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Mimicking the Sound Field of a Dodecahedral Loudspeaker by a Common Directional Loudspeaker for Reverberation Time Measurements

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Summary

A dodecahedral loudspeaker is commonly required for precise impulse response and reverberation time measurements in acoustic spaces. Alternative methods exist for the excitation of the sound field and are useful when a dodecahedral speaker is not available. A common directional loudspeaker is utilized in this study for mimicking the sound field created by a dodecahedral loudspeaker for reverberation time measurements. For this purpose the front face of the directional loudspeaker was placed in twelve positions similar to the twelve positions of the faces of a dodecahedral loudspeaker. For each of the twelve positions with the use of an exponential sine sweep, impulse responses were measured for the same microphone position. The twelve impulse responses obtained were added up creating a single impulse response. Measurements were also performed with the use of a dodecahedral loudspeaker for the same source and microphone positions according to ISO 3382-1:2009 in spaces with volumes of 192.4 m^3 and 88 m^3. Comparison for octave band reverberation time measurements between those obtained with the dodecahedral loudspeaker and the proposed method for the same microphone and source positions shows a mean absolute error of 0.038 sec with a standard deviation of 0.055 sec in the case of the room with volume 192.4 m^3. In the case of the room with volume 88 m^3 the mean absolute error was 0.056 sec with a standard deviation of 0.077 sec. Implications of the findings suggest that reverberation time measurements with the proposed method utilizing a common directional loudspeaker can provide usable results. The proposed method appears to be an alternative low-cost method for measuring reverberation time without the use of a dodecahedral loudspeaker.

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1. Introduction

Reverberation Time (RT) is recognized as being the most important acoustic parameter that defines an acoustic space. It is the time necessary for the sound to decay by 60 dB from its initial level. RT can be presented as a single value but since it is frequency dependent, it is commonly presented and more precisely described in terms of frequency bands (one octave, 1/3 octave etc.). Appropriate RT is required in acoustic spaces according to their usage (classrooms, theatres, music halls etc.). Hence the precise measurement of the RT is of

great importance.
Usually the measurement of RT utilizes a dodecahedral loudspeaker following the sound source requirements according to ISO 3382-1:2009 [1]. Dodecahedron loudspeakers are the most widely used “omnidirectional” sources for room acoustics measurements. However other polyhedron loudspeakers can be used which in some cases can be viewed as equally omnidirectional [2]. It is important to note that directivity of a dodecahedral loudspeaker is not optimum above certain frequencies. Stepwise rotation of dodecahedron sound source can be employed to improve the accuracy of room acoustic measurements [3]. It has been shown that constructive interference of the pressure field across the spherical baffle surface and not individual loudspeaker pistonic radiation characteristics is the most significant factor with respect to deviations from omnidirectional radiation [4].
The most common excitation signals that are used with a dodecahedral speaker are Exponential Sine Sweep (ESS) and Maximum Length Sequence (MLS). Also white or pink noise can be used as excitation signals.
In the case were a dodecahedral speaker is not available, the most common sources for excitation are pistol shots [5], wooden clappers [6], balloon bursts [7], firecrackers [8], shotshell primers [9], or even handclaps [10]. However, there are certain drawbacks associated with the use of such impulse sources. Typically a lack of repeatability is common and the frequency response of the sources is not flat. Through experiments in different acoustic spaces it is found that using such impulse sources leads to greater variation in the results, especially at low frequencies [8], [11], [12].
With this in mind there is still a need for an inexpensive, practical method for measuring RT without the use of a dodecahedral speaker. This study set out to explore if a common directional loudspeaker can be utilized for mimicking the sound field created by a dodecahedral loudspeaker for RT measurements. RT between the results obtained with the common directional loudspeaker and dodecahedral loudspeaker were assessed in order to quantify the results.
The results of this investigation show that the proposed method utilizing a common directional loudspeaker can provide usable results for RT measurements. This method represents a viable, low cost method for measuring RT without the use of a dodecahedral loudspeaker.
Chapter 2 is concerned with the methodology employed for this study, while chapter 3 presents the findings of the research. Discussion section analyses the data gathered and addresses the research questions in turn. Concluding remarks are presented in the final chapter.

