MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

The Acoustic Camera as a Tool for Room Acoustic Optimisation

Kümmritz, Sebastian[1]
GfaI tech GmbH
Volmerstraße 3, 12489 Berlin, Germany

Kerscher, Michael[2]
GfaI tech GmbH
Volmerstraße 3, 12489 Berlin, Germany

ABSTRACT

This contribution demonstrates the Acoustic Camera as a powerful tool for room acoustic optimisation. The goal is to get a good acoustic in a room of about 17 square meters for music mixing purposes. The Acoustic Camera records the multiple room impulse responses, which are excited by bursting balloons and sinusodial sweeps. Beamforming is applied in the time and frequency domain to a 3-D model of the room. This allows the local distribution of the spatial impulse response to be visualized.

Two measurement series were done: the first one in the empty room and the second one in the furnished room with several acoustic treatments. The results of the first measurements form the basis for the arrangement of the furniture. The second series of measurements was used to investigate the influence of several acoustic treatments to the acoustic behaviour of the room impulse response.

Keywords: Room Acoustics, Acoustic Camera, (Directional) Room Impulse Response, Acoustic Optimisation
I-INCE Classification of Subject Number: 71

1. INTRODUCTION

The procedure for the acoustic optimisation of a room depends first of all on the purpose of use (teaching, music, meeting, acting, concert,...). From this, specific objectives can be set, such as reverberation time, early decay time, speech clarity, etc. Ideally, acoustic optimisation starts as early as the architectural planning stage. For example, studio rooms are designed in such a way that room modes cannot arise in the

[1]kuemmritz@gfaitech.de
[2]kerscher@gfaitech.de

first place due to non-parallel walls. Unfortunately, acoustics usually play a subordinate role compared to optical aspects, so that unwanted sound behaviour often only becomes apparent in the finalized building. Thus, room acoustic optimisation often only begins with a given room.

Simulation software tools are well-established for the analysis of room acoustics [1]. They enable the acoustic investigation of complex rooms. The effects of acoustic optimisation measures such as the placement of diffusers and absorbers can be assessed immediately. But simulations are only a model of reality and they are only accurate if all boundary conditions are known exactly.

An alternative to simulations is the visualization of room acoustics with the Acoustic Camera [2]. Beamforming on the surface of a 3D model of the room is performed with a spherical microphone array. This allows, for example, the determination of the directional pattern of the reverberation field [3]. Also the localization of the early reflections [4] or the localization of hotspots in the complete reverberation process ist possible. Concrete knowledge of the positions of the individual reflections can help to improve room acoustics by specific measures in the most efficient way possible.

2. THEORY

2.2.1. Room impulse response

The room impuls response (RIR) h(t) is the acoustic transfer function of a room. The perception y(t) of a sound source x(t) is always a convolution of the sound source with the room impulse response:

$$y(t) = h(t) * x(t). \tag{1}$$

The RIR can be determined via the frequency domain by

$$h(t) = \text{ifft}\left(Y(f) \cdot X(f)^{-1}\right), \tag{2}$$

with ifft for the inverse Fourier transform. To dertermine the RIR over complete frequency range of interest, the excitation signal should also include all frequencies. Sweeps, noise and impulsive noises such as pistol shots or bursting balloons are suitable for this purpose. Impulsive noise has the advantage that there is no need to calculate the impulse response over the frequency domain. If a sound event can be assumend to be a Dirac delta function $\delta(t)$, the impulse response results directly from Equation 1 due to the stifting property of the delta function. However, the delta function is only a mathematical construct and does not exist in the real world. Impulsive sound events always have a certain duration, little signal energy and usually do not have a completely uniform frequency response. Furthermore, excitation signals like bursting balloons or pistol shoots are not reproducable. The time signal of two balloons bursting one after the other will never be exactly identically. This is one of the reasons why sine-sweeps are preferred as measurement signals in room acoustics. They have a very good SNR, a high signal energy and they are reproducable.

In room acoustics, the RIR is of elementary importance. The most essential quantity that can be determined from the impulse response is the reverberation time. It is defined as the time it takes for sound energy to drop to one millionth part of its initial value. This corresponds to 60 dB and therefore, the reverberation time is often written as T_{60}. Beside the reverberation time a plurality of further quantities like early decay time, speech clarity or definition can be derived from the RIR.

