoufin 2000). The periodic acoustic field is induced by a pair of speakers, facing each other and connected in opposite phase. Stroboscopic visualization of the jet is done using the Schlieren technique. Filtering is applied to each image in order to determine the time evolution of the centerline of the turbulent jet, as shown in figure 2.

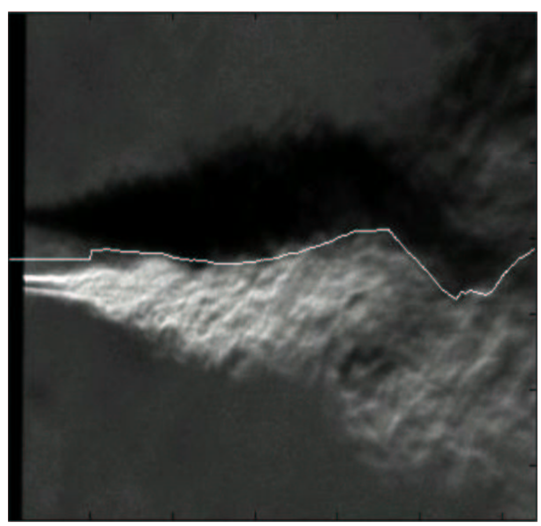

Figure 2: Center line detection by image filtering

The Reynolds number is controlled by varying the blowing pressure, while the Strouhal number is controlled by changing the driving frequency of the speakers. Experiments have been carried out for Re lying between 1000 and 6000, and for St lying between 0.01 and 0.03. Figure 3 shows a comparison between a laminar (low Re) jet and a turbulent (high Re) jet.

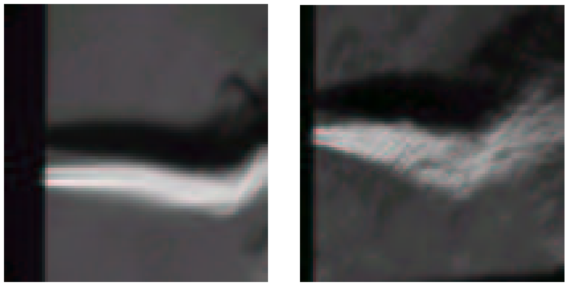

Figure 3: Jet under acoustic excitation by loudspeakers. Left: Laminar jet, Re = 600; Right: turbulent jet, Re = 4000

2.3.2 Preliminary results

It has been observed that the behavior of the turbulent jet is qualitatively similar to the behavior of a laminar jet in the sense that transverse waves propagate along the jet.

A relevant parameter to describe the behavior of the jet is the propagation velocity of the transverse waves traveling along the jet. Using Schlieren images, we have estimated this variable by measuring the speed of the intersection point between the centerline of the jet and an horizontal reference line. Measurements carried out for different Re (see figure 4) indicate that during the transition from a laminar to a turbulent regime, the velocity of hydrodynamics perturbations (adimensioned by the jet average velocity at the channel output, estimated using Bernoulli's equation) slow down by a factor 2. This result could explain the stability of the Ouldémé flute on the first regime of oscillation for a larger range of blowing pressures than the recorder. A decrease on the wave propagation velocity in turbulent jets was also measured by (Thwaites and Fletcher 1980) although the magnitudes found are different.

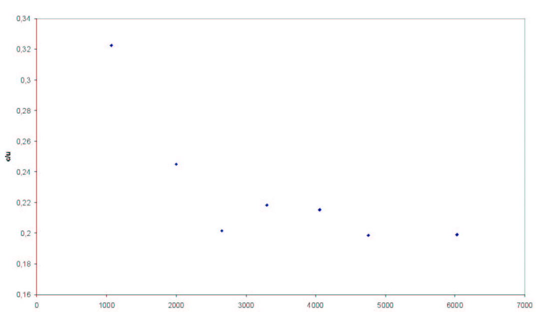

Figure 4: Influence of Reynolds number (Re) over the speed of the perturbations(c/u) for a constant Strouhal number (St=0,018).

Another relevant parameter to describe the jet is the amplitude of the jet deflection (adimensioned by the acoustic displacement) when it is submitted to periodic transverse perturbations. Experiments clearly indicate that a turbulent jet is far less sensitive to perturbations than a laminar jet. Like in the laminar jet, for a given Re, the sensitivity of the jet is highly dependent on the St number. For example, figure 5 shows the dimensionless amplitude of the jet deflection at a given distance from the channel output, for different St. .

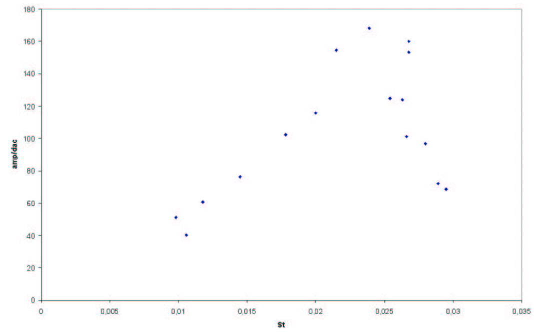

Figure 5: Influence of Strouhal number over adimensional amplitude, for a constant Reynolds number (Re = 2600).

