Hand-in Assignment 2 (HA2):
Room Acoustics

Department of the Built Environment, Building Acoustics Group
7LS8M0 Architectural Acoustics

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Contents

Instructions

The guideline of the Hand-in Assignment 2 (HA2) includes the concepts as well as the tasks needed to be submitted. One MATLAB example is provided as part of this assignment. Your report is needed to be submitted on Canvas **before** the deadline. **Late submissions are not accepted, and graded with zero!** Your submitted report is needed to be in a **pdf** format and **named** such GroupNumber_Assignment.pdf (e.g., Group01_HA2.pdf) and your MATLAB scripts such GroupName_Assignment.m (e.g., Group01_HA2.m). In addition, both the MATLAB functions and scripts are needed to be separately submitted in a **zip** file. All the MATLAB scripts need to be commented very clearly, explaining what you are doing in every line of the code using comments. The figures must have the same format as the figure generated. All the generated figures need include title, labels in axes, and legends. In your report, the figures need to have a proper size, so that all the information to be well observable. At the appendix of your report, you need to include all your MATLAB codes. All the tasks are needed to be accomplished and included into the report. Support your evidence with the proposed literature or other literature from your side. Finally, the grading of HA2 report is based on the Table 1, indicating the distribution of points in the tasks.

Table 1: Distribution of Points for HA2.

	Tasks Sec. 2	Tasks Sec. 3	Tasks Sec. 4	Structure/Lang.	References/Cites	Total
Points (pts)	1.50	4.00	1.50	0.50	0.50	8.00

1 Introduction

In this assignment, three captured room impulse response (RIRs) of an enclosed space are analysed, investigating their properties and calculating acoustical parameters associated to the quality of the enclosed space in terms of its usage (i.e., speech and music). More specifically, the room acoustics metrics; reverberation time, clarity for music and speech as well as the centre time are considered. By analysing and interpreting the values of metrics with respect to the literature and some assumptions, the usage of the enclosed space may be estimated.

2 Exploring the Room Impulse Responses (RIRs)

A room impulse response (RIR) is a time signal used to express the characteristics of an enclosed space (i.e., direct signal, early reflections and late reflections), with respect to a source (SRC) and a receiver (REC) position. An example of a RIR is presented in the Figure 1.

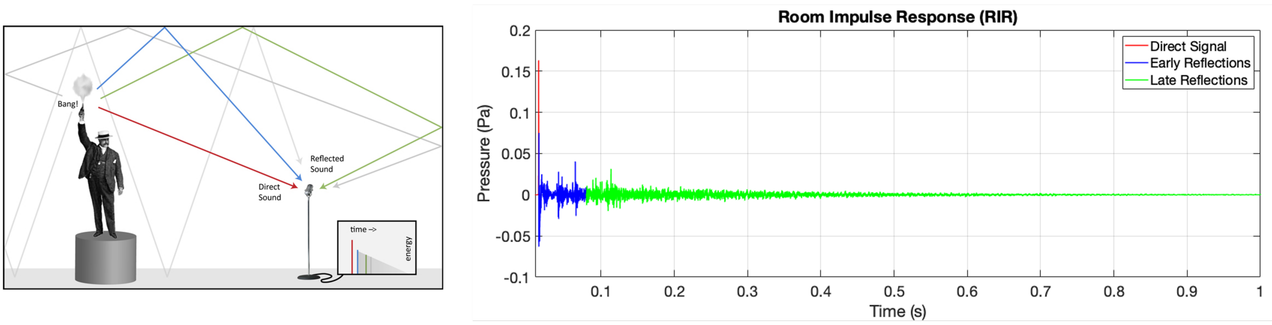

Figure 1: Physical components of a room impulse response (left) and its representation (right).

In this assignment, three RIRs are provided (i.e., see folder "Signals" into 'MaterialHA2'), corresponding to one position of sound source and three positions of receivers in different distances.

Tasks [0.25 Pts]

2.0.A. Read the three RIR signals (i.e., "RIRdist1.wav", "RIRdist2.wav", and "RIRdist3.wav") and create their time-vector.

2.0.B. Plot the three RIR signals into the same figure. Note: Plot from 0 to 0.5 seconds.

2.0.C. Calculate the distance between the SRC and RECs, assuming that the speed of sound is $c = 343m/s$. Present the calculated distances in a table.