2. Methods Description

In order to investigate our hypothesis, measurements were performed with a common directional loudspeaker and also with a dodecahedral loudspeaker for the same source and microphone positions according to ISO 3382-1:2009.
The measurements were carried out in two acoustic spaces of the Technical Educational Institute of Crete in the Department of Music Technology and Acoustics with volumes of 192.4 m^3 and 88 m^3. The first space is a typical classroom, while the second one is a smaller classroom used mainly for lab exercises.
For the measurements with the dodecahedron speaker the ESS signal was used [13]. The sampling frequency of the measurement was 44.1 kHz. The particular excitation signal was preferred because of the low background noise [14, 15]. Impulse response measurements were performed. An appropriate sequence length and time constant for the ESS signal was chosen according to the expected RT. Three iterations were performed for each of the measurement points. Averaging was used for better signal to noise ratio and to reduce the temperature fluctuation effect. The variations of temperature and hence the sound velocity with time and position cannot be entirely avoided but the effects which are caused by these in-homogeneities can be considered to be small. RT was extracted from the impulse responses. Three microphone positions were used for each of two loudspeaker positions to obtain a good average at each of the octave intervals. A microphone (Type 4190, Earthworks) was used for each of the measurements. An omnidirectional dodecahedral loudspeaker (Type DO12, 01 dB-Stell) was placed at two loudspeaker positions which were at least 3 m apart.
For measurements with the common directional speaker the same source and microphone positions were used. For this purpose the front face of the directional loudspeaker (Behringer Truth B2031A

Active 2-Way Reference Studio Monitor) was placed in twelve positions similar to the twelve positions of the faces of a dodecahedral loudspeaker. For each of the twelve positions, impulse responses were measured for the same microphone position.

According to the measurements with the dodecahedron loudspeaker measurements, an ESS excitation signal was used with the same sampling frequency of 44.1 kHz. The same appropriate sequence length and time constant for the ESS signal was chosen according to the expected RT. Three iterations were performed for each of the measurement points for each of the twelve loudspeaker positions. Averaging was used for better signal to noise ratio and to reduce the temperature fluctuation effect.

Three microphone positions were used for each of two loudspeaker positions to obtain a good average at each of the octave intervals. The same microphone (Type 4190, Earthworks) was used in the same position for each of the measurements. The twelve impulse responses obtained were added up with the use of the software 'Matlab' creating a single impulse response. The impulse response was normalized so that it had approximately the same sound level with the impulse response obtained from the dodecahedral loudspeaker. The speaker was handheld for practicality reasons.

2. Results

Comparison for octave band RT measurements between those obtained with the dodecahedral loudspeaker and the proposed method for the same microphone and source positions are presented in Fig.1 and Fig.2 for the rooms with volumes 192.4 m^3 and 88 m^3 respectively. Comparison shows a mean absolute error of 0.038 sec with a standard deviation of 0.055 sec in the case of the room with volume 192.4 m^3.

