Development of a 7th Order Spherical Microphone Array for Spatial Audio Recording

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Introduction

Spherical microphone arrays form the basis for various applications in the context of spatial sound-field recordings- or analysis. Increasing research on spatial audio processing and the effort to improve the immersion in the reality-virtuality continuum by providing high-fidelity virtual acoustic environments, created a demand for appropriate microphone arrays to record and reproduce immersive spatial audio. As shown in current research findings, high order spherical microphone arrays can be a good choice for an adequate spatial audio reproduction [1].The order N describes the amount of spatial detail that can be resolved and thus determines the spatial aliasing frequency. High order microphone arrays therefore require a high amount of microphones as the maximum obtainable order is defined by the number of given microphones (min. $(N+1)^2$) [2]. A 7th order array would require at least 64 microphones. However, such microphones are barely available on the market. Most commercially available consumer products like the Ambeo VR Mic by Sennheiser or Zoom´s HR-VR only offer first order with 4 microphones. Professional solutions like the mh acoustics Eigenmike are already capable of 4th order applying 32 microphones on a rigid sphere with a diameter of 8.4 cm [3]. VisiSonics 5/64 Audio/Visual Camera is to our knowledge the only available product offering a 7th order spherical microphone array with 64 microphones on a Fliege grid with a sphere diameter of 20 cm. Our own investigations on sound field decomposition for binaural rendering revealed that a 7th order rigid sphere microphone array with the size of an average human head (approx. 18 cm) and 86 microphones arranged according to a Lebedev grid provides good perceptual results [4]. As there is no microphone array matching these specific requirements, we developed one within the scope of this research project [Figure 1]. In addition to the above mentioned requirements, the development also focuses on providing high quality audio by using high-fidelity microphones and audio components as well as the ability for real-time spatial audio reproduction using binaural rendering, high-order Ambisonics or wave field synthesis. The audio processing can be done in the SOFiA Toolbox [5] or the corresponding Python port [6]. Both are being currently extended with stream/block-based plane wave decomposition for real-time applications. The array is distributed as an open-source hardware (OSHW) project [7] with self-producible components provided as 3D models and a signal flow architecture with easily accessible audio periphery [Figure 2]. In this paper we describe the development and implementation of the array, including decisions on modeling, size and material of the sphere, as well as the construction of the microphones, shielding measures and used audio components in this project. Further we provide a first technical evaluation, validating the applied shielding as well as a signal-to-noise ratio measurement of the assembled microphones inside the sphere.

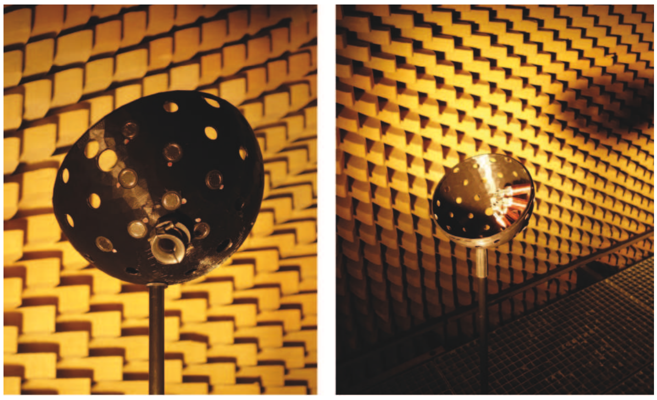

Figure 1: The array during the development process. A hemisphere from the outside and inside including 8 microphone tubes.

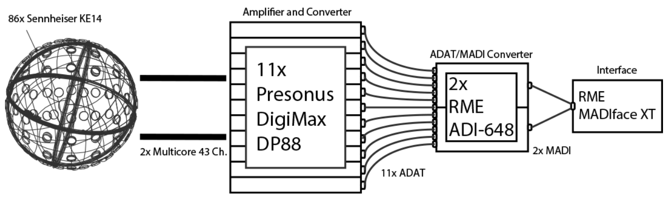

Figure 2: Setup of the microphone array including signal flow of the used audio components.

