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OPENWIND: A SOFTWARE TO SIMULATE WIND INSTRUMENTS, AS A TOOL FOR ACOUSTIC TEACHERS

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ABSTRACT

Openwind is a python library, (free and open source) dedicated to the simulation of wind instruments. It provides the computation of the acoustic response in the frequency domain (impedance or admittance) or in the time domain (impulse response), from the geometry of the instrument (main bore, side holes, valves) . Several models are implemented and gives the possibility to take into account thermo-viscous losses, several radiation conditions etc. It is also possible to perform a sound simulation of brass and reed instruments. A graphical interface freely available online (<https://demo-openwind.inria.fr>) gives the possibility to perform frequency domain simulations without coding.

After having presenting the main features of the python library and the associated documentation, we will focus on the graphical interface through the presentation of a pedagogical activity. During this course proposed by the ITEM (school for instrument makers), the students in musical instrument making were asked to study several problems common in wind instruments, and especially the optimization of the main bore or the position of the side holes. From geometry design to impedance curves and resonances analysis, we will present how students learn to implement a general methodology for solving problems in wind instruments using this virtual prototyping tool.

Keywords: *musical acoustics, simulation, graphical user interface*

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1. INTRODUCTION

Openwind (for open Wind INstrument Design) software is an open-source (GPL-v3) python library available for free: <https://openwind.inria.fr> [1]. It aims at solving state-of-the-art models in musical acoustics for wind instruments with accurate, robust and efficient techniques from scientific computing science and numerical analysis. It allows the direct computation of the acoustic response in the frequency domain (input impedance) of a given instrument (knowing its main bore and side holes geometrical parameters), or of the sound of this instrument when coupled to different types of oscillators (reed, lips). It also relies on inversion techniques used in the field of geophysics (Full Waveform Inversion, [2]) to perform reconstructions from measurements and investigate some sensitivity characteristics of the instruments.

Initially, the purpose of this library was to propose a collaborative tool for researchers from musical acoustic community, as still currently, the usual practice is to re-implement in each laboratory, similar models with small individual specificities. A second objective was to provide a virtual workshop to manufacturers. As these users are often not familiar with coding, a graphical user interface (GUI) has been developed and is freely available online (<https://demo-openwind.inria.fr>).

In addition to these two communities, some acoustics teachers took advantage of these tools to build educational activities around the acoustic of the musical instruments. For example Morrison and Worland [3] designed an educational laboratory activity on the acoustic of brass instruments using Openwind library to illustrates the link between the geometry of the instrument and its acoustic properties. The activity presented this time has been designed in the context of the training of instrument makers

in ITEM. This uses the GUI to help the future manufacturers to understand the relation between the geometry of an instrument, the distribution of the energy along its main bore and its frequencies of resonance.

After a short presentation of the features of the python library and the GUI in sections 2 and 3, the educational activity addressed to the future instrument makers of ITEM is presented in section 4.

2. THE PYTHON LIBRARY

2.1 What is behind

Finite Elements Method (FEM) is used in Openwind to perform the spatial discretisation of the one-dimensional (1D) pipe equations [4]: telegraphers' equations with visco-thermal effects, or their approximations [5–7] [8, Chap.5]. The presence of side holes, valves (pistons) are modeled by using pipe junctions including acoustic reactances and inertances to model the distribution of the acoustic energy between the pipes [9]. The radiation of each opening is modeled through radiation impedance [10]. Several radiation conditions can be used (infinite flanged, unflanged, semi-open hole, etc). With some constraints on the radiation models, a technique computing directly the modal parameters from the FEM discretisation [11] has been also implemented. It gives directly access to the frequency, the quality-factor and the magnitude of the impedance resonances.

The FEM constitutes a variational approximation of the pipe equations, suitable for energy consistent time-stepping strategies allowing the coupling with various elements such as nonlinear oscillators, pipe junctions or radiation conditions (see [12]). The FEM generalizes the method used in [13] where a low order approximation is performed. A one-degree-of-freedom oscillator modeling the reed or lips has been implemented in Openwind, allowing the simulation of the sound of brass or reed instruments. This necessitates to estimate the values of the oscillator parameters adapted to the studied instrument, which can be challenging in itself.

Moreover, the FEM formulation provides an efficient framework for the computation of the gradient of the acoustic field with respect to design parameters, as the bore radius or the side holes parameters (see [14]). This gradient can be used to perform bore reconstruction (estimate the geometry of the instrument from acoustic measurement) by designing optimization problem. This necessitates a good first guess of the geometry to reach the

expected local minimum. This has been used, for example, to guess the inner geometry of an historical trumpet [15].