2.2.2. Beamforming

Delay-and-Sum

The Acoustic Camera is a tool for localizing sound sources and is based on the principle of beamforming. The first technical realisation of a beamforming system was already presented by [5] in 1976. Beamforming uses the evaluation of run-time delays from a sound source to various receivers. The basic approach is the delay-and-sum algorithm

$$p(x,t) = \frac{1}{M}\sum_{k=1}^{M} p_k(t - \Delta_k), \tag{3}$$

with p for the corresponding sound pressure level for a given time t at a position x. M denotes the amount of microphones of the array and p_k the sound pressure of the k-th microphone on the array-grid. The delay times Δ_k are calculated by the sound travel paths x_k to the image points and the sound velocity of air. The image points can be placed on an arbitrary surface, for example a photo plane or a 3D-model. With Equation 3 the sound pressure level for all image points are determined. The points are coloured according to a colour scale, which defines corresponding sound pressure levels. This so called acoustic map is overlaid with an optical photo or a 3D modell of the device under test.

Differential beamforming

If there are only small changes between two measurements with the acoustic camera, the acoustic maps will be very similar. So a visual comparison and validation is difficult. To investigate these changes, the difference of two spectral beamforming maps can be calculated and visualized in a result map. This approach is called differencial beamforming [6]. It is used in this paper to visualize changes in the RIR caused by the adding of several acoustic treatments.

3. METHODS

The investigated space was a small appartment room of about 17 square meters. The room is primarily intended for mixing music. Figure 1 shows a top view of the furnitured room. The red circle marks the position of the array, which corresponds to the listening position. The rectangles in the different colours show the different acoustic measures carried out one after the other.

Figure 2 shows the used Acoustic Camera. It consists of a spherical array with 120 microphones and has a diameter of 60 cm. This array can localize sound sources three dimensionally and is therefore capable of evaluating the entire sound field in the room.

For every measure step (empty room, room with furniture, adding diffusor, adding absorbers) a 3D scan of the room was done. After each scan the Acoustic Camera was placed at the intended listening position in the room. As excitation signals to measure the RIR of the empty room, bursting balloons were used at the planned positions of the studio monitors. For the measurements in the furnished room logarithmic sine sweeps were played over the loudspeakers to excite the RIR. The sweeps went through a frequency range from 20 Hz up to 22 kHz within 8 s. The excitation signal was additionally measured with a measuring microphone directly on the membrane of one of the two monitors.

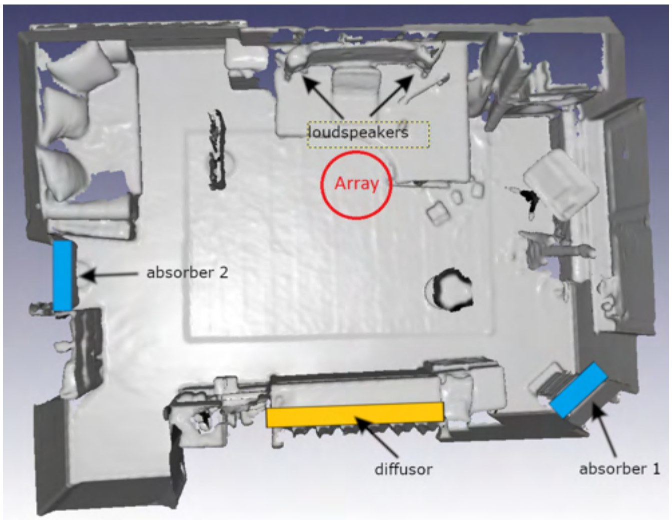

Figure 1: Top view of the room with the positions of the loudspeakers, the Acoustic Camera, the diffusor and the absorbers

Figure 2: The used spherical microphone array

4. RESULTS AND DISCUSSION

4.4.1. Empty room

The first measurements in the empty room were used to create a basis for the arrangement of the furniture. One goal of the room acoustic optimisation was to achieve a reverberation time between 0.2 and 0.4 ms. These are typical reverberation times for recording studios.

The empty room has a reverberation time of 2.04 seconds. In order to reduce the reverberation time as efficiently as possible, scattering or absorbing objects should be placed at the positions of the first reflections. Therefore the locations of the early reflections were determined by applying the beamformer to the 20 ms after the bursting of the balloon. The results are shown in figure 3. The left part of the illustration shows the room from the corner with the view towards the window and the right part shows the room from the opposite side. Three dominant reflection regions can be recognized:

1. On the corner next to the window (left part of the figure)

2. On the wall opposite the position of bursting balloon (left part of the figure)

3. In the corner of the room opposite the window (right part of the figure).

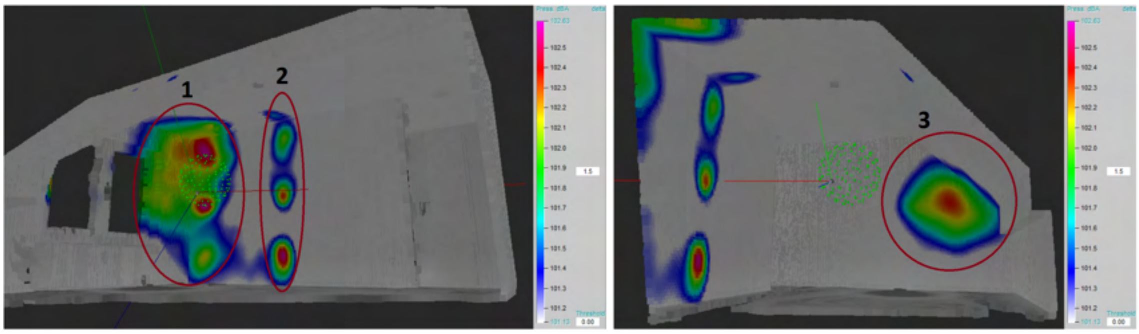

Figure 3: Early Reflections during the first 20 ms of the impulse response; left: view from the corner towards the window; right: view from the opposite side

Based on these findings, the following measures were taken with regard to the positioning of the furniture:

1. A small shelf was placed in the corner by the window. An absorber made of Basotect can be easily positioned on the shelf.

2. A sideboard with a diffuser on it was positioned behind the listening position.

3. A couch was putted in the corner of the room opposite the window

4.4.2. Furnitured room

After furnishing the room, a second series of measurements was performed. The purpose was to investigate the influence of various acoustic measures on the RIR. Four measurements were carried out:

1. Room without acoustic treatment

2. Adding a diffusor on the top of the sideboeard in the back of the listening position

3. Adding an absorber on the wall opposite the window

4. Adding an absorber in the corner by the window

Table 1 summarizes the measured reverberation times for all modification steps.

Table 1: Reverberation times for each measurement

Measurement	1	2	3	4
T_{60} in ms	343	343	332	320

The measurement in the furnished room shows that the reverberation time has already been reduced to 343 ms by the furniture alone without further acoustical treatment (absorber, diffuser), which is sufficient in principle. However, the reverberation time alone does not provide any information about how diffuse the sound field of the RIR

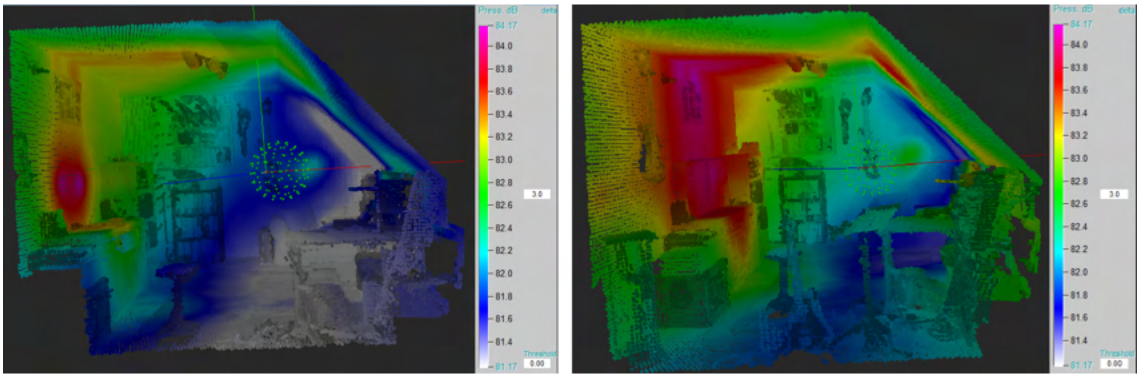

Figure 4: Early reflections (10-30 ms after the excitation) without (left) and with the diffusor (right)

is. A look at the dominant first reflections (Figure 4 left) still shows a strong reflection behind the listening position, but the other two reflective areas are no longer to be found. Propably this may be caused due to the directional characteristics of the loudspeakers.

The reflection behin the listening postion may be removed by adding an absorber on the top of the sideboard. However, this might lead to a very dry sound that could cause an excessive use of reverberation in the mixing process. Therefore, two diffusing elements were positioned at this point. These are 1D diffusers of the company Thomann (t.akustik Spektrum D30 diffusors) and they provide a good diffusion in the frequency range between 1 and 6 kHz. To visualize the changes in the sound field between the situation with and without diffusors, differential beamforming in the frequency range between 1 and 6 kHz was done. Figure 5 shows that the signal energy of the reverberation at the position of the diffusers has decreased in the concidered frequency range by more than 6 dB. Note that the reverberation time itself has not changed.

