EXTENSION OF THE BEAMFORMING-METHOD BY SYNCHRONIZED MULTIPLE MEASUREMENTS

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ABSTRACT

The fast identification of acoustic (noise-)sources becomes more and more important in the process of automotive engineering. Beamforming as a far-field method is capable of localizing sound sources by detecting the direction of incidence. The interpretation of measurement results is sometimes complicated because of inherent drawbacks of the system and the method itself, and moreover by bad acoustic conditions. The finite number of sensors and the final size of the arrangement of sensors limits the dynamic range and the spatial resolution. In this study synchronized multiple measurements were used to create a virtual larger array, that is, to improve the spatial resolution especially at lower frequencies. In terms of an extended applicability of the Acoustic Camera method first results are discussed.

1 INTRODUCTION

When measuring with simple array geometries the inherent drawbacks of these systems have to be taken into account. The limited array-size, the number of microphones as well as their arrangement determine the quality of the results in the acoustic photo.

The main focus of this study is to enlarge a single 32-microphone ring-array virtually by performing multiple measurements. For this purpose it is assumed that the recorded signal, a motor at constant revolution, is quasi-periodically, i.e. determined. Nevertheless there is a undefined stochastic component in the signals so that a non-stationary behaviour within multiple measurements can influence the results.

Corresponding to their relative positions the microphone signals are pre-delayed before feeding them into the beamforming algorithm of the software *NoiseImage* (GFaI) [1], [2]. Performing measurements at p positions yields an acoustic photo of a synthesized array consisting of p*32 microphones.

First results on a series-production motor in an engine test facility are presented and discussed in terms of an improved dynamic range and spatial resolution. Additionally, the simulated patterns of synthesized arrays at certain frequencies are shown.

2 SIMULATED SYNTHESIZED ARRAY PATTERNS

The spatial resolution is enhanced by arrays of large dimensions. An irregular arrangement of microphone positions also has positive effects on the aliasing structure. Fig. 1 illustrates the pattern of a single 32-channel ring array compared with synthesized arrays, shifted in a plane, for an assumed point source at 5 kHz.

At frequencies higher than the Nyquist-frequency for spatial sampling, the aliasing structure causes ghost images that must not be interpreted as real sources. Generally, in an acoustic photo a high dynamic range is desired to see as much as partial sources. But if the dynamic range in the analysis is expanded side lobes of the pattern can produce artefacts. A multiple measurement can eliminate disturbing structures and simplify the interpretation of the acoustic scene with a higher dynamic range.

