

# Measurements and Room Acoustic Analysis with the ITA-Toolbox for MATLAB

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## Introduction

During the last years, a MATLAB toolbox for acoustical signal processing has been developed at the Institute of Technical Acoustics (ITA) at RWTH Aachen University [1]. Recently, two new applications have been released for *measurements* and *room acoustical evaluation*. In this paper we describe these two additional open-source applications currently released inside the ITA-Toolbox.

The measurement application includes basic features, such as signal recording, playback and deconvolution techniques for noise, sweep or MLS transfer function measurements. The possibility of simulating an entire measurement chain including convolution, filters, noise, quantization, clipping and nonlinear transfer characteristics helps to understand artifacts observed in real measurements and is considered very useful for didactic purposes for academic education during laboratory exercises and lectures.

Using the room acoustics application monaural parameters can be evaluated according to ISO 3382 employing different evaluation methods. The routines help to understand the noise detection algorithms and the differences between the evaluation results. In combination, these two applications provide a powerful tool for uncertainty analysis in room acoustics.

## About ITA-Toolbox

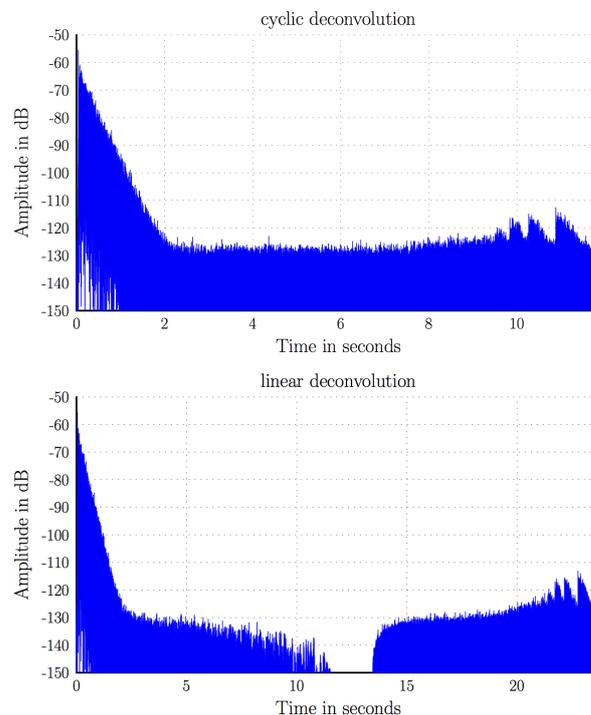
The ITA-Toolbox was primarily intended for in-house use at ITA as basic container for MATLAB routines. This toolbox handles common post-processing tasks in the field of acoustic research, including data import and export as well as different graphical representations of the data. Professional audio recording interfaces can be directly connected to enable data acquisition. During the years the functionality grew and stable routines for various signal processing and measurement tasks were developed. A kernel containing basic functionality was released in 2012. Advanced functionality is provided by dedicated optional applications that work hand in hand with the ITA-Toolbox kernel.

A tutorial script to demonstrate the functionality of the kernel is available in the file `ita_tutorial.m`.

## Measurement App

The application *Measurement* features an object oriented approach including classes for specific measurement objects. In this context the class `itaMSTF` (Measurement

Setup Transfer Function) is used. This class realizes correlation measurements involving deconvolution techniques. Arbitrary measurement signals might be used. We mainly concentrate on sweep measurements due to advantages published in [1, 2]. MLS measurements as proposed in [3] are available but not focus of this paper. The measurement objects store the excitation signal that can be freely defined by the user. A so-called *compensation* which is the inversion of the complex spectrum of this excitation signal is generated automatically in the background. The level of the measurement can be controlled in this object by setting the *output amplification* in dBFS<sup>1</sup>. This value is automatically accounted for by reciprocally scaling the measured input signal. Hence, the absolute values of the measured impulse response remain constant regardless off the actual output amplification of the measurement. Only the signal-to-noise-ratio (SNR) will change accordingly. As most spectra of ex-



**Figure 1:** Two different deconvolution techniques (cyclic and linear), which can be chosen by parameters in the measurement object.

citation signals are band-limited regularization might be applied to reduce the noise influences outside the frequency range of interest. This can be controlled by pa-

<sup>1</sup>This is a value in dB smaller or equal to zero.

parameters inside the measurement object. Two deconvolution techniques are implemented. The first uses circular deconvolution and the second approximates linear deconvolution. The effect on the impulse response in a real room using a loudspeaker driven in a fairly linear range is shown in Figure 1. The impulse response for the linear deconvolution technique has twice the length as the measured raw signal is extended in time domain with zeros prior to multiplication with the regularized inverse of the excitation signal.

Figure 2 shows basic GUI elements of the measurement application and the MATLAB command line window with a summary of the measurement object. Parameters can be easily modified in a GUI using the function `.edit`. The measurement itself is triggered by the method `.run` and directly yields the impulse response as the deconvolution is applied to the measurement object. A so-called



**Figure 2:** Screenshots of GUI elements of the measurement application inside the ITA-Toolbox and MATLAB command window showing a summary of the parameters of the `itaMSTF` measurement object.

