Perspectives of the Acoustic Camera

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Perspectives of the Acoustic Camera

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Abstract The „acoustic camera“ is a measurement tool which joined the field of acoustics a few years ago. This technology analyses the actual sound scene, which consists of a superposition of different sound sources, into a visual sound map. The basic principle relies on accurate calculation of the specific runtime delays of acoustic sound emissions radiating from several sources to the individual microphones of an array[1].
An acoustic map of the local sound pressure distribution at a given distance will be calculated using the acoustic data of all simultaneously recorded microphone channels. The sound pressure level is displayed by color coding, similar to popular thermal imaging. Automatic overlay of optical image and acoustic map gives rapid answers about locations of dominating sound sources.
Today’s IT–technology allowed scientists at the „society for the promotion of applied computer sciences“ in Berlin, Germany, to create one of the first practical, everyday use systems for mobile and interactive applications in sound source imaging. The technology is designed to be simple, robust and flexible to be applied in diverse acoustic environments.
Our paper presents the newly developed mapping of moving sources, including video overlay and the necessary measurement technics. Problems concerning the synchronisation of optical and acoustical movie will be discussed.
The second topic of the presentation is the three-dimensional mapping of acoustic sources onto a 3D-model of a measurement object. The simple mapping of a virtual plane at a fixed distance is now replaced by different measurement distances to individual points at the 3D-model surface.
A complete 3D-mapping of interior rooms depends on omnidirectional, non-planar arrays. Such mappings can be useful inside cars, where CAD-models of the driver’s cabin are readily available very often. Possible applications, physical restrictions and future perspectives of this new technology will be pointed out.

1. INTRODUCTION

Actual commercial beamforming systems, amog 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. The assumption is made that the device and hence the image plane do not move during the measuring time. 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.

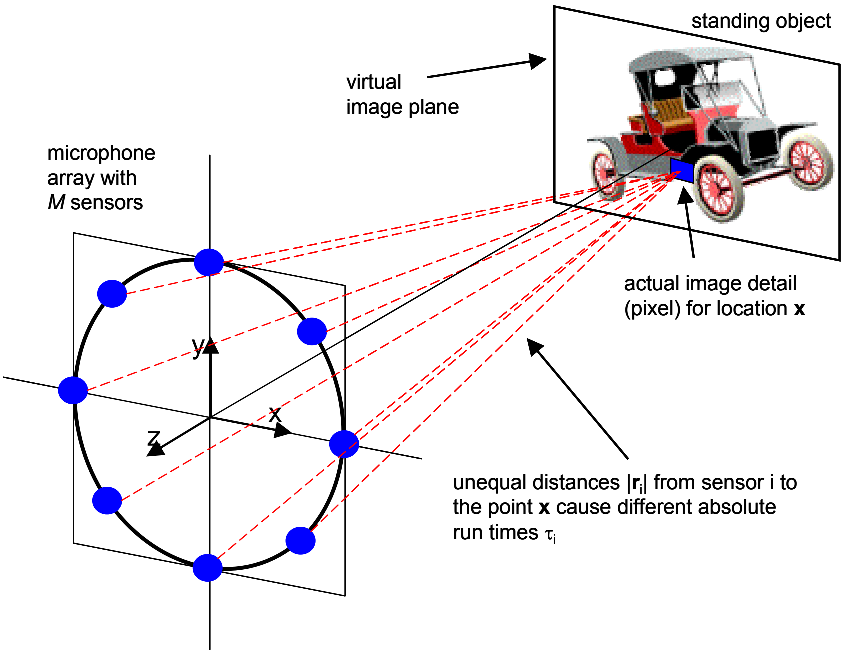

Figure 1: Runtimes between array and a virtual still image plane

In the most simple case, reconstruction of the time function $\hat{f}$ of a point $\mathbf{x} = (x', y', z')^T$ on the image plane is performed by delay-and-sum beamforming [2] according to equation (1). Here, t denotes time, M is the number of microphones in the array, the w_i are (optional) shading weights, the f_i are the recorded time functions of the individual microphones, and the Δ_i are the appropriate relative time delays, calculated from the absolute run times τ_i as $\Delta_i = \tau_i - \min(\tau_i)$. The absolute run times are trivially determined by $\tau_i = |\mathbf{r}_i|/v$, where v is the speed of sound in air and $|\mathbf{r}_i|$ is the geometrical distance from mirophone number i to the point of interest $\mathbf{x}$.

$$\hat{f}(\mathbf{x}, t) = \frac{1}{M} \sum_{i=1}^{M} w_i f_i \left(\mathbf{x}, (t - \Delta_i) \right) \tag{1}$$

