Design and Application of a Low-Cost Microphone Array
for Nearfield Acoustical Holography

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Introduction

Nearfield acoustical holography (NAH) is used to identify individual sound sources at complex structures [1, 2, 3]. It requires the use of a so-called microphone array, i.e., of several microphones that are arranged in a plane [4]. There are special array microphones available, which are considerably cheaper (€300–500) than conventional measurement microphones due to a reduced frequency and dynamic range and a smaller sensitivity. Nevertheless, since a microphone array used for NAH usually consists of dozens, sometimes hundreds of microphones, it is particularly attractive to further reduce the cost per microphone. This paper describes the design and successful application of a microphone array made up of 64 silicon microphones, which cost only about €18 each (amplifier included)—a cost reduction of 95%.

Microphone Design

The microphone array was designed at the Department of Mechatronics and Machine Acoustics, Darmstadt University of Technology [5]. It consists of 8×8 silicon microphones (type SP0101NZ2-2 from SiSonic), which are usually used for electronic devices such as mobile phones, hearing aides, video cameras, etc. These silicon microphones are mounted in small circular plastic tubes to allow an easy calibration with standard microphone calibrators. Figure 1 shows such a tube-mounted microphone. The silicon microphones are temperature and shock resistant and, due to their small mass, very insensitive to structure borne noise. They have a flat frequency response in the frequency range of interest, which

Figure 1: Detail of a tube-mounted silicon microphone.

was confirmed by comparisons with a Brüel&Kjær microphone. Also, although they are not perfectly omnidirectional, they exhibit a negligible directivity in the angle range of interest.

Array Design

Eight microphones are mounted to each of eight thin vertical aluminum rods, which in turn are mounted in a portable square frame such that their horizontal spacing can be adapted to match the vertical spacing of the microphones (currently $d = 0.2$ m, adjustable to $d = 0.1$ m). The 64 microphones require only eight amplifiers since each set of eight microphones can be connected individually to the eight amplifiers by means of an eightfold switch [5]. The complete microphone array is depicted in Fig. 2.

Figure 2: Microphone array: 64 microphones, two reference microphones and two loudspeakers in a hemianechoic room.

Application to NAH

The microphone array was tested and applied to NAH in the hemianechoic room of the Fraunhofer Institute for Structural Durability LBF. The lower frequency limit $f_{min} = 243$ Hz of the current configuration (microphone spacing $d = 0.2$ m) is determined by $f_{min} = c/l$, where $c \approx 340$ m/s is the speed of sound and $l = 1.4$ m is the length (and height) of the array, whereas the upper frequency limit $f_{max} = 850$ Hz is given by $f_{max} = c/(2d)$.

The measurements were performed using a 64-channel Scadas-III front-end and Cada-X software, both from LMS. Despite the 64 channels it is not possible to measure the sound pressure at all 64 microphone positions simultaneously because there are only eight amplifiers (see above). However, this is not problematic since one or more additional stationary reference microphones are used (see Fig. 2), which provide the phase correlation for several consecutive measurements.

Two loudspeakers, which were driven by an anti-phase sinusoidal signal at 700 Hz, were used as sound sources for the test measurements (see Fig. 2). As the name *near*field acoustical holography implies, the microphone array must be placed rather close to the source (a distance between d and $2d$ is recommended) in order to be able to detect the so-called evanescent waves [1, 2].

From the measured sound pressure level (SPL) distribution in the hologram plane the NAH software can compute the SPL distribution, the particle velocity, or the sound intensity in other planes, which can be parallel or perpendicular to the hologram plane. The middle plane in Fig. 3a shows the measured SPL in the hologram plane, which is 0.3 m ($= 1.5d$) from the source, whereas the left plane depicts the computed SPL 0.6 m away from the source and the right plane represents the computed SPL 0.3 m before the hologram plane, i.e., "at the source". This way rather small sound sources at complex structures can be identified with a resolution in the range of the microphone spacing. It is also possible to superimpose a semitransparent color plot on a photograph of the measuring object to further aid visualizing the actual sound sources (Fig. 3b).

To test the reliability of the SPL measurements and NAH computations performed with the microphones and the array described above, the SPL at some positions in space was determined with a Brüel&Kjær measurement microphone. For instance, close to the right loudspeaker the measured SPL was 105.8 dB, which is in excellent agreement with the 105.3 to 107 dB range computed by the software (see Fig. 3b).

Summary and Conclusions

A microphone array consisting of 64 low-cost silicon microphones and suitable amplifiers was designed, built, and tested by means of SPL measurements and corresponding NAH computations performed on known, predefined sound sources. The sound sources were reliably identified, and the numerically predicted SPL at selected positions in space was confirmed by SPL measurements at the same locations.

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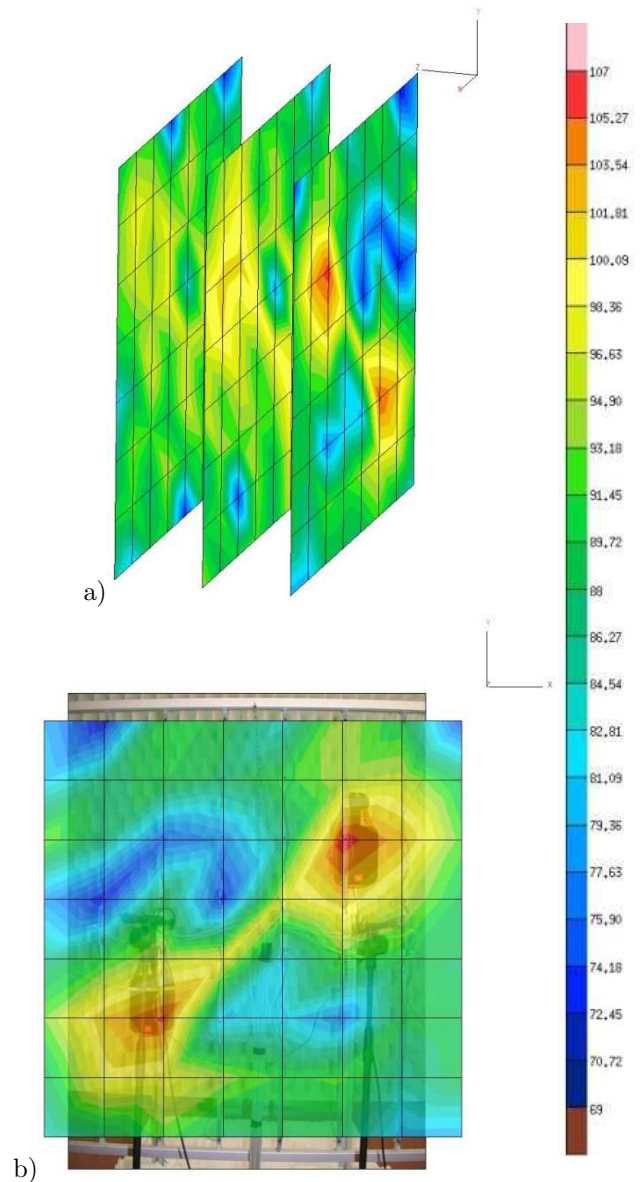
a)

b)

Figure 3: SPL distribution: a) in three parallel planes (computed, measured, computed), b) computed "at the source".

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