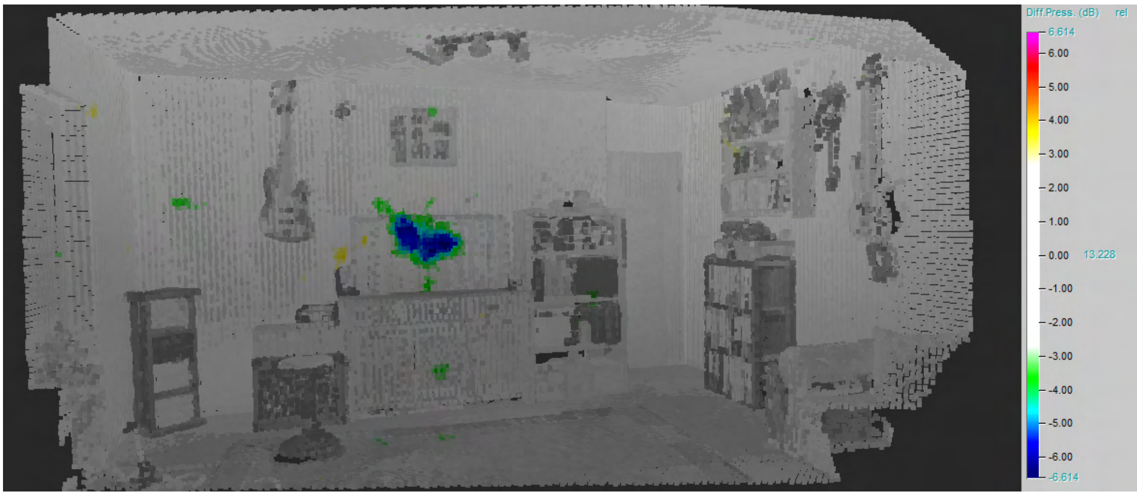

Figure 5: Differential beamforming between the measurements without and with diffusor over the whole RIR in the frequency range 1 - 6 kHz

In the next step an absorbing panel ("Freespace" by EQ Acoustics) was positioned on the wall opposite the window. The idea to position the panel there was to reduce or avoid modes between wall and window. This measure reduced the reverberation time of the room by 3.3 %. With diffentential beamforming the influence of this measure to the sound field of the RIR can be studied. In figure 6 the result of differential beamforming over the whole frequency range between the situation with and without the absorbing panel is shown. Two findings can be drawn from this: first, the signal energy of the reverberation has decreased by 2 dB and second, the largest drop in reverberation energy can be found in the height of the loudspeakers. This shows once again how specific measures for room acoustic optimisation can be derived from the measurements with the Acoustic Camera. Instead of the large absorber, which has a height of 110 cm, in this case an absorber with only one third of the size in exactly the height of the blue spot in figure 6 would suffice to achieve nearly the same effect.

