Room Modeling for Acoustic Simulation and Auralization Tasks: Resolution of Structural Details

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Introduction

All room acoustical simulations and auralizations [1] base on an underlying CAD model. These models have to be optimized for the desired simulation technique. When the demands state high quality by physically based soundfield reproduction as well as low-latency computation, geometrical acoustics (GA) become the methods of choice. They have proved to be most satisfying when it is necessary to balance simulation speed and quality. For GA, the CAD models have to fulfill several conditions - one of them stating the assumption that all faces of walls and objects are larger than any wavelength of interest. For audible sounds those wavelengths range from 1.7cm to 17m, exceeding the dimensions of common objects and room boundaries, so that a broadband simulation using only one fix model cannot deliver correct results.

A new approach that is presented in this paper introduces an auralization engine which is based on GA and which uses a set of models of the same room but with graduated level of detail (LOD). These different models can account for more physical correctness especially for low frequency specular reflections. Furthermore they allow to speed up the simulation process at the same time, which supports the engine's ability to run in real-time. The speed-up is achieved by the reduced number of polygons especially for low frequencies, where lower absorption usually causes higher reflection orders.

Physical Background

The physics behind GA makes use of the wave-particle dualism, i.e. sound waves are interpreted as particles or sound rays. If objects or surfaces are roughly of the same size or smaller compared to the wavelength of incident sound waves, those geometric reflections would be in contradiction to the acoustic wave effects that occur in such situations, resulting in reflections that would simply be wrong, see Figure 1. Consequently, the acoustic CAD model has to be matched to the sound frequencies of interest that cover three decades of human hearing, which is not possible with just one model.

Until now, a compromise is made concerning the degree of detail in the acoustic model - but without any verification. The only study done so far is [4]. The image source model used, however, is too rough an approach for room acoustical simulation. So far it is not known how much simplification is allowed without being audible or how much accuracy is needed when modeling fine details of the room structure. A highly detailed room model runs the risk of bad accuracy for mid and low frequencies and especially very high (unnecessary) computation time while a very low detailed model might be too simple, missing out on important acoustic characteristics.

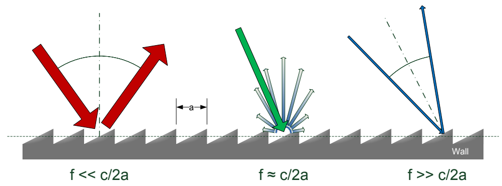

Figure 1: Frequency(f)-dependent reflections at surfaces with structures of dimension a (c: sound speed). Low frequencies are not able to see structural fine details (after [1]).

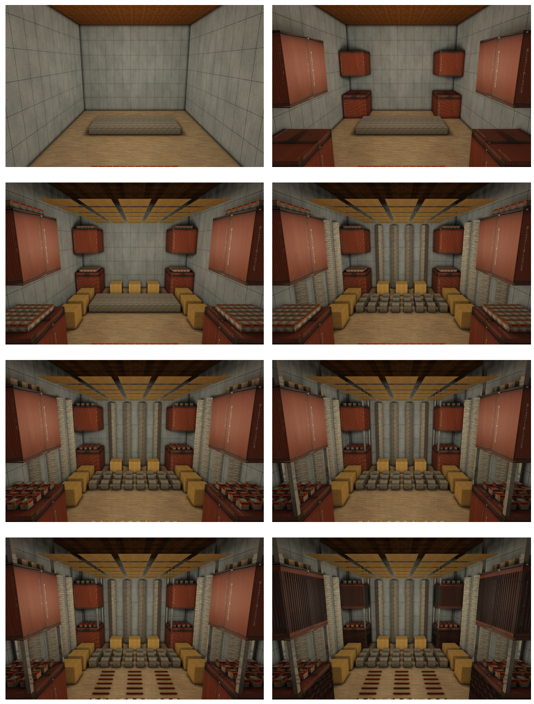

Figure 2: Example of an acoustic model set with 8 different LOD (10m, 5m, 2.5m, 1.25m, 60cm, 30cm, 15cm, 7cm).