2.4 Discussion - Toward a model of the Ouldémé flute

The effects of water inside the flute (discussed in section 2.2) can easily be included in a physical model by decreasing the equivalent length of the resonator and by lessening viscous losses.

Concerning the behavior of the turbulent jet, further investigations are now being carried out to refine the results presented above. However, these first results already provide us with a guideline concerning the physical modeling. Indeed, as discussed in section 2.3, transverse perturbations propagate along the turbulent jet. Clearly as seen in 2.3, compared to the laminar case, they propagate at a different speed and with different amplification along the jet. However these differences can be taken into account by different scaling factors in a physical model.

Therefore, within the context of a simple model, the well known model of recorder-like instruments can be adapted to the particular characteristics of Ouldémé flutes. This is done in section 3.

3 The model - Implementation

A one-dimensional model of a flue instrument (Verge, Hirschberg, and Caussé 1997) has been ported to MAX/MSP (Max/MSP 2000) and STK (Cook and Scavone 2000); two platforms that allow real time execution. In order to have control over the timbre, the implementations were designed allowing interactive manipulation of a set of relevant parameters.

The model is driven by the input pressure. The bore is modeled by a one dimensional waveguide (Smith 1992) using fractional delay lines (Hänninen and Välimäki 1996) to allow continuous pitch control. Low-pass digital filters are used to describe radiation and visco-thermal losses in the bore.

For the excitation, the following lumped elements are included:

- Jet-labium interaction, including the contribution of the acoustic field from the pipe, the direct hydrodynamic feedback from the edge of the labium, the amplification of the perturbations in the jet and its convection toward the labium.

- Vortex shedding at the labium is believed to be responsible for the major non-linear amplitude limiting mechanism of the pressure in the bore as well as the generation of high harmonics in the spectra.

- Turbulent noise is added by filtering white noise and scaling it by a constant depending on the jet velocity.

These elements model the most relevant features of the jet dynamics including the formation, velocity fluctuation and oscillations, as described in (Verge, Hirschberg, and Caussé 1997).

Even though there are some quantitative differences between the behavior of a turbulent and laminar jet (which could motivate the development of more specific models), the current model captures the common principle of operation and allows us to stretch its possibilities obtaining sounds that closely resemble those of the Ouldémé flute.

4 Adjusting and controlling the model

After exploring the influence of all the parameters on the synthesized sound the following set was chosen:

- Jet traveling distance before reaching the labium

- Jet position with respect to the labium

- Coupling gain; incidence of the jet injection over acoustic waves

- Vortex amplitude; damping effect caused by vortex shedding at the labium

- Cutoff frequency of visco-thermic losses filter

- Turbulent noise gain

The desired timbre was obtained by tunning these parameters and comparing the results with a recorded sound from the real flute.

To emulate a real performance situation, a cylindrical bakelite device was built keeping the dimensions of the original flutes. A differential pressure sensor has been inserted close to the embouchure of the flute to assure short delays in the response of the instrument. The blow is directed toward one edge of the flute, therefore the sensor was located near the upper side of the bore. It was necessary to create a conic shape to conduct the maximum amount of flow into the sensor. Analog amplification and low-pass filtering was used to create an envelope of the pressure signal. Another controller was designed to adjust the pitch of the synthesized sound. Two buttons have been inserted in the bore of the flute allowing the performer to raise or lower the pitch. Signals are then feed into an analog-to-midi interface (Fléty 2001) giving MIDI inputs for the input pressure and pitch of the model. The complete system is shown in figure 6 and figure 7

Figure 6: Synthetic flute with sensors.

Figure 7: Ouldémé flute players using synthetic flutes.

5 Conclusion

An ethnomusicologist study regarding the tunning strategy of the Ouldémé flutists has been assisted by the use of sound synthesis by physical modeling and real-time MIDI control.

Through a preliminary experimental study of the Oulémé flute functioning, it has been highlighted that a simple physical model could reasonably be derived from the (better known) model of recorder-like instruments. Parameters of the model have then been adjusted to produce sounds very close to natural sounds.

Efficient real time implementation has been performed allowing the use of up to ten instantiations of flutes with 30 MIDI controllers simultaneously using MAX/MSP in a Macintosh laptop (PowerBook G4, 400MHz).

It is worth noting that an alternative synthesis technique based on samples of their original flutes, was tested by Ouldémé players using the same MIDI control interface. The preferred synthesis technique was incontestably physical modeling, judged more natural by Ouldémé flute players.

As far as deeper understanding of Ouldémé flutes functioning is concerned, experimental studies on turbulent jet in transverse acoustic fields are being currently carried out.

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