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INTERACTIVE SIMULATION APPS FOR TEACHING ACOUSTICAL PHENOMENA AND VIBRATION EFFECTS.

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ABSTRACT

Teaching acoustical phenomena, such as the propagation of acoustic waves through different environments, poses many comprehensional challenges for pupils and students due to their abstract nature. Therefore, technical aids play a crucial role in teaching by making acoustics comprehensible and understandable while ensuring learning success. To overcome these difficulties, we present interactive simulation apps that visualize acoustic phenomena and vibrations in essential application areas. These apps enable students to validate the results of hands-on experiments by numerical simulations. The visualization and adaptation of simulation parameters facilitate understanding the underlying physical principles. The interactive apps were initially developed at the Technical University of Munich and employ the numerical software COMSOL MULTIPHYSICS to visualize acoustic phenomena in various fields. During an interdisciplinary cooperation project of the German Acoustical Society (DEGA), students from several universities worked together to create apps related to their respective areas of study, such as noise control, hearing acoustics, room acoustics, and musical acoustics. The apps can be accessed by students and lecturers via the website of the Chair of Vibroacoustics of Vehicles and Machines at the Technical University of Munich (https://apps.vib.ed.tum.de). They are freely available for academic use without license requirements and provide an opportunity to explore acoustical phenomena.

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1. INTRODUCTION

The 'junge DEGA' group unites young acousticians in Germany to establish a network and promote professional exchange. As part of this group, a collaborative German university project was initiated to develop interactive acoustics apps for teaching acoustics. The students contributed with the expertise of their supervising institutes, resulting in apps for various sub-areas of acoustics. Based on the existing acoustics apps, which have been developed by the Chair of Vibroacoustic of Vehicles and Machines at the Technical University of Munich [1–4] using the software COMSOL MULTIPHYSICS [5], new apps have been developed to illustrate phenomena in the areas of vibroacoustic, hearing acoustics and musical acoustics. They can be accessed via the website https://apps.vib.ed.tum.de.

2. BACKGROUND INFORMATION

The study of acoustic phenomena, e.g., the knowledge about sound propagation, is associated with some difficulties due to the abstractness of acoustic wave visibility. Certain technical aids help ensure effective knowledge transfer between lecturers and students in the context of school and university teaching. This includes collaborative working and learning in teams, mutual feedback, and the use of active learning methods [6]. The visualization of the phenomena, in combination with practical application, significantly increase understanding of acoustics [7]. The acquisition of expensive measuring instruments and limited access to anechoic chambers restrict the possibility of conducting experiments in teaching. For this reason, interactive learning apps aim to conduct experiments using digital devices. Over time, many different apps were developed to explain acoustic phenomena [8]. The complexity of the problems restricts these tools since they can be resolved only analytically. The multiphysics software COMSOL MULTIPHYSICS allows users to solve problems described by differential equations. Individual geometries and boundary conditions can be modified according to the user's needs. The simulations are calculated on a server and made available to the user via a browser.

3. NEWLY DEVELOPED ACOUSTICS APPS

In the following section, a brief introduction is given to the four apps developed as part of the cooperation project. The interdisciplinary research of the participating institutes resulted in apps dealing with vibroacoustics, musical acoustics, psychoacoustics, and noise reduction.

3.1 Comparison of a Schroeder-diffuser and a meta-surface-based Schröder-diffuser

Mert Dogu, Technical University of Munich

The objective of the app is to compare the Schroeder-diffuser to the meta-surface based Schroeder-diffuser and to illustrate the calculation of the scattering coefficient in the frequency domain. The selected Schroeder-diffuser is based on the primitive root sequence with seven as an odd prime number, which yields a diffuser with six cavities. The study is conducted in two dimensions to reduce the degrees of freedom and, therefore, the computational effort of the simulation. In the case of the Schroeder diffuser, two cases are considered: (1) a single diffuser recessed in an infinite baffle; (2) an array of three adjacent diffusers with a total of 18 cavities recessed in an infinite baffle. For both diffusers, the depths and widths of the indentations can be varied to show the different influences of the geometry. The app offers the possibility to vary the depths and widths of the Schroeder-diffusor and the metasurface-based Schroeder-diffusor to demonstrate different geometrical influences on the sound pressure field. The simulation visualizes the sound pressure and sound pressure level in the room depending on various angles of incidence, varying from $-80°$ to $80°$ per octave band. A visual radiation pattern of the sound pressure displaying the directional characteristic shows the radiation's effect depending on the incidence angle, which can be seen in Figure 1.

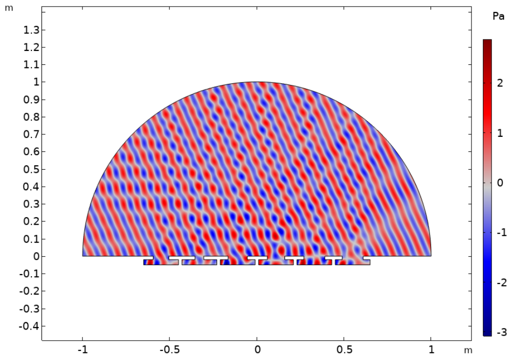

Figure 1. Visualization of the sound pressure field around a meta-surface-based Schroeder-diffuser.