Development and Implementation

Sphere

Results from studies made in advance [4] yield in specific development constrains: the array needs to have 86 microphones arranged on a Lebedev grid on a sphere with, ideally, a diameter of the size of an average human head (approx. 18 cm). Due to space problems inside the sphere, the radius of our array had to be extended up to 12 cm. This leads to a spatial-aliasing frequency f_A of, in this case, around $f_A = 3186\,Hz$ (radius of the surface, $r_0 = 0.12\,m$) instead of $f_A = 4248\,Hz$ (ideal radius, $r_0 = 0.09\,m$). Values estimated using [8]:

$$f_A = \frac{N_{sg}c}{2\pi r_0} \tag{1}$$

(Order of the sampling grid, $N_{sg} = 7$, and sound propagation velocity, $c = 343.2\,m/s$)

The grid had to be rotated because of constructional requirements on the 3D model, regarding cuttings to separate the sphere into printable parts as well as holes for outgoing multicore cables and a tripod rod. Detailed information about the microphone positions are provided and need to be considered in the signal processing. The 3D model of the sphere was constructed in Autodesk AutoCAD as shown in Figure 3. We chose to divide the whole sphere into 8 parts (approx. 12x12x12 cm^3) so it can be printed on a wide range of 3D printers, even with a smaller print volume. For printing we used an Ultimaker 3 3D printer with a conductive PLA material from ProtoPasta to provide additional shielding from the outside of the sphere.

Figure 3: Sphere model constructed in Autodesk AutoCAD. Model can be printed with a 3D printer using conductive PLA material.

Microphones

As microphones we chose the omnidirectional electret condenser capsules KE14 from Sennheiser with a diameter of 14 mm. For small scale capsules, the Sennheiser KE14 are characterized by a satisfying frequency response and signal-to-noise ratio (see Technical Evaluation). They are also being used in Sennheiser´s own Ambeo VR Mic and other microphone arrays in the scientific community [9]. The capsules are operated by dedicated converter circuit boards from Sennheiser providing a voltage divider to down-scale standard phantom power (12 - 48 V) to the operating voltage of the capsules. Furthermore, the circuit boards include a balun converter to transform the unbalanced signal from the capsules into a balanced signal outputted on a standard XLR-pin connector on the board. The capsules and circuit boards are placed in custom designed plastic microphone tubes [Figure 4]. This allows to keep the unbalanced, and sensitive for electromagnetic interference (EMI), signal wires short. Here we used shielded 3-Pin microphone cables of approx. $2 - 3\,cm$. The tubes also allow to attach individual shielding on the outside of each one. This is realized by one layer of sprayed conductive graphite with a second layer of EMI-shielding copper tape on top.

Technical Evaluation

The EMI-shielding evaluation was done by placing an assembled microphone tube near a main power plug and measuring the recorded hum noise at 50 Hz. For our

Figure 4: Custom designed microphone tubes holding Sennheiser KE14 microphone capsules and converter boards. With two layers of shielding provided on the outside of each tube, one layer of sprayed conductive graphite with EMI-shielding copper tape on top.

testing scenario the main power plug seemed to be an accessible and appropriate source for a strong electromagnetic radiation of a known frequency. As shown in Figure 5, we placed the microphone tubes of different shielding types (sprayed graphite, copper tape and both combined) approx. 5 cm in front of a main power plug. This distance provided a high magnitude peak at 50 Hz using un-shielded microphone tubes. The measurement with our final shielding shows a strongly reduced noise caused by electromagnetic interference [Figure 6]. We also compared our applied shielding methods (sprayed graphite and copper tape) separately and in final combination [Figure 7]. While there was still hum noise applying the individual shielding methods, there is a significant improvement measurable when combining both. With graphite sprayed on the whole microphone tube and a layer of copper tape added on top, the peak at 50 Hz completly vanishes.

Figure 5: Measurement setup with a microphone tube placed $5\,cm$ in front of a power plug to record $50\,Hz$ main hum noise.

