Fields of application for three-dimensional microphone arrays for room acoustic purposes

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ABSTRACT

Many acoustic indicators used in the standards of room acoustics consist of global criteria which allow characterizing the most important properties of a room relatively well. In addition to the well-established and standardized methods, the application of three-dimensional microphone arrays in connection with calculations in the time domain (delay and sum beamforming) can give far more detailed insights. However, the application of 3D-beamforming requires a geometric CAD-model of the room which is often not readily available in practice. This paper shows an approach that is based on using a 3D-scanner to quickly acquire the geometry information of the room. The scanning times achieved are in the range of a few minutes. The scan points recorded by the scanner are algorithmically processed to a sufficiently dense and homogenous 3D-mesh. The room model computed this way then forms the base for the following acoustic 3D-beamforming. This combined system of scanner and array allows a very fast evaluation of interiors. The advantages, the possible application ranges as well as the limits of the method will be discussed, and practical application examples from real environments will be shown.

INTRODUCTION

In the last years the use of microphone arrays ("*Acoustic Camera*") has become vitally important for acoustic measurement engineering. The localization of sound sources (in time and frequency domain) known as beamforming (Johnson & Dudgeon, 1993) has become an important technique of acoustic analysis and the reduction of noise. The increasing power of computers facilitates the transition from two-dimensional acoustic maps to complex three-dimensional acoustic models that opens new fields of application. (Döbler & Meyer 2007; Döbler & Meyer 2006; Döbler, Hambrecht & Meyer 2011)

This paper points out the possibilities enabled by using three-dimensional microphone arrays for purposes of room acoustics. It shows the new kinds of information won by this application.

THREE-DIMENSIONAL ACOUSTIC MODELS

To determine the acoustic characteristics of a room a three-dimensional model of the room is needed as well as a beamforming system that consists of a microphone array, a data recorder and software for calculating the acoustic maps. Many manufacturers (e.g. car manufacturers) can easily request CAD models from their construction department.
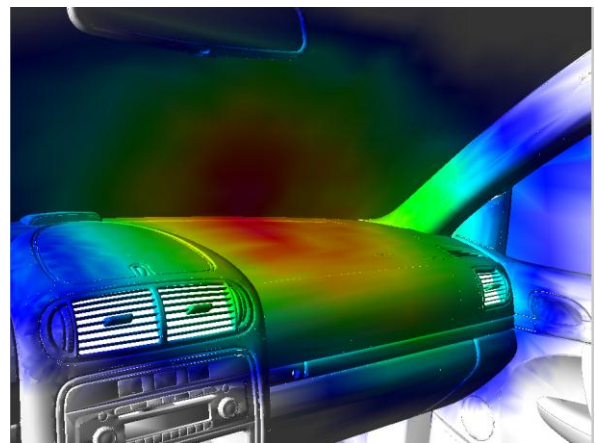

Figure 2 – three-dimensional photo that shows the consequences of a defect windshield wiper
the red colored area shows high noise levels, the blue area shows low noise levels

Figure 1 – 3D - microphone array with 120 spherically distributed microphones for the analysis of interiors

In room acoustics it can prove difficult to acquire suitable models mainly due to the significant differences of the single measurement object. In that situation one way is to manually create a CAD model of the object. But that is time-consuming and comes along with high costs. Available laser scanners (FARO®, Leica, etc.) are able to determine a room's dimension in a short period of time. Unfortunately, these scanners are not tailored to the needs for room acoustics. Measurement accuracy in a range of sub-millimeters is much higher than needed for room acoustic purposes. The very high exactness of measurement leads to a large amount of data and comes along with high purchase costs. The GFaI (sSociety for the Promotion of Applied Computer Sciences) has developed a laser scanner assembled from standard components that is a reasonable alternative for the requirements of room acoustics. The measurement accuracy covers the range of centimeters and optimized algorithms will be used to create homogeneous triangle meshes. The laser scanner consists of a two-axis rotation module (SCHUNK GmbH & Co. KG) and a laser scanner module produced by Leuze electronic GmbH + Co. KG.

Figure 3 – laser scanner developed by the GFaI

This scanner allows fast and cost-efficient acquisition of the room dimensions. In combination with the acoustic recording and analysis software it represents an integrated solution for the accomplishment of simulation and measurement tasks.