The effective sound pressure at point **x** is now determined using equation (2); every individual pixel is then coloured corresponding to its effective value and a given colour table. In (2), n is the total number of discrete time samples taken into account for the estimation of the effective value, $\hat{f}$ is the reconstructed time function (1) of the sound pressure at location **x**, and t_k is the time value at a discrete sample index k.

$$\hat{p}_{eff}(\mathbf{x}) = \sqrt{\frac{1}{n}\sum_{k=0}^{n-1}\hat{f}^{2}(\mathbf{x}, t_k)} \quad (2)$$

State of the art is the simultaneous taking of an optical photo by means of an integrated digital camera and the subsequent automatic overlay with the acoustic colour map. A typical example of an acoustic image is shown in figure 2.

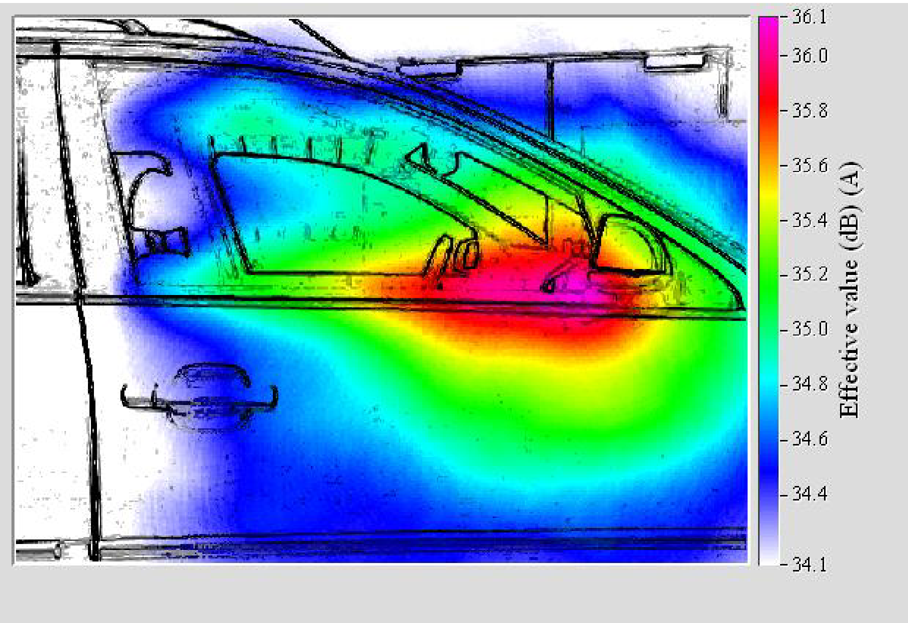

Figure 2: Acoustic image of a power window

2. MAPPING OF MOVING SOURCES

Mapping of moving objects is desirable in many areas, e.g. automotive and aviation industries. Two methods can be applied:

1. The image plane is shifted along with the moving object. Run time delays to the individual microphones undergo a continuous change and are explicitly taken into account in the calculations (figure 3). The advantage is an implicit automatic compensation of doppler effects which enables meaningful spectral mapping of moving objects [3]. Disadvantage of this method is its high computational demand, because the discrete step size of the tracking has to be choosen so small that all discrete changes in the time delays resulting from the movement are acquired correctly.

