2018-00405 - Post-doctoral - Optimal design for wind musical instruments using the full waveform inversion

Level of qualifications required: PhD or equivalent
Fonction: Post-Doctoral Research Visit

About the research centre or Inria department

Magic-3D was created to apply in different geophysics, and particular seismic wave propagation. First, advanced models have been developed in order to take into account the complexity of underlying phenomena. Second, these models can be applied to realistic cases that require the solution of large systems, which in turn require that numerical methods have been optimized.

Context

Scientific priorities: Modeling and Simulation
Scientific Research context:

Makers have improved musical instruments for centuries by a "trial and error" procedure, where the final sound and playability were the main criteria. Since a few decades, musical acoustics has tried to rationalize this established empirical knowledge, understanding the reasons for past evolutions, and contributing to future evolutions thanks to a scientific approach. Indeed, our advanced understanding of acoustic phenomena, associated to considerable resources allocated to numerical analysis, now allows to explore unprecedented dimensions in musical instrument design. Regarding wind instruments, it is nowadays possible, thanks to physical models, to precisely model and simulate the acoustical behavior of the instrument from the only knowledge of its interior geometry (bore). If this direct model is realistic enough, we can then consider the inverse problem, which is to find which instrument(s) corresponds to a targeted acoustical characteristics set. Optimization strategies must be developed in order to seek, in pre-defined design spaces (as large as possible), the ideal instruments based on the full waveform inversion technique. The objective of this project is therefore to overstep the constraints of usual instrumental handcraft making, by building for and with the makers a "virtual workshop" in which new ideas can be virtually tested and evaluated before being effectively constructed via handcrafted techniques but also modern tools as additive synthesis (3D printers).

Assignment

This research program follows the work done in the team since July 2017. We have now (1st Feb 2018) implemented a finite elements direct model and are currently comparing it with existing methods in the literature. Before July, we aim at developing a « prototype » for inverting a musical instrument bore aiming at a « toy cost function » in order to make a proof-of-concept regarding the use of full waveform inversion for musical instruments. This research program should extend the current work to the real-life application, in collaboration with makers and experimental acoustic researchers.

Scientifically, this is a highly trans-disciplinary topic since it involves several major components: acoustics, model reduction, numerical analysis, inverse problems and psychoacoustics. We collaborate with the academic research team I2M University of Bordeaux. Regarding societal impact, we collaborate directly with makers in Dordogne (Augustin Humeau, bassoon) and Oise (Luc Gallois, trumpets). We are also in direct contact with the national professional cluster ITEMM (Le Mans) that trains the future makers and organizes meeting days between scientific researchers and makers.

Main activities

Depending on the candidate's skills, the work will include the next steps:

- A deep understanding of acoustic phenomena requires the derivation of a reliable and realistic model, followed by its robust and efficient discretization. We aspire to keep improving the existing pipe models (radiation condition, multimodal coupling, etc...) thanks to an experimental study off, first, simple, and then, complex shapes, via a collaboration with Samuel Rodriguez (entry impedance measurement, I2M, Bordeaux). We wish to extend the domain of validity of the reduced models (Webster equation with visco-thermal losses) thanks to state-of-the-art numerical methods (high order spectral FEM in harmonic and time domain), based on mathematical proofs of robustness for the proposed algorithms (energy-based for the time domain)

- A crucial point is then to properly define the underlying design problem: what are the important objectives for the maker and for the musician? Which instrument parameters do
we want to modify? We are lucky to work hand in hand with makers on this part of the project, because no matter the scientific quality of the work, its value for musicians is inseparable from this expert eye. Once the target cost function is established, we wish to implement the full waveform inversion procedure and compare it with various other optimization methods as neuronal networks (fed with direct numerical simulations), or more classical optimization techniques

- The optimal instruments will be prototyped by the makers using usual handcrafted techniques and/or additive manufacturing (3D printers). The prototypes will be evaluated quantitatively by acoustical measurements (entry impedance) realized in collaboration with I2M and actual sound played by real musicians. Perceptive tests will evaluate, in a musical context, the effects of the chosen modifications on the final sound and instrument's playability, in collaboration with the makers

**Keywords**: full waveform inversion, optimal design, numerical analysis, wind musical instruments, manufacturing

**References**:


**Skills**

**Required knowledge and background**: optimization, numerical analysis, psychoacoustics, musical acoustics, acoustic measurements, a pronounced taste for trans-disciplinary subjects, relation with non-scientific actors

**Benefits package**

- Subsidised catering service
- Partially-reimbursed public transport

**Remuneration**

2653€ / month (before taxes)