2.0.D. Discuss possible difference among the plots in the **Task 2.0.B.**

2.1 Filtering the Room Impulse Responses

In room acoustics, all the acoustic parameters are expressed in 1/1-octave frequency bands. Hence, it is important to filter the room impulse responses before continuing to the calculation of the room acoustics parameters. The filtering is conducted in the time domain, whereas the filters are defined in the Z-domain. For the purposes of this task, a second order Butterworth band-pass window is used per 1/1-octave frequency band with central frequencies f_c ranging from $125Hz$ to $4kHz$. The magnitude responses of these filters are presented in Figure 2.

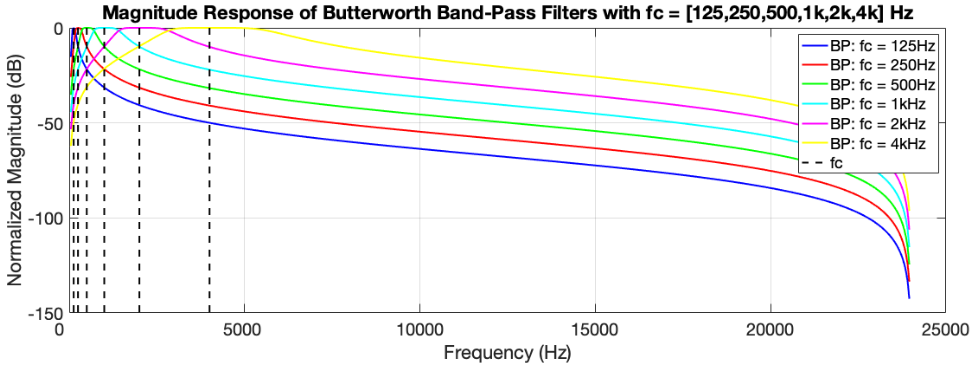

Figure 2: Magnitude responses of the constructed band-pass Butterworth filters with central frequencies ranging from $125Hz$ to $4kHz$.

The construction of these filters is out of the scope of the course and therefore of this assignment. An example code is provided to you with the name `OctBandsFiltering.m`.

Tasks [0.25 Pts]

2.1.A. Read very carefully the provided example `OctBandsFiltering.m`.

2.1.B. Transfer the part of the example which filters the RIRs in your script.

2.1.C. Adjust the central 1/1-octave frequency bands, ranging from $125Hz$ to $4kHz$.

2.1.D. Plot the filtered RIRs per 1/1-octave frequency band. Suggestion: Use the `subplot` into the for-loop. Also, adjust in the plots the time from 0s to 0.5s and the amplitude from $-0.4Pa$ and $0.4Pa$.

2.1.E. What are you observing in the latter plots with respect to 1/1-octave frequency bands?

2.2 Energy Time Curve (ETC)

Energy time curve (ETC) is commonly used for identifying the decay part (i.e., red dashed-line in Figure 3), the noise floor (i.e., green dashed-line in Figure 3 gree), as well as the cross-point (i.e., black dashed-line in Figure 3) in an impulse response. Mathematically, ETC is defined such,

$$ETC_o(t) = 10\log_{10}(h_o^2(t)) \quad \text{[dB]} \tag{1}$$

where, $h_o^2(t)$ is the filtered RIR squared in 1/1-octave frequency bands.

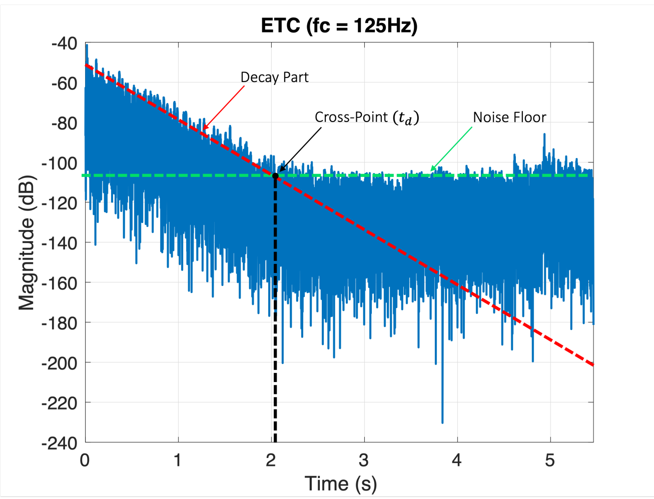

Figure 3: Energy time curve (ETC).

