

Title:

Brass instrument bore optimization via Machine Learning and physics-based sound simulations.

Supervisors:

Advisor : Jean-François PETIOT (Professor, Ecole Centrale de Nantes, LS2N (UMR CNRS 6004)) – Jean-Francois.Petiot@ec-nantes.fr

Co-advisor: Vincent FREOUR (Yamaha R&D division / LMA (UMR CNRS 7031)) – vincent.freour@music.yamaha.com

Place of internship:

Laboratoire des Sciences du Numérique de Nantes, LS2N (UMR CNRS 6004) – Ecole Centrale de Nantes, 1 rue de la Noë, BP92101, 44321 NANTES Cedex 3

2 or 3 missions to the Laboratory of Mechanics and Acoustics (LMA) in Marseille must be planned during the internship

Regular online meetings with YAMAHA corporation (Japan) will be organized during the internship

Duration: 6 months (between March and September 2024)

Gratification: in agreement with the minimum required (4,05€/h)

Language: English

Skills: numerical methods, machine learning, acoustic of brasses

Abstract

Sound simulations by physical models are interesting to transcribe the physics underlying the functioning of a musical instrument. These simulations make it possible to listen to a virtual instrument with a mode of operation representative of the interaction musician/instrument (driving a sound by the causes that create it). The work consists in studying the contribution of machine learning methods in the understanding of the relationships between the shape of an instrument and the sound produced, in order to "optimize" the shape of an instrument according to different perceptual dimensions (intonation, ease of emission, dimensions of timbre, etc.). The application concerns the brass instruments (trumpet, trombone). The method could be interesting to assist instrument making and to customize instruments. A partnership with Yamaha corporation (Japan) is planned in the frame of the internship. Yamaha will provide different case studies and the development of prototypes.

Keywords: user-centered design, acoustics of brass instruments, sound simulations, psychoacoustics, machine learning

Description

For the development of new instruments or their optimization, it is important to be able to predict during the design phase how a future product will be perceived by the musician. In this context, sound simulations by physical models constitute a very interesting approach because they allow, by working on a virtual prototype, to explore the design space, creating a large number of virtual instruments. The main interest of these simulations is that the sound result is driven by the causes that create the sound, as for a real instrument: if the physical model used is detailed enough to generate simulations in agreement with the real behavior (such as it is perceived by the musician), then the simulations can constitute a predictive tool for the development of the instrument (virtual acoustics) [4].

The project focuses on the brass instruments (the trumpet), for which a previous study was conducted in 2023 [8, 9].

In the continuation of this previous study, the objective of the project is to model the relationships between the sound of an instrument (characterized by descriptors such as the intonation, the timbre, ...) and the shape of the resonator (called the bore). Machine learning models will be fitted to a training set of virtual instruments, simulated with a classical physical model already developed in the teams of the supervisors [1-2-3].

The work will consist of the following stages:

1. **Generation of sounds.** Sound simulations by physical model are used to create a database of sounds, with the shape of the resonator as input and the sound signal as an output. This stage includes the calculation of the input impedance of the resonator. Different features will be considered to describe the sounds (spectral centroid, MFCC, inharmonicity, intonation, ...). In this stage, implementations of temporal simulations, already available in the teams of the supervisors, will be used. Non-linear propagation in the resonator might also be included.
2. **Supervised learning.** A model is fitted to the database, with the shape of the resonator (bore geometry) as an input and the different features as outputs. Different (classical) methods will be tested (regularized regression, Multilayer perceptron (MLP), neural networks, SVM, ...) [5-6-7],
3. **Optimization.** An optimization of the bore geometry is carried out, for a given target of the features, using the previous model. Different gradient-free methods can be implemented (Genetic Algorithm, Nelder Mead simplex, Rosenbrock method, ...) [10],
4. **Validation.** The objective of this last stage is to verify that the optimized bore, obtained in stage 3, produces sound features close to the target, using sound simulations.

5. **Validation with a prototype.** After the manufacturing of the shape of the resonator, tests with musicians can be carried out to test the optimized bore.

This work is a first step to be able to include simulations by physical model in the design process of musical instruments. According to the interest of the student, perceptual tests could be carried out to assess the ability of sound simulations to represent the functioning of real instruments.

