Car interior measurements using 3D-microphone arrays

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ABSTRACT

Acoustic measurements inside any cavity are mainly conducted with a small number of microphones. By this means it is possible to gain information about frequencies, orders, sound pressures. However, a space selective analysis is nearly impossible and it is not feasible to find the sound sources position in space in a practical way. Traditional beam forming systems with planar microphone arrays do not give comprehensive information about the sound sources in the entire vehicle interior. Therefore, the constituents of the Acoustic Camera of the GFaI were extended by a spherical, acoustically transparent and omni directional array. A new option is to map onto a common 3D-CAD-model of the object of interest, for instance a vehicle interior. The advantages and disadvantages of 2D- and 3D-mappings will be discussed in the paper. Furthermore, the important issue of positioning an array at first in the coordinate system of the 3D-model and second in the actual cavity which is to be measured will be addressed. The paper discusses the geometric and acoustic properties of microphone arrays which are applicable for complete 3D-measurements and mappings of cavities. A practicable way of determining the array’s position and direction related to the measurement object will be proposed.

1 INTRODUCTION

Actual commercial beamforming systems, among them the Acoustic Camera, use a rectangular virtual image plane in order to calculate the run times between microphone array and measurement object (figure 1). This way the surface of the device under test is approximated, and the z-axis of the array is usually oriented perpendicularly to the image plane. Subdividing the image plane into rows and columns results in a finite amount of rectangular display details (pixels) whose centers of area are used to calculate the delays. Sound sources which are placed on a three dimensional device surface will be localized and mapped on a two dimensional plane. This way causes two errors: At first, the focus of the

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beamformer is incorrect for most of the pixels. Dependent on array geometry, subsurface structure, frequencies of the sound source and distance between array and object, the calculated level of sound pressure differs from the level calculated with correct focus. Second, by mapping the (incorrect) calculated sound sources on a two dimensional plane we will get distortions of the mapping. Sound sources will be localized incorrectly. In most beamforming applications these effects are negligible, but for mapping of interiors these effects are noticeable. An example is shown in figure 2.
2 MAPPING OF 3D SURFACES

To solve these problems, we replace the simple mapping of a virtual plane at a fixed distance by different measurement distances to individual points at a 3D-model surface. Of course, we need a 3D-model of the measurement object, preferably available in a standard CAD file format. In many sectors of industries, this precondition is fulfilled in most cases. 3D-models of engines, cars or airplanes usually consist of several hundred thousands of triangles. For the calculation of a three dimensional sound source distribution, this resolution is far too high with respect to the immense calculation times required and the unnecessary fine degree of resolution typically resulting. For this reason, the polygon models have to be reduced in resolution before the actual acoustic mapping takes place.

In 3D-mappings, the planar virtual surface subdivided in pixels is now replaced by lots of triangles definitely oriented in space and modelling the actual surface of the measurement object. Dependent on the desired acoustic resolution and the given graphical model resolution, those triangles may either be coloured directly or may themselves be subdivided into pixels (texturing). The time delays are now calculated in three-dimensional space for every individual triangle or for every individual subpixel of all the triangles, respectively. The acoustic map of a 3D-model surface includes only the values from points respectively triangles which are really situated on the surface of the object, in contrast a mapping of a 2D virtual plane often includes calculated points beside the real object. If the beamformer is optimized to avoid sidelobes in the inner region of the visible image field, the mapping onto a 3D object often leads to seemingly better contrast values, because sidelobes in the outer region normally diminishing image contrast in the 2D case are now excluded from the calculation. On the other hand, if a real acoustic source is present in the image field which is not contained in the 3D-model, it is possible that this source or its sidelobes are erroneously mapped onto the surface of the 3D-model or they are not visible at all. Therefore, it is advisable to accompany every 3D-mapping by an additional 2D-mapping. A typical case of incorrect 3D-mapping is shown in figure 3.

![Figure 3: 2D-mapping of a sound source caused by an unfixed mounting (left), the same measurement, but mapped on a 3D-model (right). The result erroneously suggests a noise source situated on the engine](image)
3 MICROPHONE ARRAYS FOR USE INSIDE A CAR INTERIOR

In addition to the above mentioned precondition, for mapping of interiors we need a suitable microphone array. It is basically possible to generate 3D-mappings with any kind of microphone arrangements. Mandatory, the quality and the expressiveness of the results would be decreased. The following simulations (figures 4, left) show a 3D-mapping on a sphere (Ø 2m) with a sound source (white noise 0-20 kHz) in front of a ring microphone array. As result we get two sound sources. The first and the correct source is situated in front of the array. The other noise source behind the ring array is a mirror image of the first source. Because of the ambiguities between 3D points and Microphones (we can always find two points on the spherical model surface which have the same distance to all microphones), we do not get a unique solution. This fact has great relevance for measuring outside of acoustic test chambers too.