Tasks [1.00 Pts]

2.2.A. Compute the ETCs for the three filtered RIRs per 1/1-octave frequency band using the equation (1). Hint: Make this procedure into the for-loop.

2.2.B. Plot the ETC for each filtered RIR with respect to 1/1-octave central frequencies. Suggestion: Use the `subplot` into the for-loop. Also, adjust in the plots the magnitude from $-250dB$ to $0dB$.

2.2.C. Identify the cross-points in each individual ETC with respect to time (seconds), at which the decay curve meets the noise floor, in a visual way.

2.2.D. Provide cross-point time values in your report in a table.

2.2.E. Explain possible limitations of this approach.

3 Analyzing the Room Impulse Responses

3.1 Energy Decay Curve (EDC)

The energy decay curve (EDC) is used for smoothing out the fluctuations observed in the RIRs and therefore in the ETCs. A more precise representation of the captured decay field is provided. This method was introduced by Schroeder and it is known as the backward integration method. Mathematically, the EDC is defined such,

$$EDC_o(t) = 10\log_{10}\left(\frac{\int_{t_d}^{\infty} h_o^2(\tau)d\tau}{\int_0^{\infty} h_o^2(\tau)d\tau}\right) = 10\log_{10}\left(1 - \frac{\int_0^{t_d} h_o^2(\tau)d\tau}{\int_0^{\infty} h_o^2(\tau)d\tau}\right) \quad \text{[dB]} \tag{2}$$

where, $h_o^2(\tau)$ is the filtered RIR squared in 1/1-octave frequency bands and t_d the corresponding truncation time point identified from the ETC.

The truncation point (t_d) is associated to the point at which the noise floor joints the decay part. Hence, a better estimation of the decay part can be obtained. Consider the EDCs in Figure 4, where different truncation times have been used. The EDC is influenced by the noise peaks and therefore an upward trend is presented. This corresponds to an underestimation of the decay curve (purple curve). In terms of the red curve, a similar influence can be seen but now this is associated to an overestimation of the decay curve. Capturing the cross-point, the ”correct” decay curve (yellow curve) can be obtained.

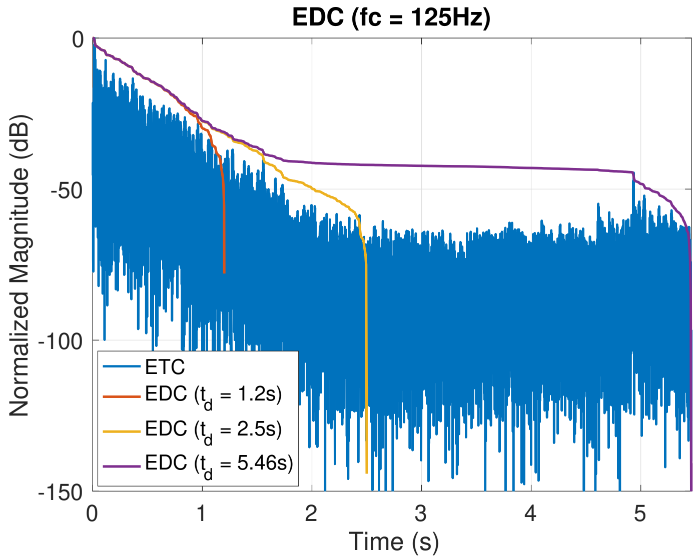

Figure 4: Energy decay curves (EDCs) of different truncation time points.

Tasks [0.75 Pts]

3.1.A. Open and complete the `EDC.m` function. Note: Fill-in only the parts pointed by three dots (...).

3.1.B. Using `EDC.m` function, compute the EDC for each filtered RIR with respect to 1/1-octave frequency band. Note: The `EDC.m` function computes *only one* energy decay curve per time due to the fact that the truncation time is not the same for each filtered RIR, corresponding to different lengths of truncated RIR signals.

