„Acoustics“ - Toolbox for Teaching

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Introduction

In classical academic teaching, theory is taught in classroom lectures and deeper practical comprehension is to happen later during laboratory experiments. This separation is due to practical reasons, because setting up an experiment takes time and transport of measurement equipment to the classroom is difficult or inconvenient. In order to support the understanding of theoretical contents, it would be helpful to have experimental demonstrations in the classroom during a lecture and right before or after the theoretical input. In acoustics there is already a variety of commercial and open source software with advanced functions, that might be used for experiments and their evaluation (e.g. [1], [2]). However, from a teacher's point of view, the complexity of such programs might make their application difficult because of the short preparation time teachers usually have and the fact that the time available for experiments during a lecture is limited. For this reason, the “Acoustics” toolbox was developed and shared on the Mathworks website [3]. It is supposed to both help teachers quickly perform live demonstrations during lectures, and to become an easily accessible tool for students to be used at home or in workshops. In the following sections its functionality is described in more detail, and some use cases are given.

Functionality of the „Acoustics“ toolbox

Conceptual purpose

The minimum content of a bachelor acoustics course is defined in DEGA recommendation 102 [4]. Students should e.g. know basic acoustic quantities, level calculations, frequency weighting, signal presentation, fundamentals of sound measurement or frequency (band) analysis. These topics should be included to the toolbox and be quickly applicable, i.e. that all functions and parameter inputs should be visible. Therefore, a GUI design without submenus was developed (Fig. 1).

Figure 1: GUI of the MATLAB toolbox “Acoustics”. Section A: data acquisition settings and display. Section B: data analysis and presentation of results.

For better understanding, a measured signal should always be presented both in time and frequency domain at the same time. Therefore, the GUI was split into two parts: section A containing all functions for data acquisition with presentation in time domain, and section B containing all functions for data analysis with presentation of results either in time or frequency domain. In order to reduce the measurement equipment needed, signal recording and playback should work with onboard soundcards, but also combined with external data acquisition (DAQ) devices having up to four channels when performing more advanced experiments. A simple signal generator should help to reduce the number of experimental equipment. Finally, the software should not work as a “black box”, but instead be extendable and open for changes or improvement.

Implemented functions

An overview of most important functions implemented is given in Table 1. During practical application of the toolbox both in lectures and laboratory experiments, the original functionality of the toolbox was extended and more and more features and functions were added.

Table 1: Implemented functions (version 2021.05.01)

Data acquisition
Devices: windows sound cards, NI 9219, 9220 and 9234
Sensor types: microphone, acceleration, voltage in general
Import of time domain data (*.wav or *.mp3 format)
Mark, cut and save signal sections
Continuous DAQ or single data set acquisition
Signal generation: sine, sawtooth, partials, noise, chirp, pulses
Zoom functions for graphical presentation
Data analysis
Sensor calibration
Input of environmental data
Calculation of sound pressure, particle velocity, RMS values, transient SPL (time constant FAST)
Single or continuous FFT
Window functions
Averaging: moving window, number of measurements
A-weighting
Octave / Third octave band analysis
Noise correction
Spectrogram
Frequency response
DIL: insertion loss
DTL: transmission loss, 2-source method by Tao/Seybert [5]
Impedance measurement [6]
Fundamental frequency and partial detection
Data export (*.mat and *.xlsx)
Detection of time/frequency/amplitude differences
Centroidal frequency

Getting started

The “Acoustics” toolbox source code including the user manual can be downloaded as a *.zip file using the file exchange service on the Mathworks website [3]. The software is then started by running the “Acoustics.m” file after having opened it in the MATLAB editor. Alternatively, the software can be installed as a regular toolbox by means of the add-on explorer in MATLAB. In this case it is started by entering just “Acoustics” in the command line.

Requirements

The „Acoustics“ GUI was developed in MATLAB version 2018b by means of the GUIDE wizard. Before first use, the “Signal Processing Toolbox”, “Data Aquisition Toolbox” and “Support Package for Windows Sound Cards” should be installed. Apart from windows soundcards, the actual toolbox version supports National Instruments (NI) data acquisition devices NI 9219, 9220 and 9234. For using them, the “Support Package for National Instruments devices” (NI-DAQmx) must be installed. When live acquisition of data is not possible or necessary, already existing time domain data can be imported in *.wav or *.mp3 format.

