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# APPLICATION OF SOUND SYNTHESIS OF PIANO TONES TO STUDY THE VIBROACOUSTICS OF PIANO SOUNDBOARDS

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## ABSTRACT

We present the framework of MAESSTRO, which is a software for the Computer-Aided Design of piano soundboards. Based on sound synthesis of piano tones using physical models, it aims at assisting piano makers by providing them the opportunity to predict the mechanical behavior of virtual soundboards and the resulting sounds of the piano in playing situation. The software is designed so that the synthesized tones reflect faithfully the mechanical and geometrical properties of the soundboard. It uses physical models that numerically simulate the phenomena that are involved in the production of piano sounds, from the impact of the hammer on the string to the radiated sound. We present applications that show the different functionalities of the software, including computing the modal basis of soundboards, studying the driving point admittance along the bridges, and the homogeneity of acoustic features along the tessitura. These applications are helpful to study the mechanical and acoustical impacts of structural modifications of a virtual soundboard.

## 1. INTRODUCTION

Many studies have been made in the past in order to fully comprehend the production of piano tones, including the vibroacoustic behavior of the soundboards [1–5] or the string dynamics [3, 6–9]

These studies allowed several models to be available for the purpose of numerically simulating separately the mechanisms of the piano tone production chain, from the hammer activation to the radiated sound. By gathering some of these different numerical methods, a framework of a program for the Computer-Aided Design (CAD) of piano soundboards is presented in this paper. It is solely based on physical models of the instrument in playing situation, and thus provide to piano makers a simple tool to predict the acoustic characteristics of a virtual piano, in regards to its specific geometry and to the mechanical properties of the materials that compose the soundboard and the strings. This CAD program is made available for any piano maker or academic researcher in the form of a software, called MAESSTRO<sup>1</sup>, which offers several functionalities to as-

<sup>1</sup><https://www.maestro.cnrs.fr>

sist the piano maker in the design process.

## 2. PRESENTATION OF MAESSTRO

MAESSTRO is a software for sound synthesis of piano tones based on a complete vibroacoustic modeling of the piano. It includes several functionalities which are: i) Graphical User Interface (GUI) for entering the geometry of the virtual soundboard, ii) feeding MAESSTRO with MIDI files to be synthesized, iii) numerical simulations of the piano tones with physical models, iv) analysis of the software outputs, and v) creating audio files of synthesized piano tones.

### 2.1 Graphical user interface

The software needs data about the geometry of the virtual soundboard and about the mechanical properties of its materials, which are gathered into a geometry file in a normalized format (JSON). In order to assist the user to build this geometry file, a specifically designed GUI has been developed in TypeScript with React language with the help of Logilab. It consists in a single-page application available from any web browser<sup>2</sup>, in which the user can draw the contour of the panels, the ribs and the bridges. The variation of the width and the thickness of the bridge along its median line and the mechanical parameters are also edited directly in the GUI.

### 2.2 Computation of the modal basis

Currently, the software proposes two different methods to compute the modal basis of the soundboard: a semi-analytical method derived from Trevisan *et al.* [5], which requires strong simplifications of the soundboard geometry, and a finite-element method, derived from the models proposed by Chabassier *et al.* [3].

The finite-element method uses the C++ library Montjoie<sup>3</sup>. The mesh is generated automatically by the software GMSH [10] according to the geometry file created

<sup>2</sup><https://maestro.demo.logilab.fr/>

<sup>3</sup><https://www.math.u-bordeaux.fr/~durufle/montjoie/>

in the GUI. The finite-element method uses a Reissner-Mindlin model of a clamped soundboard at its boundaries to compute the modal basis.

### 2.3 Simulation of the string dynamics

The string dynamics is simulated with a specifically designed module which uses the finite-element code Monjoie [3]. It considers a Timoshenko model to account for the string stiffness, and the geometrically exact model to account for non-linearity due to local geometric deformation of the string. In order to accurately model the string-soundboard coupling, the modal basis of the soundboard should be computed prior to simulate the string displacement.

### 2.4 Computation of the acoustic radiation

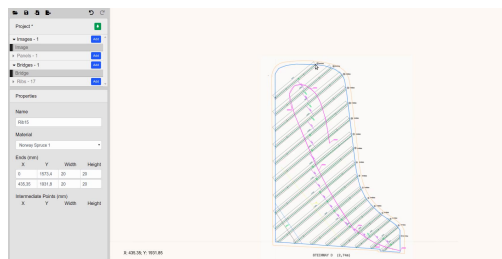
Once the displacement of the string is simulated, the transverse force applied to the bridge can be computed, as well as the resulting soundboard dynamics. The final step consists in computing the radiated sound pressure at a specific spatial coordinate in a three dimensional pressure field around the soundboard. The software uses the Rayleigh integral assuming the soundboard is baffled

### 2.5 Using the software

The source codes will be soon available in the form of an open-source software under distributed version control. MAESSTRO may be run locally, using a simple command line interface. Also, since computations may require large amount of memory, we also provide a software-as-a-service (SaaS) version, in which simulations may be run in a remote server using memory-optimized computers. The SaaS version is available through the simulagora platform<sup>4</sup>.

