Evaluating a Mobile App for Reverberation Time Measurements: Are valid values at your fingertips?

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Abstract

Reverberation time (RT) remains the main target value and assessment metric for room acoustic treatment. Most requirements are set for the reverberation time or derived metrics. Thus, RT measurements are often the starting point for needed room acoustic optimization while also being used to examine target values as projects move along or have been finished, making conducting RT measurements a core task for acousticians. Modern mobile devices offer sufficient computation power and the opportunity for pleasant and intuitive user interfaces, thanks to large touch screens. They have become omnipresent and are always at hand. Consequently, many mobile apps offering RT measurements have been brought to the market, mostly with poor accuracy and limited features. In this paper, we provide the results of a validation process for a new mobile app that allows RT measurements with interrupted noise, impulse signals, or exponential sweeps. Accurate results can be obtained by employing high-quality, yet affordable external hardware for the sound source and microphone. This has been evaluated by benchmarking octave band results from 125 Hz to 8 kHz to a commercially available measurement kit in various rooms, ranging from an office to a church with average RTs from 0.5 s to 1.3 s.

Introduction

Reverberation time remains one of the most important room acoustic parameters. Most guidelines set target values for RT depending on the intended use of the room. Moreover, room acoustic optimizations are often based on RT assessments to establish the status quo, allowing for proper acoustic treatments to be planned.

Conducting RT measurements is therefore a common and recurring task. While professional measurement equipment is available and delivers reliable results, it is often large, expensive, and difficult to use, especially for non-experts. On the other hand, smart devices such as smartphones and tablets have become ubiquitous and offer sufficient computational power to perform such measurements. Their large touchscreen displays provide numerous opportunities to display relevant information and guide users through the measurement process. Consequently, the question arises whether these devices can be used to conduct RT measurements and achieve reliable values. More precisely: under what circumstances can valid values be measured? The objective is not to replace professional measurement equipment, which remains necessary, particularly for legal assessments, but rather to offer an easy-to-use and budget-friendly alternative for cases where otherwise projects would not be undertaken, or where convenience outweighs the need for highly calibrated measurements.

Several apps are already available in app stores that claim to enable RT measurements. In his bachelor's thesis, Track [1] evaluated twelve iOS apps and found that six were incapable of achieving meaningful values. The remaining six provided valid results but lacked practical functionality for everyday usability.

Reverberation Time: Definition and Measurement

Reverberation time is defined as the time it takes for the sound field to decay by 60 dB after a previously continuous sound source has been turned off. Due to background noise, the full 60 dB energy decay is usually not achieved. Instead, a 20 dB or 30 dB decay is analyzed, referred to as T_{20} or T_{30}, respectively. Evaluation is performed by applying a linear fit to the energy decay curve (EDC) in the range from -5 dB to -25 dB or -35 dB, depending on the desired metric. A dynamic safeguard of 15 dB should be maintained to prevent noise from influencing the EDC slope in the lower region. This process is carried out separately for each examined frequency band.

The direct measurement procedure follows this definition: a broadband sound source emits sound, and once a steady state is achieved, the sound source is turned off. A microphone attached to a recording device captures the sound pressure level, allowing for data analysis as described above. This measurement method is known as the interrupted noise method.

Another approach is the indirect method, in which the room impulse response (RIR) is obtained, and the EDC is calculated using Schroeder backward integration [2]. To do so, the intersection point between the background noise and the EDC must be determined according to Lunderby [3] to find the starting time for the backward integration. Once the EDC is calculated for each band, RT is determined as previously described.

Two common methods exist to obtain the room impulse response: one involves an impulse source such as a popping balloon, a starter clap, or a pistol shot. However, this approach has limitations since no ideal impulse source exists. The other method is the exponential sweep method, as described in detail by Farina [4]. Here, the excitation signal is an exponential sweep covering all relevant frequencies. Parameters are the start and stop frequencies, as well as the sweep duration, which in combination with the playback level determine the signal-to-noise ratio (SNR). This method offers several technical and systematic advantages [5]. A general benefit of the indirect method is that once the RIR is available, additional room acoustic parameters can be analyzed. All these methods are implemented in the examined app and are referred to as the interrupted noise, impulse source, or sweep method, respectively.