Listening Tests

In listening tests that were carried out in co-operation with the Audio Communications Group at TU Berlin, some guidelines for the development of acoustic models could be discovered. The method of constant stimuli following a 3AFC-paradigm was applied, 8 models with graduated LOD as shown in Figure 2 were presented. The listening tests unveiled the abilities of the human ear to detect changes of the surrounding geometry.

All graduated models were pairwisely compared to the model with the highest detail grade and the subjects were asked to pick the different auralization from the list of three, so that 33% correct answers (67% wrong answers resp.) indicate no discriminability and values close to 100% indicate a high discriminability. The listening test included several source and receiver positions as well as various dry input signals. Figure 3 left shows the empirical relative number of wrong answers (histogram) as well as the matched normally distributed probability density function. Structural detail sizes are shown logarithmized to be perceptually adequate and they are mirrored at the ordinate to help fitting the Gaussian curve. Thus observations are restricted to the relevant half of the probability density and distribution, yielding a threshold of noticeable simplification at 75% in the cumulative distribution function that represents the collective psychometric function of all subjects [3], see Figure 3.

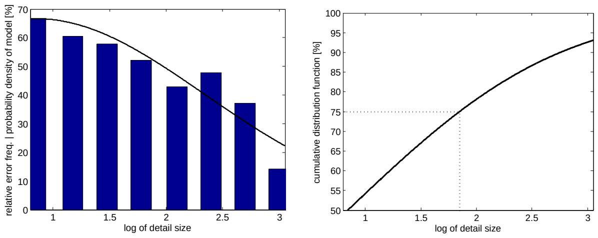

Figure 3: Histogram and probability density (left), cumulative distribution and threshold at 75% (right).

The threshold of noticeable simplification yields to *70cm*, defining a structure size which is not needed to go beyond when modeling fine details, because further elaboration would not be audible. This result is valid only for the presented room type at this stage.

Level-of-Detail Modeling

Ideally, the number of models should be matched to the desired frequency resolution of the simulation. For real-time auralizations, it is common to limit the frequency range to 10 octave bands.

In the listening tests it became apparent that differences of structural details below the size of 70 cm become more and more indistinguishable. At the same time, a minimum size of 70 cm qualifies the model to run GA based simulations as from 500 Hz. Thus, for octave resolution we propose a set of 5 models, as shown in Table 1.

Table 1: Parameters for the proposed set of LOD models, with minimum structural sizes and resulting valid frequencies.

Min. struct. size [m]	0.7	1.4	2.8	5.6	11.2
Valid frequency [Hz]	>500	>250	>125	>63	>31

Such a model set yields physically correct reflection patterns for every single frequency band, and additionally reduces the average number of polygons that have to be taken into account in a broadband simulation, saving valuable computation time.

Results and Performance

The real-time auralization software *RAVEN* [2], that combines image sources (IS) and ray tracing (RT), was used for performance measurements. The whole simulation process is mainly dominated by the RT algorithm, which consumes much more computation power compared to the audibility test of the IS. The audibility test runtime is not affected by the LOD control, unless the physically more precise combination of IS of all LOD models is desired. Figure 4 shows how the RT runtime is highly accelerated, yielding an overall speed-up of factor $2.23x$ in a test environment that used 8 different LOD, see Figure 2.

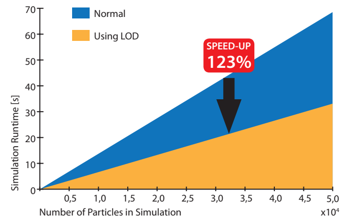

Figure 4: Speed-up of the LOD approach compared to the simulation of the highest detailed model only.

Conclusion and Outlook

The LOD approach is convincing in consideration of the physics behind GA simulations. Higher accuracy and about two times faster RT calculations are very appealing for physically based real-time auralization software such as Raven. Also IS algorithms profit, as they can use a certain model of the LOD set, making the IS method even more scalable along with the IS order.

A further implementation of LOD controlled RT can include a time-dependency using decreasing model details with increasing time in the impulse response (IR). Due to psychoacoustic masking effects of the late part of IR as well as late reflections majorly being diffuse, structural fine details lose relevance in that late part. Another important topic for future research lies in the field of scattering patterns, which are strongly dependent on the structural fine details and their geometric orientation.

References

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