論文の内容の要旨
Abstract of Dissertation

論文題目: Time-domain swept signal based measurement and processing of impulse responses for room acoustic evaluation (インパルス応答の時間領域掃引信号による計測法と室内音響評価のための信号処理手法に関する研究)

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Abstract

Room acoustic measurements and evaluation play a key role in the objective assessment of spaces used for living, working, cultural or entertainment purposes. The importance of accurate and reproducible measurements and objective evaluation is in common interest both scientifically and economically. Room acoustic measurement and evaluation techniques are continuously evolving together with other scientific fields, such as with developments in electrical engineering, telecommunication, signal processing and representation, and with life sciences and emerging multi-disciplinary fields. The utilization of room acoustic measurements is multi-fold, but basically serves the purpose to support the evaluation, design, construction and reconstruction of acoustic spaces, such as halls for public performances, music practice, or spaces for work such as open-plan offices.

In current room acoustic measurements and evaluation, the study of room impulse responses (RIRs) and extracting information therefrom plays a key role. The series of reflections in single RIRs are commonly interpreted as to contain all information about the room and the sound transfer properties between two given spatial positions where the measurement was made. But RIRs have a considerable size both in time and in frequency range, therefore this information is easily contaminated by noise and other perturbation effects and is often difficult to handle. In certain practical conditions, noise is beyond our control, so emphasizing the excitation signal is the only workaround, requiring a flexible measurement signal generation method that besides is also easy to use. On the other hand, appropriate signal processing and representation matching given purposes can also increase or magnify useful information in a measured or simulated RIR.

The main objective of the research described in the present thesis is to consider and formulate new methods that provide flexible solutions to room acoustic measurement and evaluation problems.

Presently available measurement methods are either limitedly flexible for practical use or show considerable disadvantages, such as the requirement of a large amount of a priori input information, which leads to inconveniences such as a considerable on-site preparation time during a measurement, limitedly useful measured data, or increased uncertainties. Flexibility in the present thesis stands for providing offline or adaptive capabilities for customizing measurement signals to on-site conditions easily. A general time-domain formulation of excitation signals that can be controlled with only a few input parameters is not yet available, therefore the present work first proposes a solution for this problem and then discusses its application. The proposed granular signal generation approach is aimed to provide automatic and scalable applicability for recent computer systems or advanced hand-held devices of the future.

In room acoustic evaluation, particularly in the calculation of room acoustic parameters from measured or numerically simulated room impulse responses, there is a multitude of challenges. Presently established room acoustic parameters in their traditional calculation methods are often unreliable in hostile field conditions, such as in the presence of a considerable amount of background noise, in case the measurement time is limited, or at

certain physical placements of the measurement devices (source-receiver positions). Several room acoustic parameters are not just unreliable but even unobtainable under certain measurement conditions that are still realistic to appear in practice. There is room for both the improvement of currently established methods and for extending their applications, and also for introducing alternative ways of representing and processing RIRs for the purpose of obtaining current or new room acoustic parameters. The thesis addresses these issues, and proposes evaluation and signal processing methods based on theoretical, numerically simulated and measured data as well. The proposed methods are aimed to support improved information extraction, especially for real-life non-ideal decays. The thesis however does not consider the matching of newly proposed objective measures to subjective perceptions, but hopefully opens opportunities for further work to provide additional insight in that respect.

Firstly, a perfect-amplitude time-domain flexible signal generation method is presented and discussed, providing the capability of creating arbitrary magnitude excitation signals. First, sweeplet signals, then spectrally extended composite sweeps are introduced and their usage discussed and compared.

Secondly, time-domain representations of room impulse responses are discussed. Given a literature review, aspects of the energy decay function is discussed in more detail and systematically analyzed, which cannot be found in the literature in this detail. Thereafter, discussions on the signal-to-noise and peak-to-noise ratios and a new method to calculate the SNR based on analytic considerations and simple assumptions is suggested and compared with previous methods. After the review of presently used room acoustic parameters, detailed focus is given to decay time estimation methods. Two new decay time estimation methods, the Fourier-based method and the multicomponent iterative nonlinear regression are introduced and compared to the currently published methods.

Finally, a method achieving inter-sample independent controllable smoothing is introduced and examined. Based on this concept, a generalized decay function (GDF) with controllable smoothing is introduced, providing flexibility in representing RIRs in time-domain. Application examples of the GDF are presented, including enhanced accuracy low frequency reverberation time calculations, mitigating a strong direct sound or reducing the effect of the background noise. The controllable smoothing is used to redefine the reverberation time and offer a calculation method based on forward integration, a fundamentally different concept from previously published methods in the room acoustic literature. A new definition of reverberation time, a reverberation interval is proposed and the forward integration method is presented and verified. Afterwards, a unified representation of some temporal and energetic room acoustic parameters is presented. The concept is introduced by presenting a correlation analysis using a large measurement database. As a result, various room acoustic parameters are representable on a smoothing-dependent scale, and correspondingly, it is concluded that the early decay time may also be considered as a parameter in between the categories temporal and energetic.

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