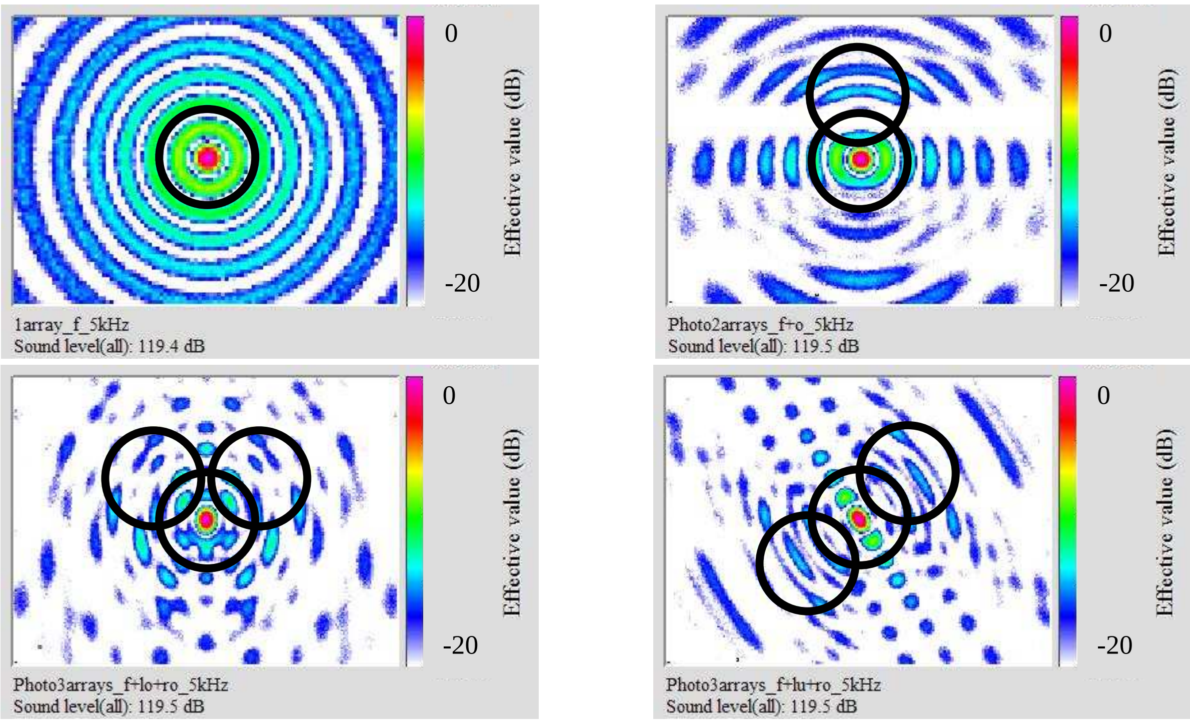

Fig. 1. Simulation of synthesized array patterns

At lower frequencies the width of the main lobe has noticeable influence on the spatial resolution. Fig. 2 compares the single array with the 3-ring synthesized array at 500 Hz. The differences in the simulation between the synthesized and the single array are obviously. Especially at low frequencies the main lobe of the synthesized pattern, respectively the hot spot becomes smaller. In reverse it means that the dynamic range of the analysis could be expanded by keeping the size of the hot spot generated by the single array. Of course, narrowing of the hot spot has its limit when you consider the fact that a source radiating low frequencies to the far-field has a minimum radiating surface. But if there are reflections a narrow main lobe can exclude them.

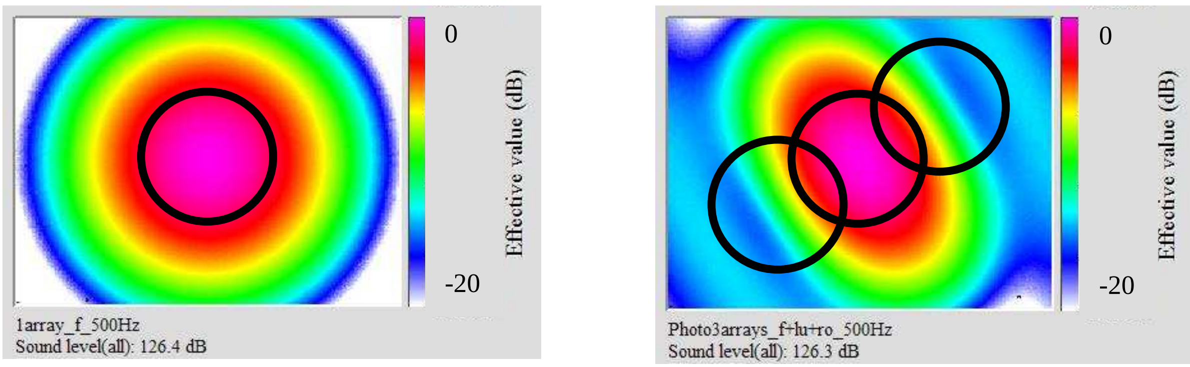

Fig. 2. Single and synthesized 3-ring array pattern focussed on a point source at 500 Hz

The simulation bases on a point source radiating an omnidirectional soundfield at the given frequency. The analysis of a real acoustic scene, that is, applying the beamforming algorithm on the recorded microphone signals, respectively projects the detected sound pressure onto a point source in the plane the array is focussing on.

In the next chapter the array synthesis is applied on a typical measurement scene.

3 PRACTICAL MEASUREMENTS

The practical measurements were done with a serial-production motor in a test bench. The recordings were made at a fixed number of revolutions to have a quasi-periodical, reproducible signal. In order to show the effects of a synthesized array in a real acoustic scene the single ring-array first was focussed on a source that was clearly identified in a range of 750-850 Hz by a sound intensity measurement.

To obtain a correct analysis the microphone signals of several positions first have to be synchronized relating to the trigger of recording. In the next step the delay-times from the assumed “ideal” point source to the array positions have to be considered relative to the reference position. Therefore it is fundamental to identify the correct positions of the microphones. Of course, it is more difficult in 3D-space than in a plane where just the translation in x- and y-direction has to be measured. Fig. 3 shows the results of single and a multiple 3-position measurement.