Use cases

In this section, two simple experiments are presented, that might be part of a teaching unit in a fundamental acoustics or physics course. The basic equipment needed is a notebook with MATLAB and the “Acoustics” toolbox (including all supplementary toolboxes and packages mentioned in the section before).

Case 1:

Beat demonstration / Influence of FFT parameters

Additional equipment:
Two equal tuning forks (one with adjustable frequency, see Fig. 2). The open ends of their resonators should not point to each other in order to avoid coupling effects.

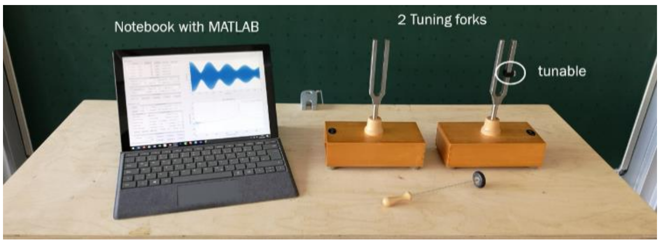

Figure 2: Equipment and experimental setup for use case 1

Description:
First the sound of both equally tuned forks is recorded and analyzed, then one fork is slightly put out of tune and the procedure is repeated. Frequency spectrum could be calculated for different FFT sizes, measurement durations or window functions, until the slightly different frequencies of the tuning forks can be resolved (Fig. 3). The period / frequency of the envelope of the beat signal (volume modulation) could be detected and compared to the frequency shift of the tuning forks.

Potential learning goals:
Demonstration of how the interference pattern of a beat looks like in time domain, frequency detection of the audible beat and the interference signal, relation between these frequencies and those of the tuning forks, understanding of the influence of FFT parameters on frequency spectrum.

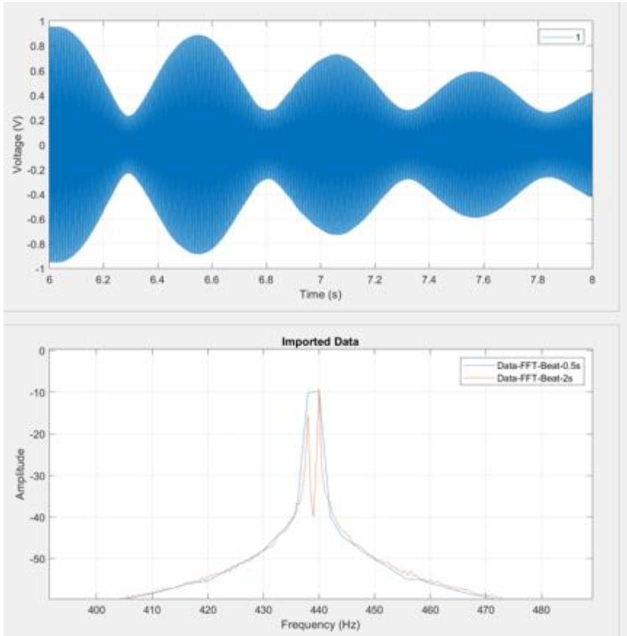

Figure 2: Frequency spectrum of a beat (438 Hz + 440 Hz), Blue line: Measurement duration 0,5 s. Red line: Measurement duration 2 s.

Case 2:

Speed-of-sound determination / Reflection of waves

Additional equipment:
Any tube (one end closed, diameter d = 4-5 cm, length L = 80-100 cm) with supports, small external microphone (cable length ca. 0,5 m), external USB audio device to provide the microphone input, external active (bluetooth) loudspeaker, thermometer for air temperature measurement (Fig. 3).

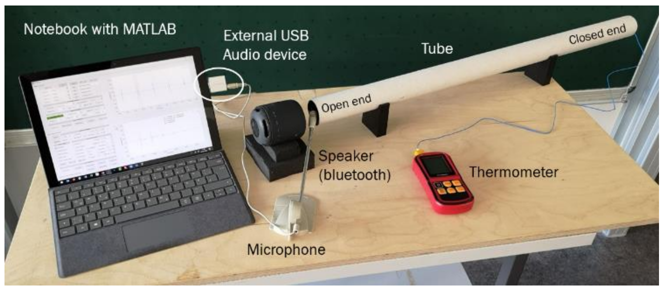

Figure 3: Equipment and experimental setup for use case 1

Description:
The loudspeaker (distance 5 cm in front of the open end of the tube) emits Gaussian pulses (signal generator of the toolbox: 3 kHz, interval 1 s), the microphone is located directly in the open end, then propagation time between direct sound and reflection is measured (Fig. 4), finally speed-of-sound is calculated by $c = 2L/\Delta t$ and compared to the adiabatic value given by $c = \sqrt{\kappa RT}$.