3.2 Simulation of a 'Head-related transfer function'

Mihály Tamás Bárány, RWTH Aachen University

The app calculates the head-related transfer function (HRTF) for a three-dimensional scanned geometry of a human head and torso. Two different simulations are carried out using the Boundary Element Method (BEM), one for the left and one for the right ear so that the differences in sound perception between the two ears can be illustrated. Instead of determining the HRTF by calculating the sound pressure at the entrances of the ear canals for sound sources at certain positions around the head, which would correspond to a measurement setup, the reciprocity principle was applied. In this case, the entrances of the ear canals were each assigned a sound particle velocity in the normal direction, and then the sound pressure was evaluated at positions around the head. This reciprocal approach leads to the same transfer functions as with sources around the head but reduces the number of simulations to only two per frequency. The HRTFs displayed in the app are referenced to the sound pressure measured at the center of the head as if the head is not present. Accordingly, a value of $0\,\mathrm{dB}$ indicates that the body has no influence

on the sound pressure at the ears at a given frequency, while negative dB values indicate shadowing and positive dB values indicate amplification effects, e.g. due to pinna resonances. According to the reciprocity principle, the sound pressure values of the BEM simulation are normalized by the analytically calculated sound pressure of a point source located in the center of the head and whose sound flux corresponds to the sound flux at the ear canal entrances [9].
The app includes three sliders that can be used to adjust the azimuth and elevation angles as well as the distance of the sound source. The selected position is also displayed in a separate window together with the model geometry. In addition to the frequency response, a polar diagram, directivity diagrams and balloon diagrams help to visualize the spatial properties of the HRTF. The polar diagrams show the directivity in the horizontal plane for a given frequency along a circle centered at the center of the head with a radius of one meter.

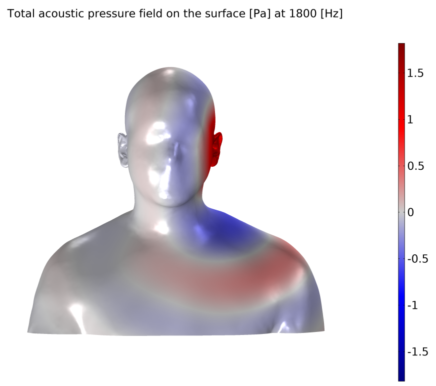

Figure 2. Visualization of the sound pressure field with a sound source in the left ear channel.

3.3 Numcerical simulation of a noise barrier

Tabea Breitkreutz, Louis Heggemann, Hochschule Mittweida, University of Applied Sciences

This app calculates the sound propagation from a sound source along a noise barrier. It shows how sound waves are refracted, absorbed, or reflected at the barrier. The calculation is realized by using the finite element method. A two-dimensional simulation environment was chosen for the display due to the reduced computational effort compared to a three-dimensional calculation domain. The user can change the geometrical properties of the computation domain as well as individually adapt the parameters of temperature and density. The sound absorption coefficient can be entered into the user interface and is incorporated into the model. This app computes numerically the acoustic effectiveness of sound barriers that are used, e.g., to protect neighbors from roadway noise. Analytical approaches calculating noise reduction by noise barriers are delivered by Maekawa [10]. The reference formulas by Kurze [11] and calculation results are displayed in the sidebar. The app shows the cross-section of a sound barrier (see Figure 3), which can be further adjusted in height and thickness using the sliders in a sidebar. Here, the acoustic phenomena of diffraction, refraction, and reflection can be sufficiently well recognized and explained.

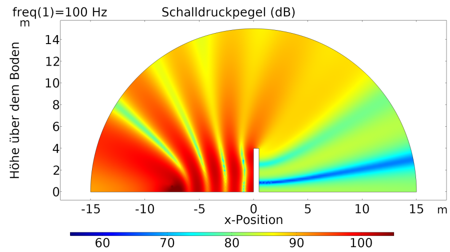

Figure 3. Representation of the sound pressure level at a frequency of 100 Hz, with all sound absorption coefficients set to zero.

3.4 Numerical simulation of the comb filter effect

Luis Enrique Roca Paz, HfM Detmold

The comb filter effect is an acoustic phenomenon that occurs when the same signal arrives at different times at the receiver. This effect is caused by sound reflections from hard surfaces, from multiple sources generating the same tone, or electronically through delay effects and latency. The transfer function between the loudspeakers and the microphones represents the frequency response of the receiver at a specific position and illustrates the effect of comb filtering (see Figure 4). [12]
By using this app, users can explore the influence of various parameters related to the comb filtering effect and observe changes in frequency response in real-time, which helps them to deepen their understanding. The application is also integrated into the learning platform wiki.audio [13, 14]. Wiki.audio is a free online encyclopedia that can be used by pedagogues and audio enthusiasts to easily and intuitively understand various topics in audio technology.

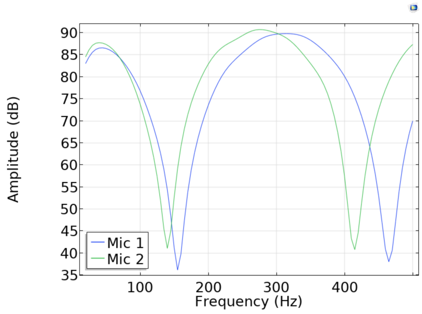

Figure 4. Transfer function of two microphones at a distance of 0.5 meters.

4. OUTLOOK

Students developed acoustic simulation apps using the software COMSOL MULTIPHYSICS during this collaboration project. The apps are related to the research areas of the participating institutes and are intended for use in teaching. For most of the students involved in the project, developing their app was their first experience working with numerical simulation, allowing them to gain many new insights. Through regular meetings and mutual support, they also gained insights into other areas of acoustics.

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