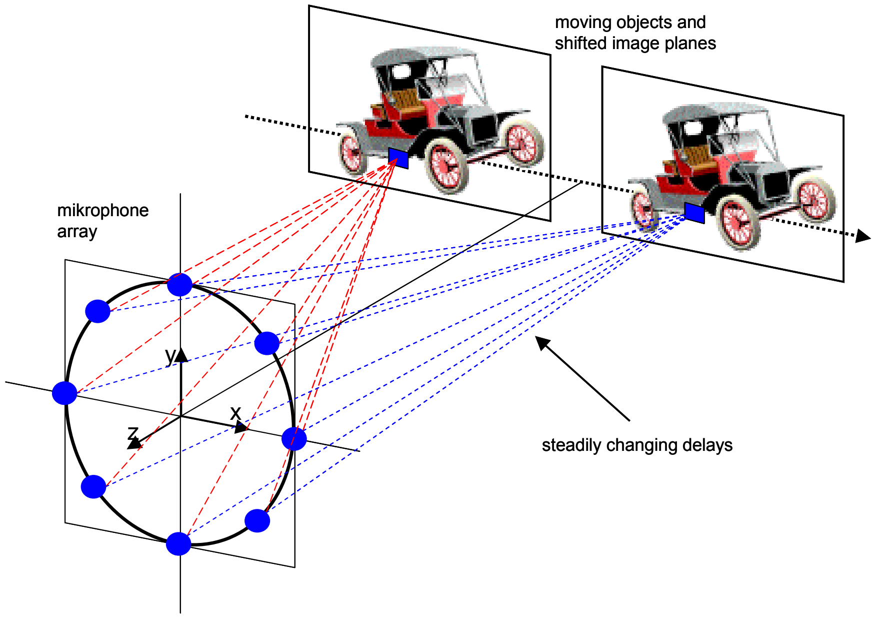

Figure 3: Delays between array and a moving object image plane

2. The image plane is laterally adjusted as it was with the first method. But now, the step size of the lateral displacement is equal to the size of one display detail (rectangular sub-window or pixel). Within this window, the same approximated (relative) time delays are used, thus keeping calculation times moderate. This method is appropriate for sound pressure mappings of moving objects, but here a leakage of spectral lines occurs due to the missing doppler shift compensation.

In either case, integration of a video camera into the array is neccessary, which records a video file in parallel to the acoustic measurement. A problem arising here is the synchronisation of optical and acoustical images. The framerates given to the video camera's driver software often do not correspond to the actual framerates of the video recording. Problems during transmission can result in the loss of individual pictures (dropping). Since acoustic movies can exhibit time resolutions up to several thousand frames per second, in some measurement scenarios the application of integrated optical high speed cameras may be useful.

At Internoise 2005, for the first time the GFaI presents a solution containing all the neccessary methods and tools for moving objects. In addition to the usual overlay of still image and object, now the overlay of a moving acoustic map with a moving optical image taken by an integrated video camera during measurement is possible (movie on movie). Synchronisation between video image and acoustic image is performed by recording additional trigger signals from the video camera. For this purpose, high grade industrial cameras, delivering the actual exposition times during recording of the video images as trigger pulses, can be integrated into the arrays. Therefore a high precision in the assignment of acoustic map and optical image is achieved. A screenshot is shown in figure 4.

Figure 4: Screenshot from the software module " Movie on Movie"

3. MAPPING OF 3D OBJECTS

The above mentioned approximation of an object onto a virtual planar surface is sufficient for many applications. But for the acoustic inspection of interiour rooms, e.g. inside cars or airplanes, this method is not appropriate. To solve this problem, special 3D-mapping methods have been developed at GFaI. Prerequisites for a 3D-mapping are the following:

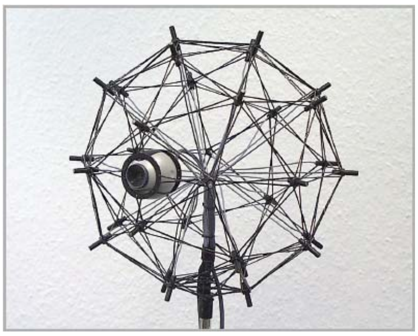

Figure 5: Spherical array for 3D-measurements

1. A suitable microphone array. Conventional planar arrays with a favoured 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. In addition, the array should offer acoustic transparency. An example for an array fulfilling this demands is shown in figure 5.

2. A 3D-model of the measurement object, preferably available in a standard CAD file format. In the said sectors of industries, this precondition is fullfilled in most cases.

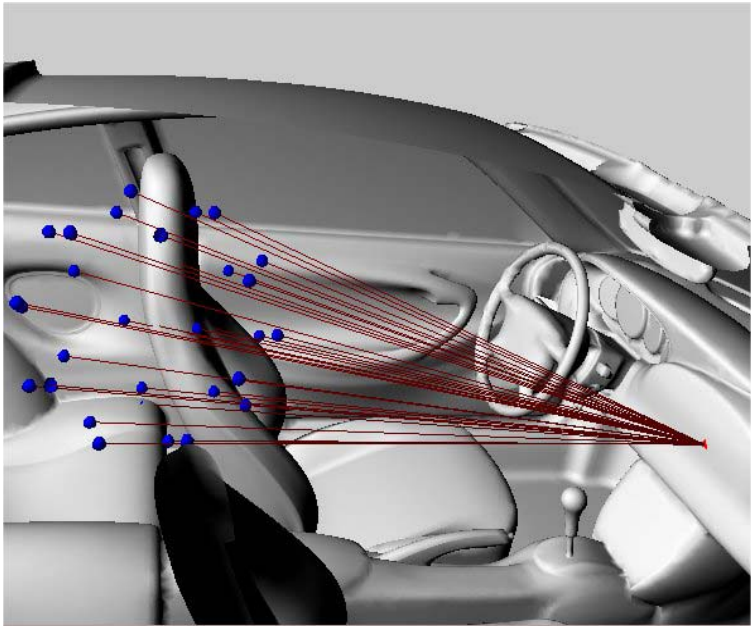

Figure 6: Array in the interior room of a car, screenshot taken from the software "NoiseImage"