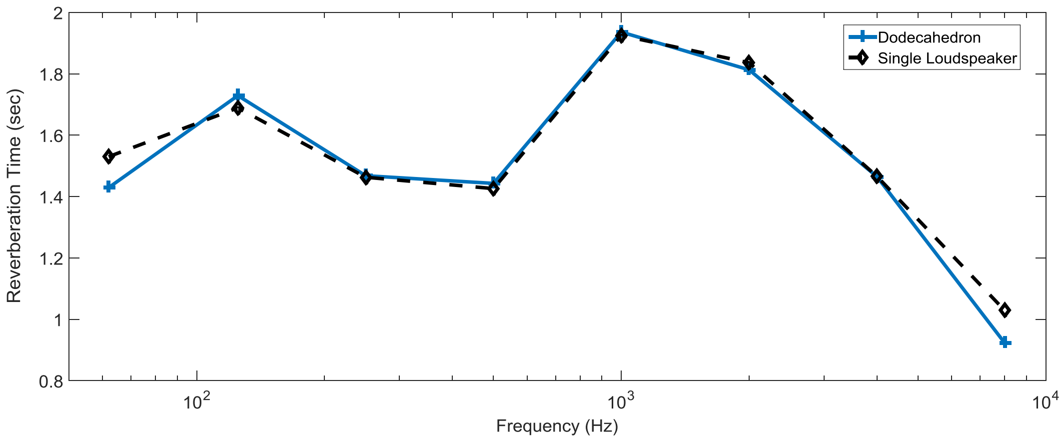

Figure 1. RT measurements, room volume 192.4 m^3

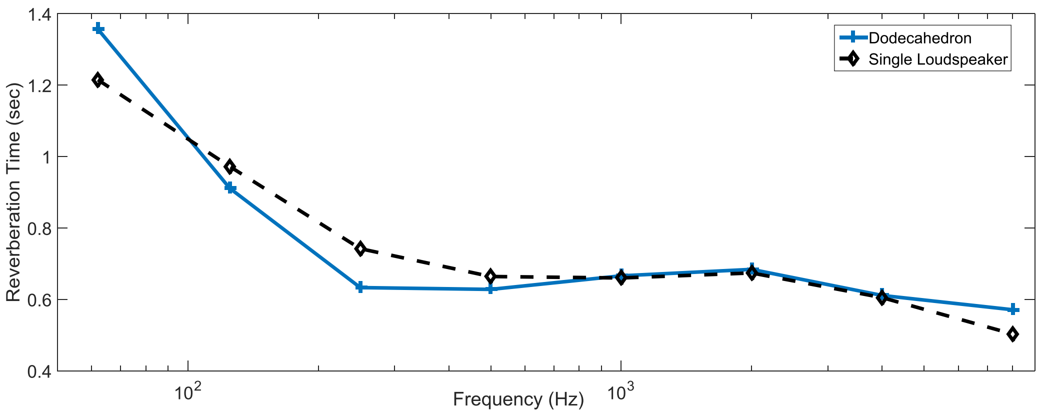

Figure 2. RT measurements, room volume 88 m^3

In the case of the room with volume 88 m^3 the mean absolute error was 0.056 sec with a standard deviation of 0.077 sec.

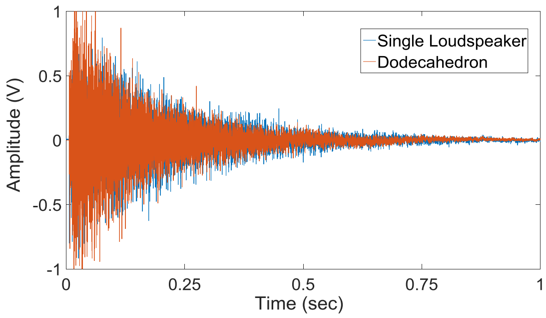

Figure 3. Impulse responses, room volume 192.4 m^3

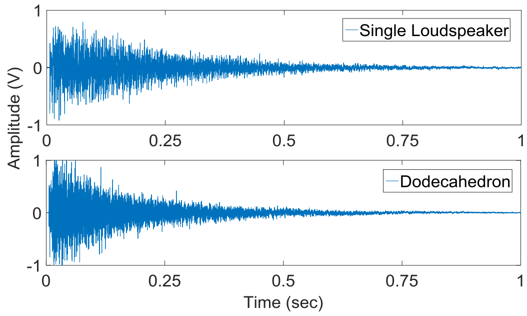

Figure 4. Impulse responses, room volume 192.4 m^3

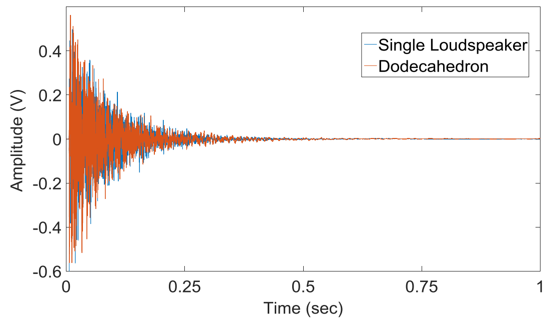

Figure 5. Impulse responses, room volume 88 m^3

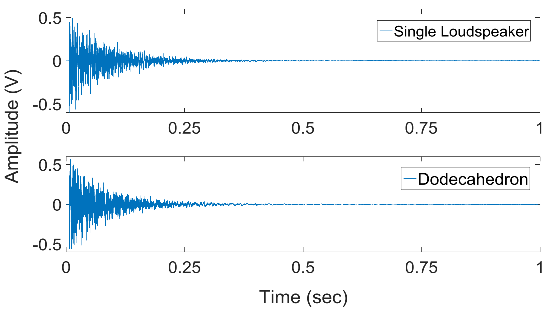

Figure 6. Impulse responses, room volume 88 m^3

Figures 3 and 4 present the impulse responses obtained with the dodecahedron and the single loudspeaker for the room of volume 192.4 m^3. Figures 5 and 6 present the impulse responses obtained with the dodecahedron and the single loudspeaker for the room of volume 88 m^3.

4. Discussion

The main goal of this study was to attempt to utilize a common directional loudspeaker as a source for RT measurements. The results seem to support the hypotheses. Overall, the results presented above show that the proposed method represents a viable alternative that can be used for the measurement of RT for practical applications with low cost.