SURVEYING ROOM DIMENSIONS FOR ACOUSTIC MAPPING

To determine the full geometry and surfaces of a room it is normally necessary to scan the room from different positions. The result of these scans is a set of point clouds that represent the surfaces of the room as well as all objects located in the scan area. Before the construction of a digital three-dimensional model all scanning results have to be combined to one data set. At this point

it is already possible to overlay the point model with an acoustic map. But in order to get a better illustration and for further use with other applications it is necessary to triangulate the point cloud to get a homogeneous triangle mesh (Figure 4).
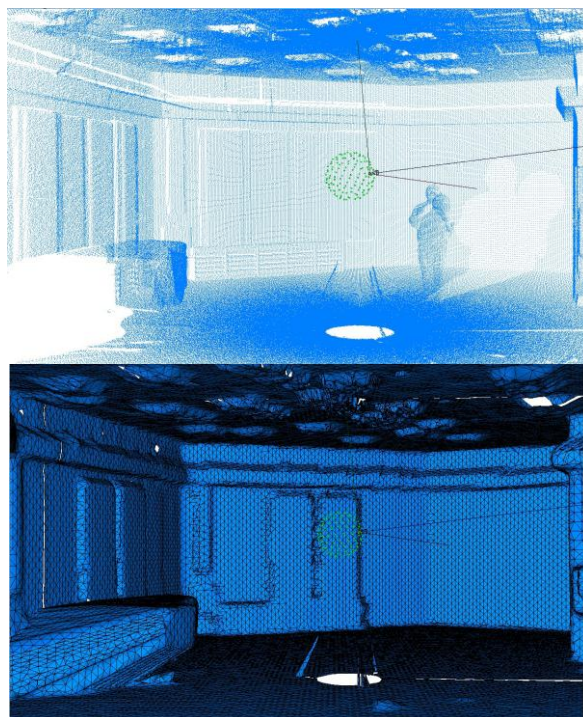

Figure 4 – point cloud (top) and triangle mesh (bottom) of a sound studio

REVERBERANT DECAYS

Probably, the most important characteristic of a room is its reverberation. The *reverberation time* as an acoustic indicator was introduced by Wallace Clement Sabine (1868 - 1919). The definition of the RT is the time needed for reflections of a sound event to decay by 60dB below the level of the direct sound (RT_{60}). Many rooms do not allow a dynamic range of 60dB, so the beginning part of the decay corresponds much better with the subjectively sensed reverb of the room. For this situation the *early decay time* (EDT or RT_{10}) was introduced.

In practice the RT will be determined from different points in the room. Averaging the results will lead to an appropriate confidence level. With the usage of three-dimensional microphone arrays it is possible to determine the RT by calculating and averaging the RT for each microphone. This method can increase the confidence level. But measurements at different positions will remain indispensable. By choosing an appropriate integration interval (slow, fast, etc.), an acoustic map for the RT_{10} and RT_{60} can be calculated.

Figure 5 – acoustic photo (sound pressure) of a sound studio RT10 (top) and RT60 (bottom)

Figure 5 shows two different sound events in a sound studio. The surface shown in figure 5 (top picture) tends to strong reflections so that it is significantly responsible for the EDT. It has obviously more influence on the evaluation of the room than other surfaces. The part of the room shown in the bottom picture of figure 5 is of little importance. The RT was calculated with measuring results in a range of -5 dB to -35dB, so the bottom picture of figure 5 has no practical relevance. This example is meant to show the possibility to perform those calculations.

ABSORPTION AND REFLECTION

The propagation of sound in a closed environment comes along with absorptions and reflections from surfaces depending on their material characteristics. These effects will decisively be influenced by the room's design and the wavelength of the sound. For the conceptual design of rooms or halls, model-based measurement techniques and methods of computer simulation have been developed to predict the propagation of sound and the influences of reflections and absorptions. For the modification of rooms the simulation results will be completed by measurement results from the real environment to find and eliminate possible model errors. That is the way to efficiently enhance the room acoustic. The combination of the *Acoustic Camera* and the laser scanner introduces new methods to analyze and visualize the time dependent progression of the reflections. In order to process this analysis a pulse signal has to be emitted. Applicable signals are to clap one's hands, bursting balloons or even a shot of a starter pistol. After recording the emitted signal and all of its reflections the delays of the sound event travelling to each microphone within the given array will be determined and the acoustic map can be calculated.