The right figure shows the same situation as in the left figure. Only one modification has been carried out. The position of the noise source changed from the front of the microphone array to the right hand side. Poor geometric cutting conditions result from the position between the noise source and the microphones. It is impossible under these terms to locate the source exactly.

Conventional planar arrays with a favored imaging direction are not able to perform undistorted 3D-mappings. The characteristics of the array (frequency response, resolution, sidelobes etc.) should be as identical as possible for all directions in space. An array having its microphones equally distributed on a (virtual) spherical surface and with the sensor’s direction vectors perpendicular to this sphere will be adequate.

The frequency range of an array is depending on minimum and maximum distances between the microphones. If we spread microphones on a virtual spherical surface, we need more microphones to get the same frequency range as a planar array.

In order to construct a spherical array there are two possible ways: solid sphere or acoustic transparent sphere. A solid sphere is easier in manufacturing. But it has some disadvantages: the soundfield will be disturbed, half the number of microphones is shadowed and the surface of the sphere will be generating reflections and frequency dependent errors in measurement results. Of course, the shadowed microphones also receive the acoustic waves from the noise source because the waves are diffracted around the sphere, but the diffraction and therefore the time delays are frequency dependent. These properties of a solid sphere enforce a
calculation of the acoustic map in the frequency domain to correct these errors. The calculation of three dimensional acoustic maps in the frequency domain requires high computational power, and the analysis of non-stationary noise events is difficult and imprecise. Last but not least, the weight of a solid sphere may make the handling difficult. Therefore we use only acoustically transparent arrays. Some examples of spherical transparent arrays are shown in figure 5.

The example in figure 6 shows the employment of such an array. Two sources have been placed in the scene. The first one is situated behind and the second one is situated on the right hand side of the array. Both noise sources (white noise 0-20 kHz) were exactly located on the 3D Model (Ø 2m).
Porsche in Weissach uses the option of mapping on 3D objects mainly in the case of sound localization in the interior of the car during development process and in quality control. The mapping on 3D objects has to be considered as add on to the standard acoustic tools and has its advantages in the domain of squeak and rattle noise.

The following samples are a selection of “quality-sounds” generated during normal operation in the car. Quality sound in this term means a good acoustic feedback of the mechanism during operation for the driver and not a disturbing-noise.

The sounds are recorded with a 48 channel array positioned in the middle of the front seats (figure 7) with no position-change during the session. Basis for the mapping are A-weighted and high pass filtered (1 kHz) signals. For better visualization of the samples, the 3D-mappings are shown in a partial view of the full interior and the dynamic scale of the acoustic color-maps is set to 6dB.

To present the performance of 3D-mapping in reality the mentioned samples are chosen in the way that the color-maps (figure 8 to figure 13) indicate the origin of the sound. In practise the quality of the mapping comes to limits if sources are hidden or covered relatively to the array, for example: sources under seats or behind pillars. In this case a precise localization is not possible and the phenomena of absorption, reflection and diffraction have to be taken into account. Additionally room-acoustic and array-geometry set limits to the resolution in low frequencies, so the recommended frequency-band for the application of the 48 channel array is approximately 1 kHz and higher.
Figure 8: Press button to open side-window

Figure 9: Folding out the side-mirrors, both electric motor-drives in function
Figure 10: Open drawer of console

Figure 11: Ejection of the cigarette lighter situated in the drawer
Figure 12: Close cover of centre-box

Figure 13: Switch on lamp of co-driver-side
5 CONCLUSION

Beamforming and mapping of a 3D-model surface expand and complete the conventional 2D-mapping on a virtual plane. Preconditions for 3D-mapping are a 3D-model of the measurement object and, for mapping of interiors, an omni-directional array. A Sphere array having its microphones equally distributed on a (virtual) spherical surface accomplishes this condition. Acoustically transparent sphere arrays have some advantages in contrast to solid sphere arrays. A 3D-mapping can offer a better contrast in the acoustic map, but to avoid misinterpretation a 3D-mapping should always be accompanied by an additional 2D-mapping.

Many measurements show that the Beamforming of a 3D-model is a fast and effective way to locate sound sources in a car interior. Particularly the System is dedicated for squeak and rattle.

6 REFERENCES