One possible explanation for these results may be that the requirements for an omnidirectional sound source acquired from ISO 3382-1 [1] are met to a certain extent by using a directional speaker. The requirements are:

1. a maximum deviation of directivity of source in decibels for excitation with octave bands of pink noise and measured in free field is expected
2. the dodecahedral speaker shall produce a sound pressure level sufficient to provide decay curves with the required minimum dynamic range, without contamination by background noise
3. synchronous averaging is possible

Requirement 2 is sufficiently fulfilled by the proposed method since a common directional loudspeaker can provide sufficient levels of sound pressure without distortion. Requirement 3 is also met since synchronous averaging is possible if excitation signals such as ESS and MLS are applied. So if the requirement for directivity is covered to a satisfactory degree, then the results are justified to a certain extent.

The above results show how much the proposed method can outperform the other low cost excitation sources that were presented in the introduction (pistol shots, wooden clappers, balloon bursts, firecrackers, shotshell primers, handclaps). While it is relatively easy to provide a sufficiently high signal to noise ratio using some of the low-cost sources, their signal energy tends to be unevenly distributed across a wide range of frequencies. Also there is not good repeatability of the excitation signal and the directivity is not even. However, the utilization of a directional

loudspeaker with the proposed method ensures repeatability of the measurements. Signal energy tends to be evenly distributed across a wide range of frequencies in the case of a domestic loudspeaker of good quality. Our method seems to be a clear improvement on current low cost methods.
The low cost of the method can be further enhanced by commercially free software or digital audio workstations that can be utilized to generate the final impulse response from the sum of the partial impulse responses. Also commercially free software is available for ESS impulse response measurements.
This study is the first step enhancing our understanding of how a directional loudspeaker can be used for RT measurements. These observations have several implications for research into many fields where acoustic measurements are required. This approach has the potential to be the prime method for low cost methods without the use of dodecahedral loudspeaker. In our view these results constitute an excellent initial step for the proposed method. Our approach would lend itself well for use in all cases where a dodecahedral loudspeaker is not available, hence for many practical applications for measuring RT.
A possible implication of this study is that it can lead to the design of a directional loudspeaker specific for low cost RT measurements. This directional loudspeaker could also be utilized for impulse response and acoustic parameters measurements.
Given that our findings are based on measurements with a single domestic loudspeaker, the results from such analyses should thus be treated with the utmost caution. It is possible that these results are due to the specific loudspeaker and might not be generalizable to other speakers to the same extend. Another source of uncertainty is that due to practical reasons the domestic loudspeaker was hand held. Hence there is a probability that different body types may influence the results.
This research has raised many questions in need of further investigation. We are currently in the process of exploring the effect of different loudspeakers in different price ranges for acoustic measurements with the proposed method. A greater number of domestic loudspeakers could lead to a higher generalization of our results and perhaps guide the way for a custom speaker design for better results. We hope that our research will serve as a base for future studies on directional speaker design for measuring acoustic parameters.
A natural progression of this work is to analyze the applicability of the method for measuring acoustic parameters. Another course of direction is the exploration of different placements for the directional loudspeaker. The front face of the loudspeaker can be placed in different arrangements beside the twelve positions similar to the twelve positions of the faces of a dodecahedral loudspeaker that were used in this study. Our investigations into this area are still in progress and seem likely to confirm our hypothesis that the method can provide even better results for RT measurements, acoustic parameters and impulse response measurements.

5. Conclusions

We have found an innovative solution for measuring RT without the use of a dodecahedral loudspeaker. A common directional loudspeaker was utilized in this study for mimicking the sound field created by a dodecahedral loudspeaker for RT measurements. RT between the results obtained with the common directional loudspeaker and dodecahedral loudspeaker were assessed in order to quantify the results. Our work has led us to conclude that the proposed method can provide acceptable results with satisfactory accuracy.
The present study should prove to be particularly valuable to practical applications were a dodecahedral speaker is not available. A key strength of the present study is that a domestic directional loudspeaker is commonly available hence RT measurements can be utilized with minimum cost.
Since the present study has only investigated a single domestic loudspeaker the results from such analyses should be treated with the caution. To develop a full picture of the method additional studies will be needed. A natural progression of this work is to explore the applicability of the method for measuring other acoustic parameters. We are currently in the process of investigating the applicability of the method with a variety of speakers in different price ranges. Our investigations into this area are still in progress and seem likely to confirm our hypothesis since results so far have been very encouraging. These topics are reserved for future work.

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