Methodology

A new app, RTmeter, developed at Sarooma, was evaluated in a 2024 bachelor's thesis [6]. Reverberation times (RT) in octave bands from 125 Hz to 8 kHz were measured and compared to reference systems in six rooms: meeting room, classroom, church, reverberation chamber, lecture hall, and open-plan office (only the first four are shown due to space constraints). Table 1 provides room details, while Figure 1 offers a visual impression. Measurements were taken at various source-receiver positions (marked for reproducibility), using different hardware and excitation signals, to identify potential issues. Spatial averages were computed and compared to reference values.

Figure 1: Reverberation times for interrupted noise and sweep reference measurements, done twice on different days in the classroom.

Reference Systems

Two reference systems were used: one for the interrupted noise method and one for the exponential sweep method. The reference for the interrupted noise method consisted of a NTi Minirator (signal source), dodecahedron speaker with amplifier, and NTi XL2 (signal recording and analysis). Due to limitations in available professional systems for the sweep method (no professional system could employ sweeps with sufficient length), Room EQ Wizard (REW v5.3) was employed with the same hardware setup, where the Minirator played the sweep signal and the XL2 recorded it.

Used measurement hardware

The RTmeter app aims to offer a simple, functional tool for measuring RT and other room acoustic parameters

Table 1: Overview of the examined rooms with their core parameters. Reverberation time averaged over octave bands from 125 Hz to 8 kHz.

	meetin room	class-room	church	reverb. cham-ber
Area $/m^2$	29.3	67	250	43.7
Volume $/m^3$	75	202	1800	203
# sources / re-ceivers	2/3	2/3	4/5	2/4
Length $/m$	7.01	8.41	31	7.89
Width $/m$	4.16	7.97	19	5.54
Height $/m$	2.56	3.02	7	4.65
avg. RT $/s$	0.62	0.65	1.32	4.85

using mobile devices and affordable, widely available hardware. The app is not intended to replace professional systems but to serve as an accessible alternative for smaller-scale projects. As mobile device speakers are insufficient to excite the room, external sources are necessary. Commercially available Bluetooth speakers, such as the JBL Charge 5 used here, were used for this purpose, as they provide sufficient power, despite being non-omnidirectional. Studies [7] indicate omnidirectionality isn't strictly required for valid RT measurements, which aligns with the approach in this study.

Figure 2: Picture of the App hardware setup: on the left: class 2-compliant external microphone, right: JBL Charge 5 Bluetooth loudspeaker.

For impulse source excitation, the Norsonic Origami Impulse Source was used, though it only became available for the classroom measurements. While the internal microphone in mobile devices can give reasonable results, earlier studies [8] showed variability between devices. Internal microphones are also prone to handling noise and their directivity patterns, which are often unknown and may vary between devices. These issues prompted the use of external microphones, specifically the MicW i436 with a TRRS-to-USB-C adapter. All measurements were conducted with a Samsung Galaxy S20 phone (SM-G781B/DS) with Android 13.

Results

When comparing measurement results, it is crucial to determine the threshold for when results can be considered sufficiently identical and thus in agreement. Several approaches can be used to set this threshold. In this study, we chose reproducibility as the metric. To assess this, measurements were repeated in the same rooms with the same equipment, at identical source and receiver positions, on different days.

Although reproducibility generally yields larger tolerance values compared to repeatability comparisons, we believe it to be a fair metric. There is no reason to assume that one measurement–taken with the same equipment and at the same marked positions–should be trusted more than another. In some cases, measurements were repeated with different hardware components or excitation signals. While positions were marked, and utmost care was taken to reproduce the setup between measurements, smaller deviations might occur. These deviations are expected to not be larger than conducting the measurements twice on different days, thus yielding an upper limit.