2.2 How to use it?

The python library is divided in several modules dealing with the three main features describe above (computations in frequency domain, time domain and inversion), the interpretation of the geometry files, the meshing of this geometry, the physical models (approximation, inclusion or not of several effect), etc. The organization of the library and the detail of each class, method, etc is described in the online documentation available from the main website [1].

This documentation provides also basic tutorials and several examples (“how to”) to help get started with the software. For example, one file describes how to tune the temperature along the main bore of the instrument (uniform or not). Computations can be performed very simply with high level methods, without the necessity to fully understand the articulation between all the modules of the library. For example, the input impedance of a 50 cm long conical pipe, with inner radius from 7 mm to 15 mm can be computed and plotted with the following lines:

```
import numpy
from openwind import ImpedanceComputation

# define freq. axis and pipe geometry
freq = numpy.arange(50, 5001, 1)
geom = [[0, 0.5, 7e-3, 15e-3, 'cone']]

# perform the computation
res = ImpedanceComputation(freq, geom)
res.plot_impedance() # plot the curve
```

3. THE GRAPHICAL USER INTERFACE

For people who are not familiar with python coding, a GUI has been developed giving access to some features of Openwind (Fig. 1). It is freely available online: <https://demo-openwind.inria.fr> [1]. Currently only the frequency domain simulations can be performed with this interface.

In a first part, the geometry of the instruments can be specified. It is divided in three tabs for the main bore, the holes and valves (pistons) and the fingering chart. Some examples can be loaded to illustrate how to fill these forms. The geometry can be saved locally and re-upload later if necessary.



Figure 1. Screenshot of the GUI, freely available online.

In a second part, different options can be chosen before to perform the impedance computation: the fingering applied, the temperature, the frequency range, the radiation conditions, etc. The resulting impedance is then plotted (Fig.1). In a last part the resonances characteristics are displayed (magnitude, Q-factor, frequency and the corresponding pitch). For each of them, the acoustic fields (pressure and flow) along the main bore are also plotted. All these results can be downloaded and saved locally.

4. A TEACHING ACTIVITY FOR INSTRUMENT MAKERS

As presented in [3], this library can be used to illustrate some acoustical concepts in college or university courses. Here a different approach is presented, as it stands for the musical instruments making context. The students of ITEM institute learn instruments making and especially wind instruments. They are familiar with some basic concepts of acoustics like the input impedance and its relation with the geometric parameters of the instruments.

Among the common problems in wind instrument repair, making missing parts without information about them can be complex. It is a matter of determining the right geometry to give the right pitch and other characteristics. The virtual prototyping enabled by Openwind, and in particular the online version, allows multiple tests to be performed before finding the right geometry without having to manufacture the actual part or instrument. This virtual trial and error process saves a lot of time and

materials, which is important for their future professional activity.

Two activities using Openwind are proposed in the teaching of the ITEM. For the first one, an initial geometry made of a conical part and a cylindrical part is given. The instruction is to modify this instrument so that its resonances are as harmonic as possible (integer ratio between the resonance frequencies). To do this, the students calculate the impedance of the initial geometry, analyze the resonance frequencies and the ratio between them. They then modify the proportion between the conical part and the cylindrical part until they obtain the desired result.

The goal of the second activity is to tune a specific frequency of resonance of a given fingering without detuning the other resonances. To do this, students must determine the position and size of a side hole. The presence of a side hole, even if it is closed, can affect the frequency of other resonances, and thus the pitch of other notes. To avoid this, the teacher explains that a local modification of the diameter of a hole does not affect the frequency of a given mode (and thus the pitch of the note) if its position corresponds to a pressure node of this mode, which can be easily checked with the GUI. The "acoustic fields" part of the graphical interface, which displays the evolution of the pressure in the instrument, and thus the position of the nodes for all resonances, is very useful here to see which modes can be altered by the modification of the hole geometry.

In a future work with students, it will be interesting to develop other way to solve problems using an hybrid ap-

proach with the bore reconstruction module of Openwind (taking into account experimental impedance curves) and the method described earlier.

5. CONCLUSION AND PERSPECTIVE

In its current state, the Openwind library and the GUI can already be used in teaching activities. To our knowledge, it has been used mainly to teach the acoustics of musical instruments at universities and in training courses for instrument makers, but also in secondary schools for student projects. We believe that this toolbox could also be useful for more general courses in acoustics or physics, for example to illustrate the concept of mode and resonance, or their dependence with the geometry or the temperature.

The development of both the library and the graphic interface still continues. Openwind is used every day by the team to carry out the research activities on wind instruments and new functionalities are released regularly. We would like to propose soon tutorial videos both for the python library and the GUI. If some features are missing for a specific use, suggestions can be made to the team. As Openwind is an open source software, everybody can also join the Gitlab project available from the main website [1] and becomes a collaborator to help developing the software.

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