## 3. APPLICATION

We briefly present an application. Fig. 1 represents the MAESSTRO graphical user interface during the design of the virtual soundboard geometry, inspired by the design of a Steinway D, including ribs and bridges. Note that it is possible to load an existing detailed plan of the soundboard to ease its drawing in the GUI.

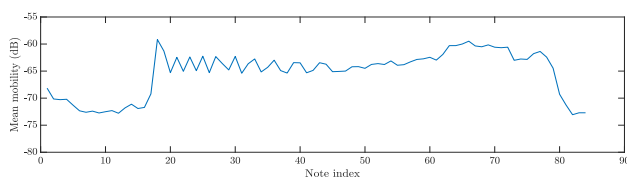


**Figure 1.** Screenshot of the MAESSTRO GUI during the design of the Steinway D.

<sup>4</sup> <https://simulagora.com>

The parameters of the string set are taken from a technical report [11], which provides all of the required information to compute the dynamics of any string of the virtual reference piano, including string geometry and tension, Young modulus of the string materials, internal damping, and location of the bridge coupling points. It also provides the mechanical parameters of the hammers, namely the mass, the stiffness, and the impact location on the string.

Fig. 2 shows the distribution of the mean mobility at the string-bridge coupling points along the bridge. The string-bridge coupling is not homogeneously distributed along the bridge position, as the string with attachment points located near a rib face a locally much stiffer structure. This kind of results and analysis may be helpful for piano makers to evaluate the homogeneity of a virtual soundboard, and, if necessary, to modify the soundboard parameters in order to reach a desired distribution of the string-bridge coupling.



**Figure 2.** Mean mobility of the simulated soundboard at the string-bridge coupling points.

## 4. CONCLUSIONS

MAESSTRO is intended to help piano makers in the design process by giving them a tool to synthesize tones or short musical passages produced by virtual pianos. Case studies show the interest of the software in predicting mechanical impacts of structural modifications of a piano soundboard. If the piano makers adopt the software, they will be able to virtually test new designs, and thus significantly enhance the pace of the trial and error process. One other major evolution could be the use of composite materials: the software could be used to predict the sound of a piano with soundboard made in specific composite materials, or even be used to find the mechanical properties which could yield to the sound desired by the piano maker. Finally, we also expect the software to be used by researchers, and thus become a useful tool of communication between piano makers and academic researchers. We are planning to modify the software with the help of academic partners to use it for other string instruments, such as the guitar.

## 5. REFERENCES

- [1] H. Suzuki, “Vibration and sound radiation of a piano soundboard,” *The Journal of the Acoustical Society of America*, vol. 80, no. 6, pp. 1573–1582, 1986.
- [2] K. Ege, X. Boutillon, and M. Rébillat, “Vibroacoustics of the piano soundboard:(non) linearity and modal

properties in the low-and mid-frequency ranges,” *Journal of Sound and Vibration*, vol. 332, no. 5, pp. 1288–1305, 2013.

- [3] J. Chabassier, A. Chaigne, and P. Joly, “Modeling and simulation of a grand piano,” *The Journal of the Acoustical Society of America*, vol. 134, no. 1, pp. 648–665, 2013.
- [4] A. Chaigne, B. Cotté, and R. Viggiano, “Dynamical properties of piano soundboards,” *The Journal of the Acoustical Society of America*, vol. 133, no. 4, pp. 2456–2466, 2013.
- [5] B. Trévisan, K. Ege, and B. Laulagnet, “A modal approach to piano soundboard vibroacoustic behavior,” *Journal of the Acoustical Society of America*, vol. 141, pp. 690–709, Feb. 2017.
- [6] G. Weinreich, “Coupled piano strings,” *The Journal of the Acoustical Society of America*, vol. 62, no. 6, pp. 1474–1484, 1977.
- [7] X. Boutillon, “Model for piano hammers: Experimental determination and digital simulation,” *The Journal of the Acoustical Society of America*, vol. 83, no. 2, pp. 746–754, 1988.
- [8] H. A. Conklin Jr, “Design and tone in the mechanoacoustic piano. part i. piano hammers and tonal effects,” *The Journal of the Acoustical Society of America*, vol. 99, no. 6, pp. 3286–3296, 1996.
- [9] H. A. Conklin Jr, “Design and tone in the mechanoacoustic piano. part iii. piano strings and scale design,” *The Journal of the Acoustical Society of America*, vol. 100, no. 3, pp. 1286–1298, 1996.
- [10] C. Geuzaine and J.-F. Remacle, “Gmsh: A 3-d finite element mesh generator with built-in pre-and post-processing facilities,” *International journal for numerical methods in engineering*, vol. 79, no. 11, pp. 1309–1331, 2009.
- [11] J. Chabassier and M. Duruflé, “Physical parameters for piano modeling,” tech. rep., 04 2012.