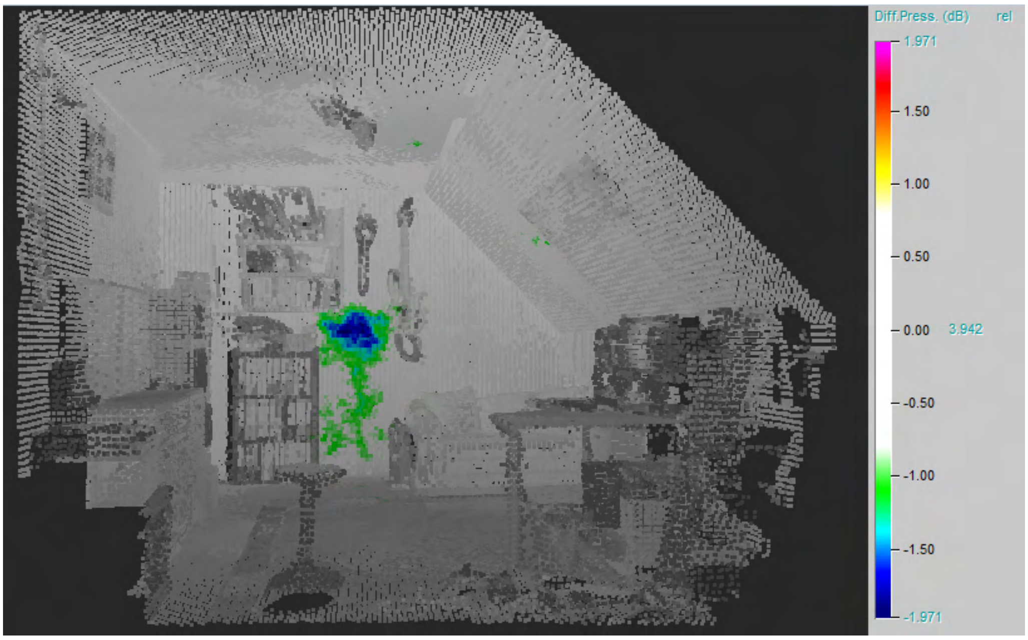

Figure 6: Differenc beamforming between the measurements without and with absorber on the wall over the whole RIR (and whole frequency range)

The last measure to be discussed is the Basotect panel in the corner of the window. It has a thickness of 12 cm and was placed in the corner at an angle of 45 degrees. This measure reduces the reverberation time again by 3.8 %. Figure 7 shows the complete RIR from the frequency range for f > 1 kHz without and with absorber. The RIR looks qualitatively identical, except for the corner of the room at the absorber. However, the amplitude of the entire reverb has decreased by a good 6 dB.

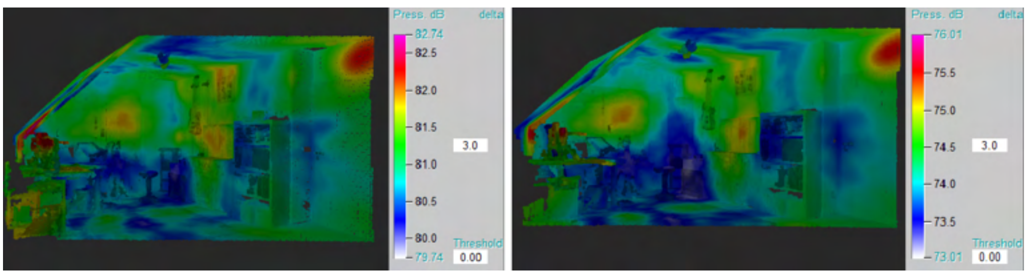

Figure 7: RIR in the frequency range from 1 - 20 kHz without (left) and with absorber (right) in the edge by the window

5. CONCLUSIONS

The investigated spatiality was a small appartment room for mixing purposes. Although the furnishing alone was sufficient to achieve good listening situation, it was possible to show how various room acoustic measures affect the reflection behaviour of the RIR. In particular, the effectiveness of the diffuser could be demonstrated. While the reverberation time of the room remained unchanged, the multiple reflections were distributed much more homogeneously over the entire room.

In general it could be shown, that the Acoustic Camera is a powerful tool for studying the acoustic behaviour of rooms. The results presented show only a fraction of what can be deduced from the measurements carried out. Measuring the directional RIR reveals a vast amount of information about the real 3D sound field. This provides a comprehensive understanding of the way sound propagates through a room, which can be instrumental in taking effective measures to influence room acoustics.

6. OUTLOOK

Sound field simulations will certainly remain to be the means of choice for room acoustic optimisation, espicially for great halls. However a big challenge for every simulation is the correct choice of the boundary conditions. The correct reflection factors of many elements are often unknown and must therefore be estimated. This is an interesting starting point where the Acoustic Camera could play an important role in the future. The comparison of measurements with the Acoustic Camera with room acoustic simulations could help to determine the correct boundary conditions.

7. REFERENCES

[1] T. Scelo. Integration of acoustics in parametric architectural design. *Acoustics Australia*, 43:59, 2015.

[2] S. Barré and N. M. Ortiz. Room impulse response measurement and delay-and-sum beamforming, application to room and building acoustics. In *EuroNoise 2015*, 2015.

[3] B. N. Gover, Ja. G. Ryan, and M. R. Stinson. Measurement of directional properties of reverberant sound fields in rooms using a spherical microphone array. *Journal of the Acoustical Society of America*, 116, 2004.

[4] M. Kerscher, B. Vonrhein, G. Heilmann, S. Barré, and P. Weigel. Measurement and visualization of room impulse responses with spherical microphone arrays. In *29th Tonmeistertagung - VDT International Convention*, 2016.

[5] Billingsley and Kinns. The Acoustic Telescope. *J. Sound Vib.*, 48:485–510, 1976.

[6] S. Schmidt and D. Döbler. Visualization of small design modifications using differential beamforming. In *InterNoise 2015*, 2015.