3D-models of cars or airplanes usually consist of several hundred thousands of triangles. For the calculation of a threedimensional sound source distribution, this resolution is far too high with respect to the immense calculation times required and the unneccessary fine degree of detailedness typically resulting. For this reason, the polygon models have to be reduced in resolution before the actual acoustic mapping takes place.
A further important step is the determination of the coordinates as well as of the inclination, tilting and rotation of the array in relation to the 3D-model. The precision of this fitting determines the quality of the results. To give an example, a rotation of the array of only 2 degrees will result in a location error of 0.07m at 2m distance.
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 algorithm for the estimation of the sound pressure levels remains the same as given in equations (1) and (2). A typical measurement scenario is shown in figure 6, demonstrating focussing on a single model triangle.

At GFaI a software module has been developed containing all tools required to perform 3D-mappings. CAD-models can be read into the program in the standard formats STL (Stereo Lithographie) and 3DS (3D Studio Max), further input formats are planned. A smart reducer is included which dramatically reduces the number of triangles, at the same time keeping object geometry as unchanged as possible. The difficult problem of determination of the correct array positioning in relation to the 3D-model has been solved successfully by a specially developed fitting procedure similar to photogrammetry. The acoustically mapped 3D-models can be rotated in a viewer, a walk-through is possible, and all the tools previously dedicated to 2D-modelling are also available for the 3D-mappings. Result of the calculations is a visualization of sound sources distributed in space that are projected onto a 3D-model surface, see figure 7.

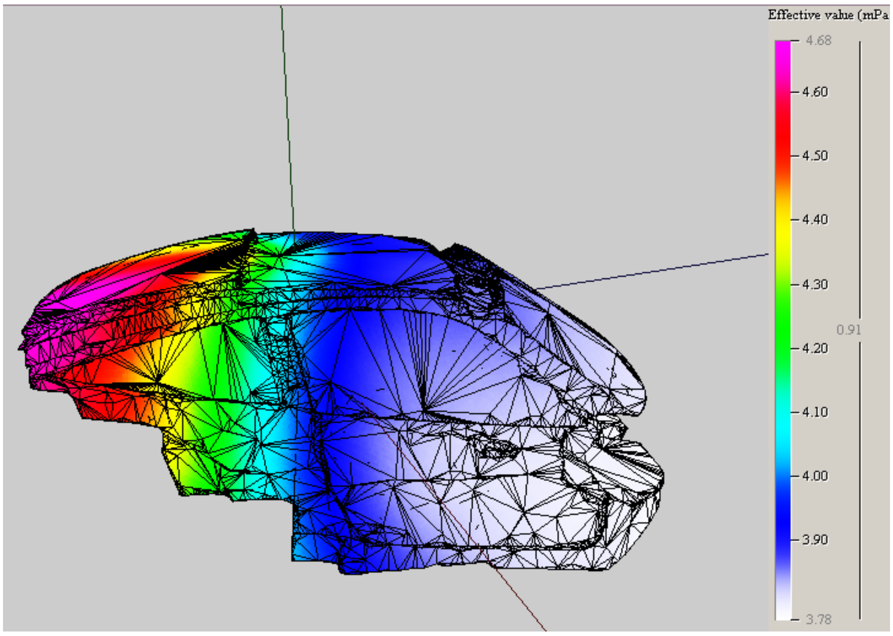

Figure 7: Mapping of an interior room of a car, noise from engine

4. SUMMARY AND CONCLUSIONS

The acoustic mapping of moving sources with simultaneous video overlay enhances conventional mapping methods, the risk of misinterpretations is reduced. Passing of cars, overflights of planes, or the movement of wind turbines can be recorded more realistically. In the near future, integrated high speed cameras will allow visualization of complex and time-critical processes of sound generated in machines and other technical equipment.
Acoustic mapping of 3D-objects gives new possibilities for fast and easy inspections of interiour rooms, e.g. inside wheeled or railed vehicles or inside airplanes. The newly developed methods are also promising in applications involving objects with strongly threedimensionally structured surfaces, where they will lead to better results than conventional 2D planar mappings.

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