3.2 Estimation of the Reverberation Time (T_{30})

The reverberation time can be either computed directly from the ETCs or EDCs, using the time difference of the range under consideration and multiplying with the a scalar factor, corresponding to the linearity in the decay curve (i.e., $T_{30} = 2 \cdot \{t_{-5_{dB}} - t_{-35_{dB}}\}$). A more precise way is the fitting of a first order linear polynomial of the form $y = a \cdot t + b$, $\forall a, b \in \mathbb{R}$, (i.e., yellow line in Figure 5) in the range $[t_{-5_{dB}}, t_{-35_{dB}}]$ (i.e., black 'o' in Figure 5) of the EDC (i.e., blue line in Figure 5). Then, the fitted line is extrapolated to $-60dB$, from which the reverberation time (i.e., vertical dash line in Figure 5) is estimated such,

$$T_{30} = \frac{-60}{a} \tag{3}$$

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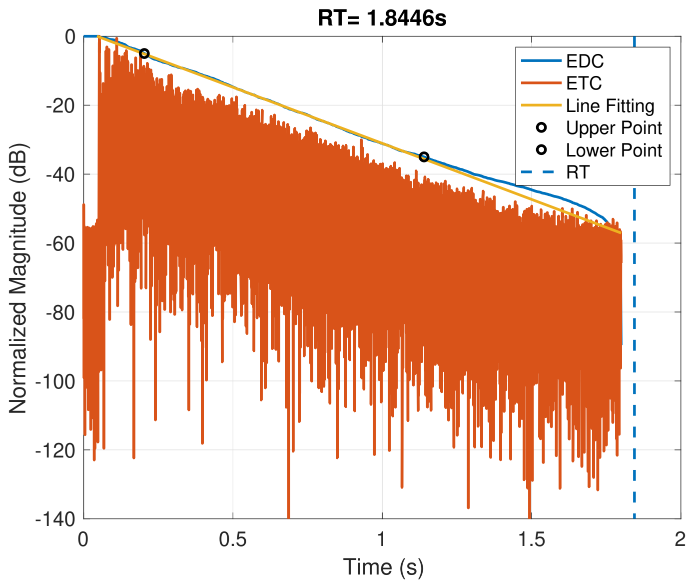

Figure 5: Estimation of the reverberation time T_{30}.

Tasks [1.50 Pts]

3.2.A. Open and complete the `RTLinFit.m` function. Note: Fill-in only the parts pointed by three dots (...).

3.2.B. Compute the T_{30} in 1/1-octave frequency band from all the RIRs, using the function `RTLinFit.m`. Note: This function estimates *only one* reverberation time per EDC.

3.2.C. Plot the values of the T_{30} per 1/1-octave frequency band for each RIR.

3.2.D. Include all the figures extracted from `RTLinFit.m` in the appendix of your report.

3.2.E. Calculate the average T_{30} per 1/1-octave frequency band.

3.2.F. Plot the average reverberation time per octave frequency band, including the standard deviation. Hint: Use the `bar` function holding on then the `errorbar` function.

3.2.G. Discuss possible differences in the reverberation time among the positions.

3.3 Clarity (C_{50} and C_{80})

Another acoustic parameter computed by the RIRs and related to the quality of speech and music in an enclosed space is the clarity, expressed such C_{50} and C_{80}, respectively. More specifically, clarity provides the energy ratio between the early reflections (i.e., until n milliseconds) and late reflection (i.e., from n milliseconds to infinity in continuous domain or the length of the signal in discrete domain). Mathematically, the clarity is defined such,

$$C_{n,o} = 10\log_{10}\left(\frac{\int_0^n h_o^2(t)dt}{\int_n^\infty h_o^2(t)dt}\right) \quad \text{[dB]} \tag{4}$$

where, $h_o^2(t)$ is the filtered RIR squared in 1/1-octave bands, limit $n = 50ms$ for speech, and $n = 80ms$ for music.