The described reflection measurement method is illustrated by figure 6. The microphone array and a small cannon used to emit the pulse signal were positioned in the middle of a stadium. From this position the sound propagation can be verified at every point of time of the impulse response. From the results it is possible to deduce the reflective and absorptive characteristics of the room. With the help of this knowledge modifications can be done in an efficient way.
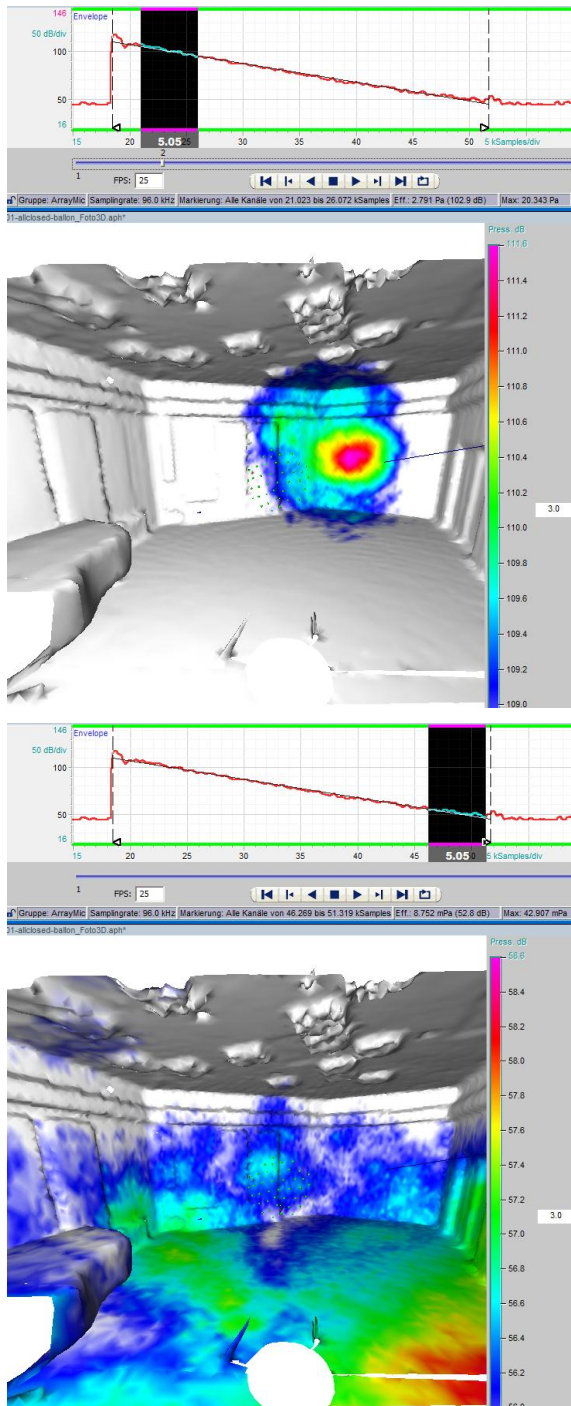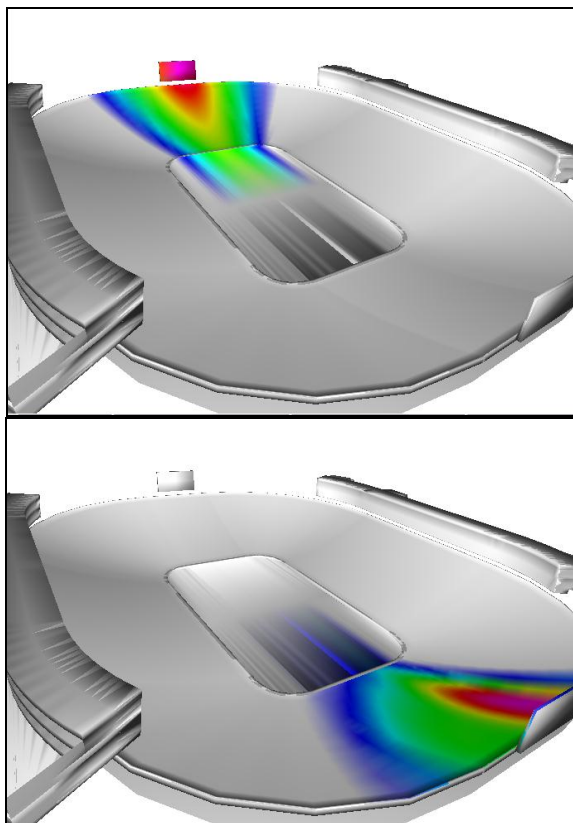
Figure 6 – distribution of sound pressure levels of the first (top) and second (bottom) reflection
(Ann Arbor, Michigan, USA)

SOUND TRANSMISSION

Another field of application of the *Acoustic Camera* is the evaluation of doors, windows, walls, etc. with regard to their noise isolative quality. To determine the characteristics of the objects a sound emitting source will be placed behind the object or outside the room respectively. The *Acoustic Camera* records the transmitted sound for a frequency-selective and location-selective analysis. This is an easy way to find and document acoustic leaks in components (Fig. 7).
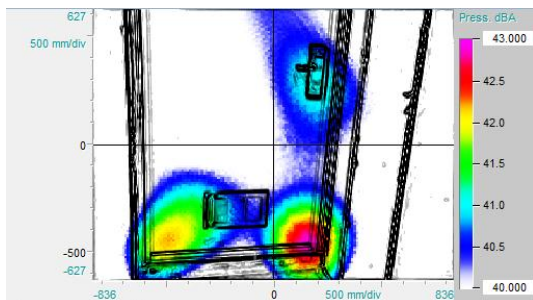

Figure 7 – sound transmission of a door due to a weak spot in the isolation

CONCLUSION

This paper introduces new ways of using the *Acoustic Camera* for the purposes of room acoustics. The construction of digital three-dimensional models with help of a laser scanner and optimized algorithms developed by the GFaI are the basis for all measurements. Due to the beamforming analysis method the sound source can be analyzed location-selective, time-selective and/or frequency-selective. It is possible to create acoustic reverberation maps to determine specific acoustic room characteristics and to modify them in an efficient way.

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