Short Bibliography:

- [1] Poirson Emilie. Prise en compte des perceptions de l'utilisateur en conception de produit. Application aux instruments de musique de type cuivre. Thèse de l'Ecole Centrale de Nantes, 2005.
- [2] Tournemene Robin. Optimisation d'un instrument de musique de type cuivre basée sur des simulations sonores par modèle physique. Thèse de l'Ecole Centrale de Nantes, 2017.
- [3] V. Fréour, L. Guillot, H. Masuda, S. Usa, E. Tominaga, Y. Tohgi. Numerical continuation of a physical model of brass instruments: Application to trumpet comparison, *Journal of the Acoustical Society of America*, 148 (2), 2020, pp 748-758
- [4] Petiot J-F., Gilbert J. Comparison of trumpets' sounds played by a musician or simulated by physical modeling. *Acta Acustica united with Acustica*. Vol. 99, (2013), 629-641. DOI 10.3813/AAA.918642
- [5] I. Maliki and Sofiyandudin. Musical instrument recognition using Mel-Frequency Cepstral Coefficients and learning vector quantization. *IOP Conf. Series: Materials Science and Engineering* **407** (2018) 012118
doi:10.1088/1757-899X/407/1/012118
- [6] Orchisama Das. Musical instrument identification with supervised learning. <https://www.semanticscholar.org/paper/Musical-Instrument-Identification-with-Supervised-Das/a20807d98e25a95c942507b547b141ea4215ec48>
- [7] Babak Toghiani-Rizi, Marcus Windmark. Musical instrument recognition using their distinctive characteristics in artificial neural networks, 2016. EndFragment.
- [8] Misael ROATTA. Contribution of Machine Learning and physics-based sound simulations for the customization of brass instruments. Rapport de TFE, Ecole Centrale de Nantes, septembre 2023.
- [9] J-F. Petiot, Misael ROATTA, Vincent Freour. "Contribution of Machine Learning and Physics-based Sound Simulations for the Characterization of Brass Instruments". In: *Forum Acusticum 2023* Turin, september 2023.
- [10] Alistair Braden. Bore optimization and impedance modelling of brass musical instruments. PhD thesis, University of Edinburgh, 2006.

Short CV of the supervisors

A) Jean-François PETIOT (Professeur, Ecole Centrale de Nantes, LS2N (UMR CNRS 6004))

Research themes

Design science; user-centered design; musical acoustics

Publications (extract)

Jean-François PETIOT. A genetic approach for the interactive design of sounds: Application to electric vehicles. In *Non Food Sensory Practices*. Edited by Anne-Marie Pensé-Lhéritier, Irène Bacle, Julien Delarue. ELSEVIER, Woodhead publishing series in Food Science, Technology and Nutrition, 2021.

Félix Gontier, Vincent Lostanlen, Mathieu Lagrange, Nicolas Fortin, Catherine Lavandier, and Jean-François Petiot, "Polyphonic training set synthesis improves self-supervised urban sound classification", *The Journal of the Acoustical Society of America* 149, 4309-4326 (2021) <https://doi.org/10.1121/10.0005277>.

Tournemenne R., Petiot J.-F., Talgorn B., Gilbert J., Kokkolaras M. Sound simulation-based design optimization of brass wind instruments. *J. Acoust. Soc. Am.* 145(6), June 2019. DOI: 10.1121/1.5111346.

Lafay, G., Rossignol, M., Misdariis, N., Lagrange M., Petiot J.-F. Investigating the perception of soundscapes through acoustic scene simulation. *Behavior Research Methods*, 2019, 51(2), 532-555. <https://doi.org/10.3758/s13428-018-1138-0>.

Gloaguen, Jean-Rémy ; Can, Arnaud ; Lagrange, Mathieu ; Petiot, Jean-François. Road traffic sound level estimation from realistic urban sound mixtures by Non-negative Matrix Factorization. *Applied Acoustics*, 143, (2019), 229-238, doi: 10.1016/j.apacoust.2018.08.018

B) Vincent FREOUR (Researcher, YAMAHA Research & Development division)

Research themes

Musical acoustics; nonlinear dynamical systems; biomechanics of music performance

Publications (extract)

Freour, V., Guillot, L., Masuda, H, Vergez, C. and Cochelin B. (2022). Parameter identification of a physical model of brass instruments by constrained continuation, *Acta Acustica*, 6, No. 9. <https://doi.org/10.1051/aacus/2022004>

Freour, V., Gautier, F., David, B. and Curtit, M. (2015). Extraction and analysis of body-induced partials of guitar tones, *Journal of the Acoustical Society of America*, 138, No. 6, pp. 3930-3940

Mansour, H., Freour, V., Saitis, C. and Scavone, G.P. (2015). Post-classification of nominally identical steel string guitars using bridge admittances, *Acta Acustica united with Acustica*, 101, No. 2, pp. 394-407.

Hezard T., Freour V., Causse R., Helie, T. and Scavone, G.P. (2014). Synchronous multimodal measurements on lips and glottis: comparison between two human-valve oscillating systems, *Acta Acustica united with Acustica*, 100, No. 6, pp. 1172-1185.

Bianco, T., Freour, V., Cossette, I., Bevilacqua, F. and Causse, R. (2012). Measures of facial muscle activation, intraoral pressure and mouthpiece force in trumpet playing. *Journal of New Music Research*, 41, No. 1 , pp. 49-65.

Cossette, I., Fabre, B., Freour, V., Montgermont, N., Monaco, P. (2010). From breath to sound: linking respiratory mechanics to aeroacoustic sound production in flutes. *Acta Acustica united with Acustica*, 96, No. 4, pp. 654-667.