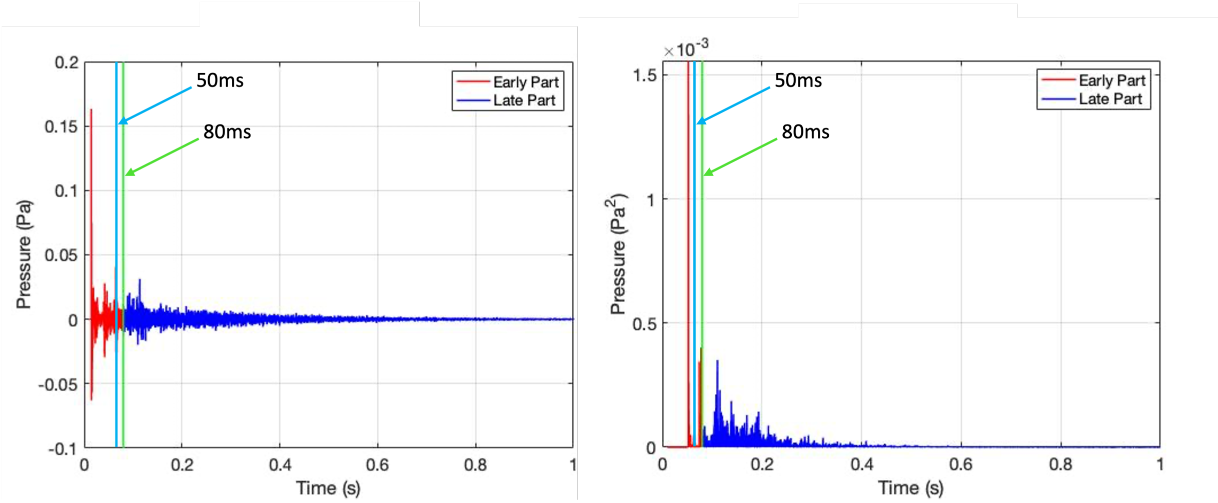

Figure 6: Early and late fields in RIR (left) and squared RIR (right).

Tasks [1.00 Pts]

3.3.A. Before computing the clarity, modify the filtered RIRs of the second and third position by removing the first 500 and 2300 samples, respectively. Why is it needed these samples to be removed?

3.3.B. Open and complete the function `C5080.m`. Note: Fill-in only the parts pointed by three dots (...).

3.3.C. Compute the C_{50} and C_{80} in 1/1-octave frequency bands for all the three RIR positions.

3.3.D. Plot the C_{50} and C_{80} in 1/1-octave frequency bands for all the three RIR positions.

3.3.E. Discuss possible differences between the C_{50} and C_{80} results.

3.4 Centre-Time (T_s)

The last acoustic parameter which can be computed by the RIRs and it is related to the spatial acoustic impression is the centre-time. Low values of centre time correspond to the domination of the direct field over the reverberant field, whereas high values of centre time indicate domination of the reverberant field over direct field. Mathematically, the centre-time is defined such,

$$T_{s,o} = \frac{\int_0^\infty t \cdot h_o^2(t)dt}{\int_0^\infty h_o^2(t)dt} \cdot 1000 \quad \text{[msec]}. \tag{5}$$

Tasks [0.75 Pts]

3.4.A. Open and complete the function `Ts.m`. Note: Fill-in only the parts pointed by three dots (...).

3.4.B. Compute the T_s per 1/1-octave frequency band for all the three RIRs. Note: Use the truncated RIRs for position 2 and 3 (i.e., Task **3.3.A**).

3.4.C. Plot the T_s per 1/1-octave frequency band for all the three RIRs.

3.4.D. Discuss possible differences among the T_s results.

4 Case Study

Suppose that one of your colleagues performed the latter RIR measurements for your convenience in the enclosed space. However, your colleague forgot to provide various information, including the usage of the enclosed space. Hence, it is needed to investigate the purpose of this enclosed space with respect to the RIRs analyses before continuing to any decision related to its acoustics modification.

Tasks [1.25 Pts]

4.0.A. Focusing on the Chapter 9 and more specifically on the subsection 9.2.1.1, 9.2.2.4, 9.2.2.6, and 9.2.2.10 in reference [Ballou, 2015], investigate the purpose of the enclosed space (i.e., speech and/or music) with respect to computed acoustic parameters. Note: The e-book of the reference [Ballou, 2015] is available via your TU/e library account.

4.0.B. Assuming that the three RIRs characterize the whole enclosed space, would you suggest an acoustic modification, improving its identified usage?

4.0.C. In the folder "ConvolvedSignals", two signals related to speech (i.e., Male Speech[1]) and music (i.e., Flamenco Guitar[2]) have been convolved with the three RIRs. By listening to the convolved signals, do the results and your decision, related to the usage of the enclosed space, match with your listening experience?

References

[Ballou, 2015] Ballou, G. M. (2015). *Handbook for Sound Engineers*. Focal Press, fifth edition.

[1] The speech signal was downloaded by https://odeon.dk/downloads/misc-anechoic-recordings/.

[2] The flamenco guitar was downloaded by http://audiogroup.web.th-koeln.de/.