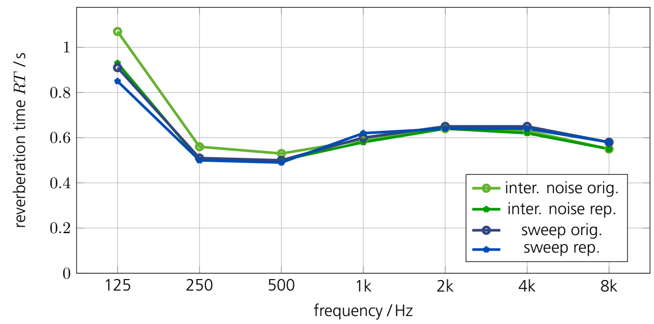

Figure 3: Measured reverberation times (T_{20}) in octave bands, averaged over all source and receiver positions in the classroom, measured with both reference systems (interrupted noise and sweep) on two different days (original and repeated measurements).

Figure 3 shows the results for the original and repeated measurements with both reference systems (interrupted noise and sweep) conducted in the classroom. The octave band reverberation times, averaged over all source-receiver positions, are plotted against frequency. Figures 7 and 8 display the relative errors for these reproducibility tests (red curves). The results show good agreement, though some deviations are visible, particularly at low frequencies.

The interrupted noise method shows deviations of up to 10% at 125 Hz, below 1 kHz, while the sweep method demonstrates good agreement for frequencies of 250 Hz and above. Overall, the interrupted noise method shows larger deviations, with a maximum of 10%, compared to a maximum of 6% for the sweep method.

As long as the deviations between the reference systems and the app measurements are smaller or of the same magnitude as the observed relative errors, fair agreement can be assumed. Therefore, the app results can be regarded as equally valid.

Classroom

In the classroom two source and three receiver positions are examined. A wide variety of hardware combinations were tested in this room. As no problems regarding the hardware components were observed, only the regular app and reference solutions are shown. Figure 4 shows the results for all excitation methods, averaged over all source-receiver combinations and octave bands: interrupted noise (star markers), sweep (round markers), and impulse excitation (square markers). All methods show good agreement above 1 kHz, but the interrupted noise method in the app appears to systematically underestimate the reverberation time (RT). In the 125 Hz octave band, noticeable differences are observed. The sweep method exhibits less deviation than the interrupted noise method (see Figs. 7 and 8), except for the 125 Hz band.

It is worth noting that the impulse source also delivers very good results, with significantly less hardware effort. Unfortunately, the impulse source was not tested in other (larger) rooms, so it remains to be seen whether the Origami impulse source can replace loudspeakers in all room types relevant for this application.

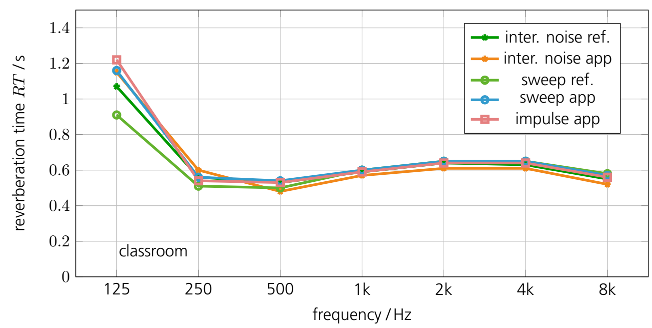

Figure 4: Measured reverberation time (T_{20}) for different measurement systems and hardware chains as room averages over all source and all receiver positions in the classroom. Here also direct impulse excitation was employed.

Meeting room

The examined meeting room is a small space, accommodating six to eight people. Figure 5 shows the app results and the reference measurements for the interrupted noise and sweep methods. As in the previous case, no noticeable difference is observed above 500 Hz, except for the 8 kHz band. As before, the 125 Hz octave band shows the largest deviation: up to -13% for the interrupted noise method and less than 5% for the sweep method.

Church

The church is the largest examined room in this study. Although the average RT of 1.3 s is short for a church, the distances between sources and receivers were large. However, the results show good agreement for the sweep method (see Fig. 6), while the interrupted noise method systematically underestimated the RT. This might be due to insufficient SNR over longer distances. The sweep method continues to show good agreement in this case as well.