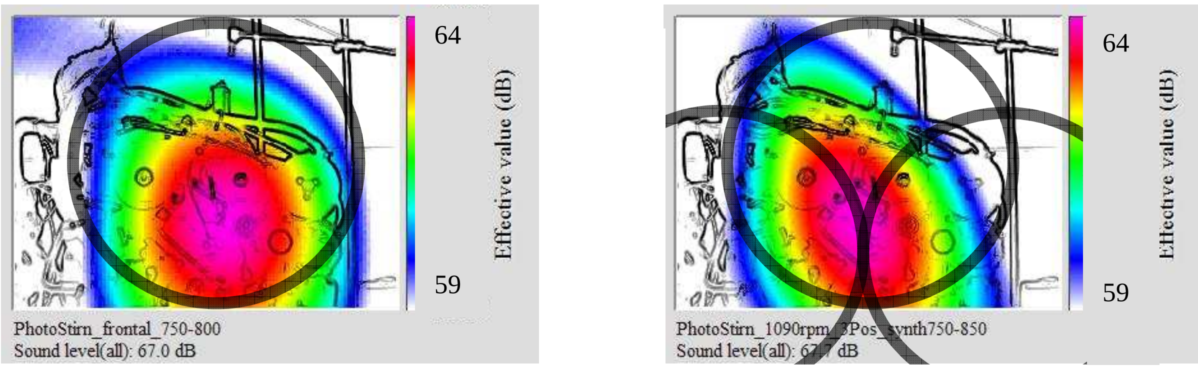

Fig. 3. Analysis in a frequency range 750-850 Hz with a single and a synthesized “triple” array (96 Mics), 5 dB dynamic range

As the simulation reveals, the hot spot becomes smaller in the directions the array is expanded to. The achieved dynamic gain can now “discover” areas of lower pressure level. At high frequencies the acoustic photo is more complex because of much more partial sources in this frequency range. Artefacts are now caused by an increasing level of side lobes (see also Fig. 1). In the left picture of Fig. 4 the ring structure around the main sources is visible. It is difficult to distinguish between ghost images and real sources. With a multiple measurement the regular structure of these aliasing effects can be “burst”. Thus, aliasing effects are minimized and the acoustic photo looks more homogeneously.

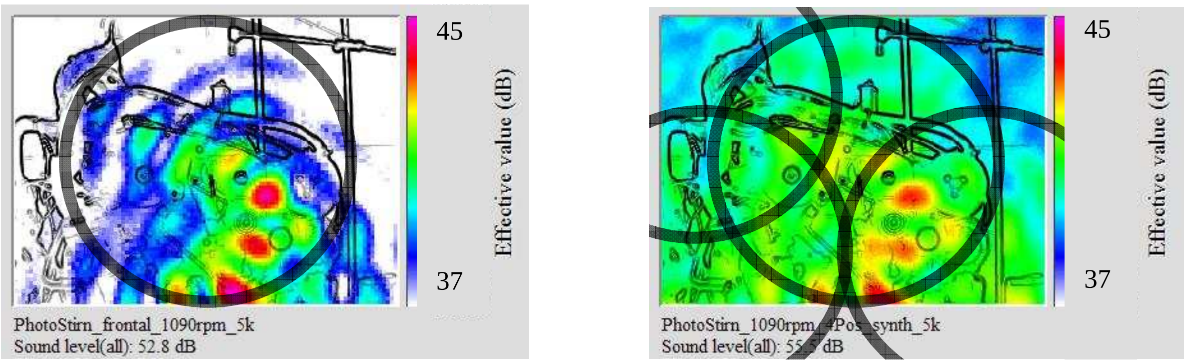

Fig. 4. Analysis at 5 kHz with a single and a synthesized 4-ring array (128 Mics), 8 dB dynamic range

According to the initially mentioned postulation of quasi-periodicity, the quality of the results can be evaluated by having a look on the coherence between two microphone channels. The coherence should be high in the interesting frequency range, but it also depends on the character of the signal (diffuse noise field, speech etc.) and the distance of the microphones. Apart from this the coherence between microphone channels in *one* array has to be high, too, since the signals in the beamforming algorithm are summed up coherently. Non-coherent components, e.g. background noise, are principally suppressed in the summing process.

4 CONCLUSIONS AND FURTHER WORK

First results show that it is possible to obtain a better quality in localizing acoustic sources when performing multiple, synchronized measurements. Regarding a minimized aliasing and a higher spatial resolution there is potential to optimize the arrangement of each single arrays.

For this purpose the exact determination of the positions is a main issue. If only shifting the array is done in a plane the position of the camera defines the microphone positions. In space an estimation of coordinates can be done with an ultrasonic positioning system. However, the most elegant way is to estimate the relative positions from the picture the cameras deliver.

In case of rendering in a 3D-space the focus planes are distributed in space. The synthesized result is an optical and acoustical panorama picture that offers the possibility to explore the directivity of the source by “walking” virtually around it. In single measurements the directivity of the source is entirely neglected.

REFERENCES

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[2] M. Kern and H. Opfer: *Methoden zur Erweiterung der Einsatzbedingungen von Beamforming-Verfahren.* DAGA 2006, Braunschweig