Potential learning goals:
Determination of speed-of-sound based on the propagation time of a short pulse, comparison of this result to the adiabatic ideal gas formula and discussion of various reasons for the deviation, demonstration of plane wave reflection at solid walls, calculation of the reflection coefficient by $r = A_r/A_i$

based on the amplitudes ratio of the incident and reflected wave.

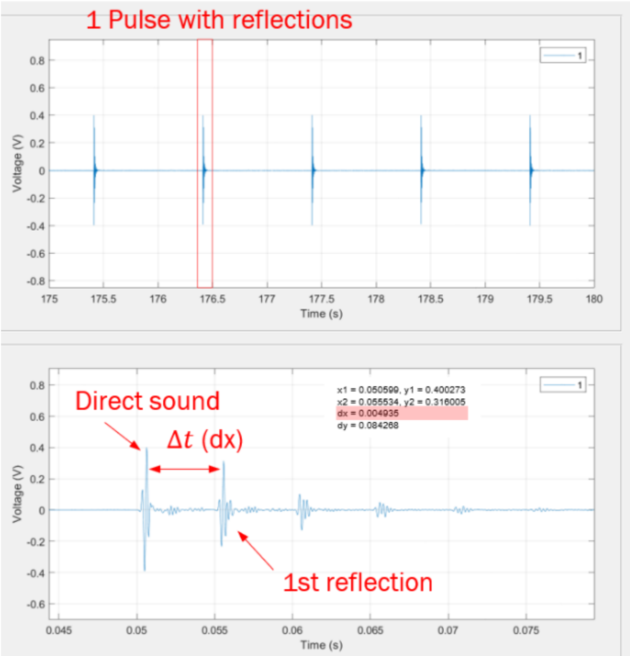

Figure 4: Pulse recording (upper diagram) and detection of time delay Δt between direct sound and 1st reflection.

Summary and perspective

A MATLAB toolbox was developed both for teachers performing quick experimental demonstrations during lectures and for students practicing measurement and frequency analysis procedures. The conceptual purpose was to support fundamental acoustics courses with contents defined by the DEGA recommendation 102 [4]. All implemented functions and parameters are visible at once and quickly adjustable by a GUI without submenus. A user manual is provided with explanations of how to get started and how all implemented functions can be applied. The toolbox probably still contains bugs. All users are welcome to inform the author about their experiences and proposals for improvement. In future it is planned to convert "Acoustics" to the MATLAB app designer format as Mathworks announced GUIDE to be replaced. Useful extensions would be additional tabs containing animations of sound propagation phenomena or sound fields caused by different sources.

Literature

[1] Berzborn, Marco, et al. "The ITA-Toolbox: An open source MATLAB toolbox for acoustic measurements and signal processing." 43th Annual German Congress on Acoustics, Kiel (Germany). Vol. 6. 2017.

[2] Brinkmann, Fabian, and Stefan Weinzierl. "Aktools - an open software toolbox for signal acquisition, processing, and inspection in acoustics." Audio Engineering Society Convention 142. Audio Engineering Society, 2017.

[3] Pitsch S. "Acoustics" Toolbox. URL: https://www.mathworks.com/matlabcentral/fileexchange/75360-acoustics.
MATLAB Central File Exchange. 2021.

[4] Deutsche Gesellschaft für Akustik e.V. „Mindestkanon: Akustik in der Bachelor-Ausbildung". DEGA-Empfehlung 102. 2009.

[5] Tao, Z., and A. F. Seybert. "A review of current techniques for measuring muffler transmission loss." SAE transactions (2003): 2096-2100.

[6] "Determination of sound absorption coefficient and impedance in impedance tubes – Part 2: Transfer-function method". Technical standard EN ISO 10534-2. 2001.