*dummy class* is available that emulates an entire measurement chain including quantization effects, measurement noise, linear and non-linear system characteristics. Details are published in [4]. This class is a very powerful tool to analyze and understand the artifacts in the impulse response caused by e.g. noise, quantization or non-linearities.

A tutorial script called `ita_tutorial_measurement.m` is available to illustrate the functionality of the measurement objects and the emulation of the measurement chain.

## Room Acoustics App

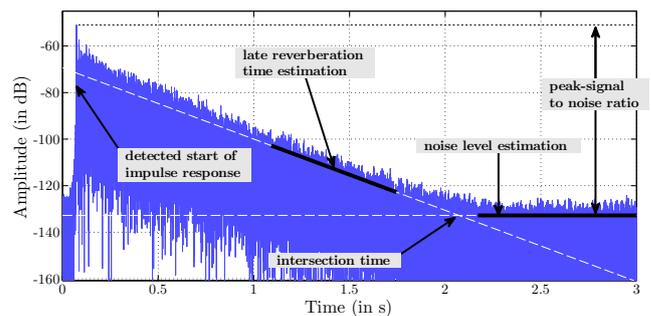
The application *Room Acoustics* is based on ISO 3382 [5]. It features the evaluation of room acoustic parameters from a measured impulse response, e.g. with the measurement application of the ITA-Toolbox, or simulated impulse response. The following monaural parameters as provided by the standard are: Reverberation times (early decay time,  $T_{10} \dots, T_{60}$ ), clarity index ( $C_{50}, C_{80}$ ), definition ( $D_{50}, D_{80}$ ), center time. Furthermore, the peak signal to noise ratio is calculated.

The evaluation of the parameters `PAR` in a *MATLAB struct* out of multi-channel impulse responses `RIR` is triggered by the command: `PAR = ita_roomacoustics(RIR)`.

The user can tweak all options regarding the evaluation methods by specifying additional parameters as documented in the help of the function calls. The evaluation itself is fully automatic and hence no user interaction is required. It directly yields the parameters in an organized structure. First, the beginning of the impulse response is detected and then a fractional octave band filter is applied. The noise detection and compensation is processed for each frequency band and each channel of the impulse response independently. This approach yields parameters with exact reproducibility and hence it is applicable for uncertainty analysis for research purposes. It is possible to analyze large sets of measured or simulated impulse responses automatically in a short time.

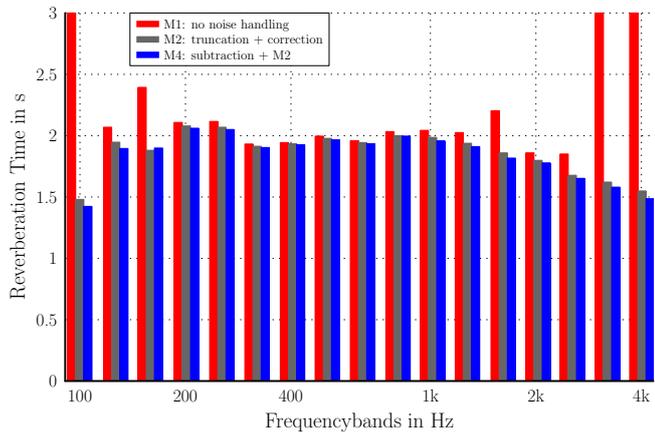
## Noise Detection and Compensation

The noise detection algorithms implemented are mainly based on ISO 3382. An iterative algorithm as proposed by LUNDEBY ET AL. [6] provides the estimated peak signal to noise ratio, the noise level, the intersection time where the decay of the impulse response intersects with the noise floor and the late reverberation time. Figure 3 illustrates the determination of the parameters. The parameters are used for the subsequent noise compensation. The algorithm delivers a robust noise estimation and has proven for measured room impulse responses from several measurement sessions in various different rooms.



**Figure 3:** Automatically detected parameters of the noise detect algorithm as proposed by LUNDEBY ET AL. in the ITA-Toolbox yielding e.g. *Peak SNR*, *late reverberation* and *intersection time*

As noise occurs in every real-life measurement and as noise can perturbate the evaluation of the room acoustic parameters a proper noise compensation is preferred. Five different ways of noise handling have been implemented in this application. Three of them are directly compliant with ISO 3382. For moderate SNRs, e.g. between 40 and 60 dB peak SNR, these methods already yield significantly different results as can be seen for the



**Figure 4:** Reverberation time  $T_{30}$  with different noise handling methods (M1, M3, M5) in third octave bands.

reverberation times  $T_{30}$  in Figure 4. The uncertainties due to measurement noise for the different noise handling methods are studied in more detail in [7].