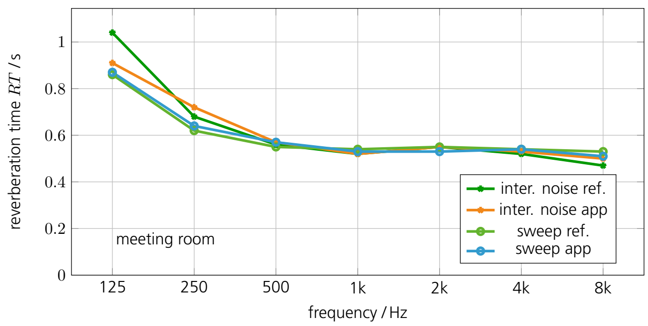

Figure 5: Measured reverberation time (T_{20}) for different measurement systems and hardware combinations as room averages over all source and all receiver positions in the meeting room.

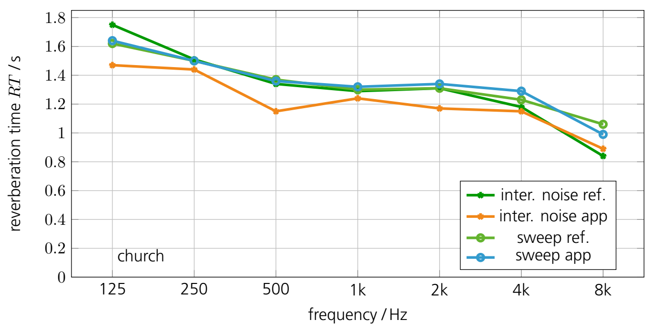

Figure 6: Measured reverberation time (T_{20}) for different measurement systems and hardware chains as room averages over all source and all receiver positions in the church.

Conclusion

Comparing reverberation time measurements in octave bands across six different rooms demonstrates that valid RT values can be obtained using mobile devices over a wide range of reverberation times. For all examined rooms except one, good agreement with reference systems was observed. In the reverberation chamber, the interrupted noise method did not provide valid results. Using high-quality consumer-grade external loudspeakers and affordable, class 2-compliant external microphones significantly improved measurement reliability. While internal microphones can yield valid results, external microphones are recommended to ensure more consistent and accurate measurements.

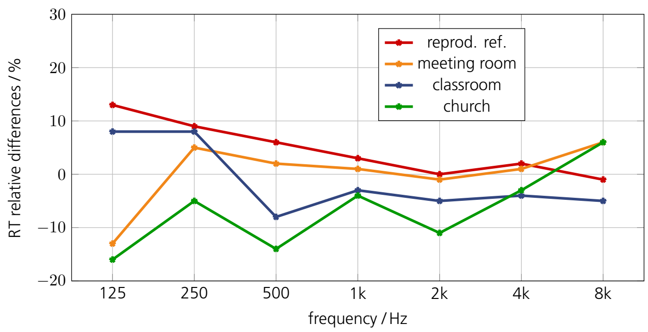

Figure 7: Relative deviations of measured RT values for different rooms, as well as the reproducibility (red) for the interrupted noise method.

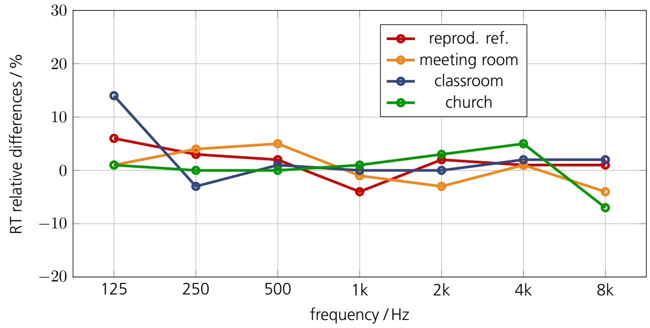

Figure 8: Relative deviations of measured RT values for different rooms, as well as the reproducibility (red) for the sweep method.

Overall, the sweep method consistently exhibited better agreement with reference solutions than the interrupted noise method. It also proved more robust, successfully calculating RT values even in cases where the interrupted noise method failed for individual source-receiver combinations. Both methods exhibited larger deviations at low frequencies, which is expected due to their higher susceptibility to room modes, placement, and filtering effects.

Future work should include further testing across a range of devices to ensure consistent performance. The app's usability can be improved by guiding the user through the measurement procedure and implementing algorithms that increase robustness by detecting disturbances during measurements. These algorithms could either correct errors where possible or suggest adjustments to the user to minimize such issues in the future.

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