Further we evaluated the SNR of the assembled microphones. The SNR was measured for a single microphone, once individually and once with three neighboring microphones powered on, to investigate potential interference of near-by microphones and to validate the shielding measures for this case. In both cases all microphones were fully assembled inside the rigid sphere. The measurement took place in a quiet, anechoic chamber. To emit the reference signal we used a Genelec 1029A speaker. The resulting SNR was calculated by forming the difference in decibels between the noise-level of recorded silence and a standard 1 kHz reference signal of 94 dB SPL (sound pressure level) present at the microphone. In both measured cases the SNR was amounted to approximately 76 dB, A-rated rel. 94 dB SPL [10].

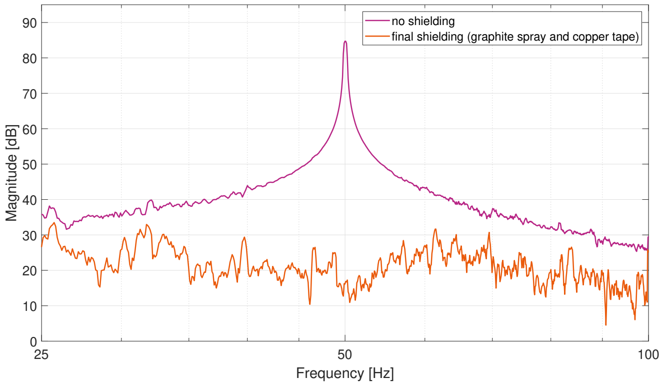

Figure 6: Magnitude response of one microphone tube with (orange) and without (purple) final shielding. The shielding significantly reduces the 50 Hz hum noise measured near a main power plug.

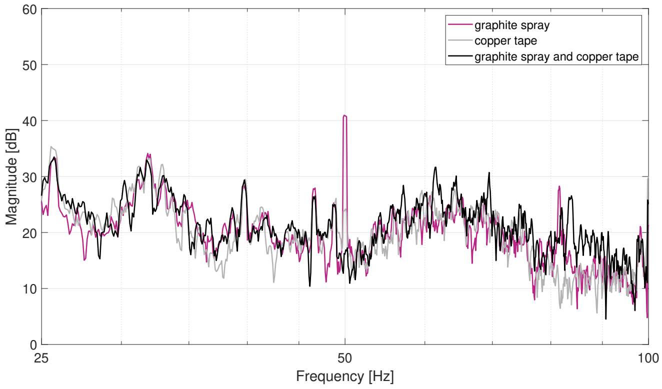

Figure 7: Magnitude response of microphone tubes applied with different shielding types: graphite spray (purple), copper tape (gray) and both in combination (black). The combination of both shielding types turned out as the most efficient with no peak at 50 Hz any more.

Conclusion and Outlook

This paper showed the development of a high order spherical microphone array for spatial audio recordings and reproduction. We developed a 7th order rigid sphere array with 86 high-fidelity microphones on a Lebedev grid. Due to space problems inside the sphere it was impossible to provide an ideal sphere diameter of an average human head. The radius needed to be extended to 12 cm resulting in an approximately 1 kHz ($\sim 1/3$ Octave) lower spatial aliasing frequency. All components are either easy to produce, using a common 3D printer, or easy to access as we were able to use high-fidelity mass-market audio periphery only. This provides adequate prerequisites for an open-source hardware project, opening the possibility for others to build their own HØSMA 7n spherical microphone array or derivatives of it. We also found a good solution for the common problem of electromagnetic interference with shielding measures which are cost effective as well as fast and easy to apply. The shielding measures resulted in a satisfying SNR of the microphones with no noticeable interference from neighboring microphones inside the array. Yet, an evaluation and measurement of the complete array is still pending. A measurement of the array SNR, as well as practical applications for spatial recordings, the real-time processing and spatial reproduction using binaural rendering or Ambisonics in mixed-reality environments form the next steps in this research project.

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