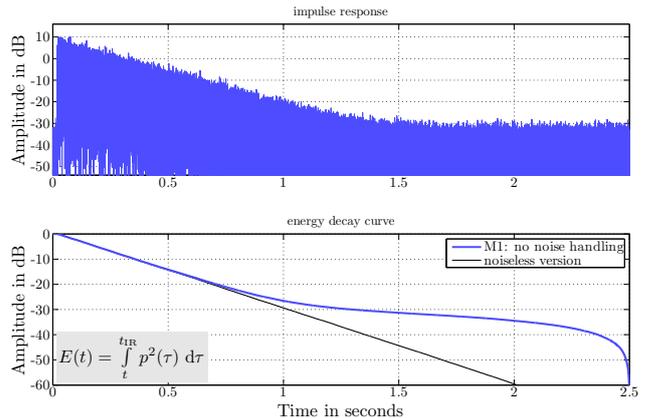
The effect on the energy decay curve if no noise compensation and no noise truncation is applied in to the backwards integration is shown in Figure 5 (Method M1). Figure 6 illustrates the noise compensation method including a truncation of the measured impulse response (M3). Finally, the complex algorithm using noise subtraction, truncation and compensation for the truncated energy of the impulse response is depicted in Figure 7.

Currently the speech transmission index (STI) is already included. The calculation of binaural features, e.g. IACC, and room acoustic parameters using a figure-of-eight microphone, such as LF and LFC, will be added soon. Furthermore, this application contains a function to simulate rectangular rooms with rigid boundary conditions by modal superposition as published in [8]. The combination of this analytic simulation and the evaluation of parameters is considered very powerful in terms of uncertainty analysis and testing the robustness of the parameters against perturbations.

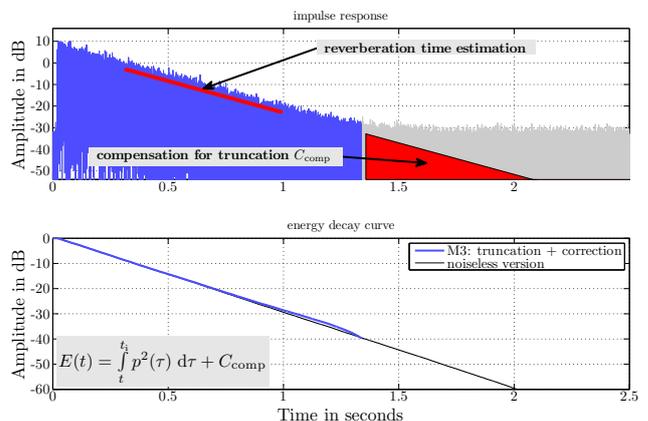
A tutorial script called `ita_tutorial_roomacoustics.m` is included to show the evaluation process of room acoustic parameters.

## System requirements and License

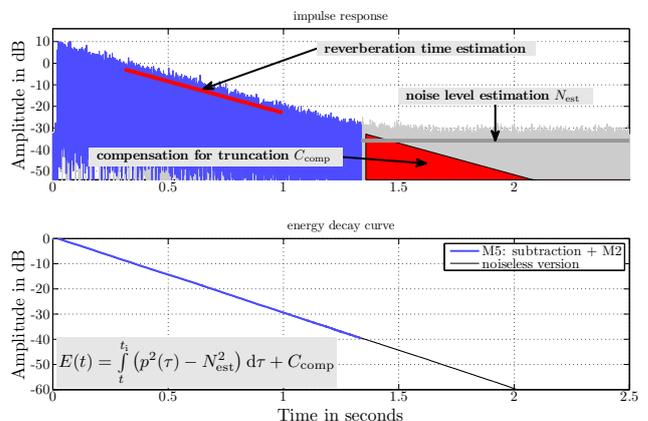
A copy of the ITA-Toolbox can be freely downloaded at [www.ita-toolbox.org](http://www.ita-toolbox.org). It is published under the original BSD-License, allowing the use of the software, any modifications and the redistribution for commercial or non-commercial purposes, as long as the copyright statement is preserved and credits to our institution are given. The ITA-Toolbox is compatible with any operating system (MS Windows, Linux, Mac OS X) running MATLAB R2010a or higher. The signal processing toolbox is required for spectral band-pass or fractional octave band filtering and time windows. The majority of the ITA-Toolbox routines runs even without this additional toolbox.



**Figure 5:** Illustration of impulse response with and without noise (top) and energy decay curve (bottom) for these impulse responses without noise detection and compensation (M1).



**Figure 6:** Energy decay curve with algorithm that truncates the impulse response and applies a correction for the energy discarded with this truncation (M3).



**Figure 7:** EDC evaluation method using noise subtraction, truncation and proper correction for the truncation (M5).

## Acknowledgments

The authors would like to thank the co-workers at the Institute of Technical Acoustics and all users of the ITA-Toolbox for their valuable feedback and contributions. We would like to thank the developers of PortMusic, especially PortAudio, and playrec which is used for communication with sound cards. The ASIO SDK by Steinberg was additionally used for this communication on Microsoft Windows systems.

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