ON THE DIRECT MEASUREMENT AND INTERACTIVE 3D RENDERING OF DUMMY-HEAD DIRECTIONAL CHARACTERISTICS USING POLAR COORDINATES

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Abstract: HRTF measurements usually incorporate with dummy-heads, broadband excitation signals and automated installations for recording and plotting results as function of frequency and direction in the so called 3D "hoop" coordinate system. Plotting results in different coordinate systems or along different axes (such as the interaural axis) requires further calculations. This paper presents an automated measurement system for direct recording and evaluation of dummy-head HRTFs in a polar coordinate system. Color plots using different scales show directional dependence of the transmission and image processing methods are introduced for interactive 3D rendering of the measured dataset (cloud) for visualization and further analysis.

1 Introduction

In human spatial hearing localization is determined by the interaural level and time differences (ILD, ITD) between the two ears. Furthermore, if no interaural difference is present, the filtering effect of the outer ears deliver information about elevation. The transmission can be described by the Head-Related Transfer Functions (HRTFs) in the frequency domain or by the Head-Related Impulse Responses (HRIRs) in the time domain [1-5].

HRTFs are usually defined in the so called „hoop" coordinate system (Fig.1.) and measurements are done by a moving sound source in the horizontal and vertical plane respectively. However, sometimes it is beneficial to define and to have HRTFs represented in the polar coordinate system. This uses the polar and lateral angles as shown in Fig.1. If the measurement is made using elevation and azimuth, further off-line calculations are needed to transfer them into the polar coordinate system.

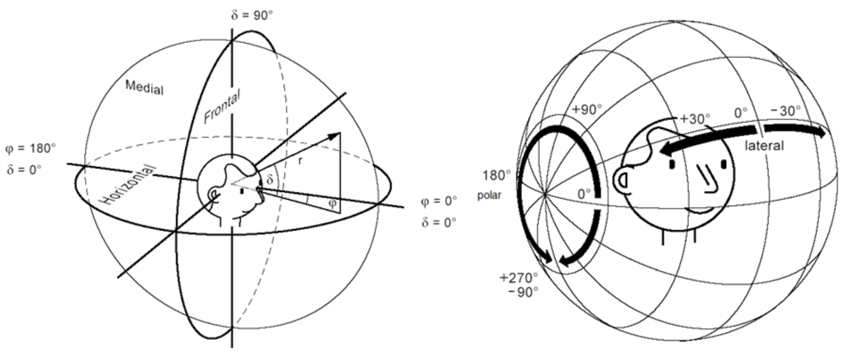

Fig. 1. Left the "hoop" coordinate system, given by δ and φ (medial and horizontal plane). The frontal plane is also displayed. Right the polar coordinate system with lateral and polar angles [1-6].

Because most of the installed systems do not offer easy transfer between these representations, and furthermore, they do not offer direct measurement in the polar system, we installed a dummy-head system for direct measurements and for real-time plotting of the directional characteristics. The literature usually incorporates with classical representations in time, frequency and space without calculating directional contours that can be very helpful in analyzing scattering, shadowing etc. effects of the head and torso [6].

Figure 2 and 3 show two examples from the literature. There is usually a quite incomplete representation in frequency and space (spatial resolution). Furthermore, representations are limited to 2D slices of the otherwise 3D directional plots. The goal of this measurement was to determine the directional characteristics of a dummy-head in given directions (planes, slices) and frequencies for creating both 2D and 3D plots. For the latter, a solution for interactive manipulation of the figures was also in focus.

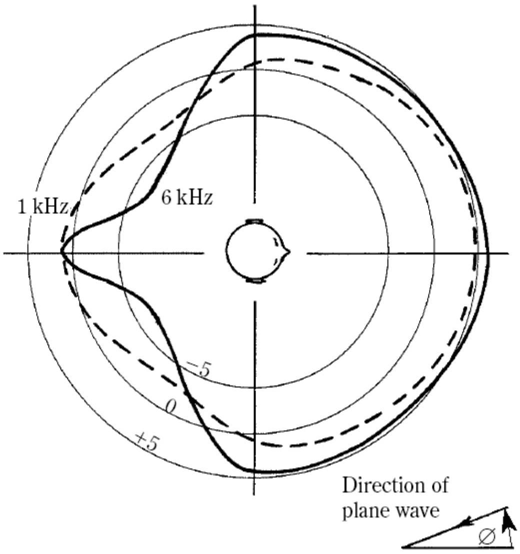

Fig. 2. An early plot from 1940 on diffraction around a solid sphere about the size of a human head. For sound in the 1-6 kHz range, sound pressure is generally increased in the front hemisphere and generally reduced in the rear [7].

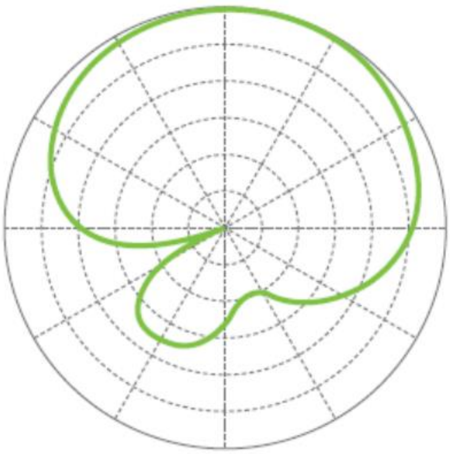

Fig. 3. Measured directional head characteristics showing the head shadow effect in a schematic plot from a commercial pamphlet of a hearing aid device (no frequency information) [8].

2 Measurement setup

For measuring the HRTFs a HEADAcoustics dummy-head was installed in the anechoic chamber. It was mounted on a turntable (OWIS DMT 130) controlled by the software (OWIS SMS 60). The generator output and data input were controlled by a Rhode/Schwarz Audio Analyser and the user interface was programmed in LabView. The sound source was a T&M SYSTEMS T&M 8PA loudspeaker on a stand. The reference signal was measured with a Brüel & Kjaer omnidirectional microphone (reference signal). Spatial resolution is one degree in the plane where the turntable is actually rotating. No data collection is made during the movement. The dummy-head can be mounted on the turntable horizontally, vertically and in tilted positions (10-degree steps) in between. Excitation was white noise, evaluation was made in octave bands, however, it is possible to reduce the bandwidth. The software controls the output signal, the movement of the turntable, the data acquisition, saving and plotting of measured data [9].

Figure 4 shows a general block diagram of the system and the GUI of the software. The system is capable of testing equipment other than a dummy-head as well.

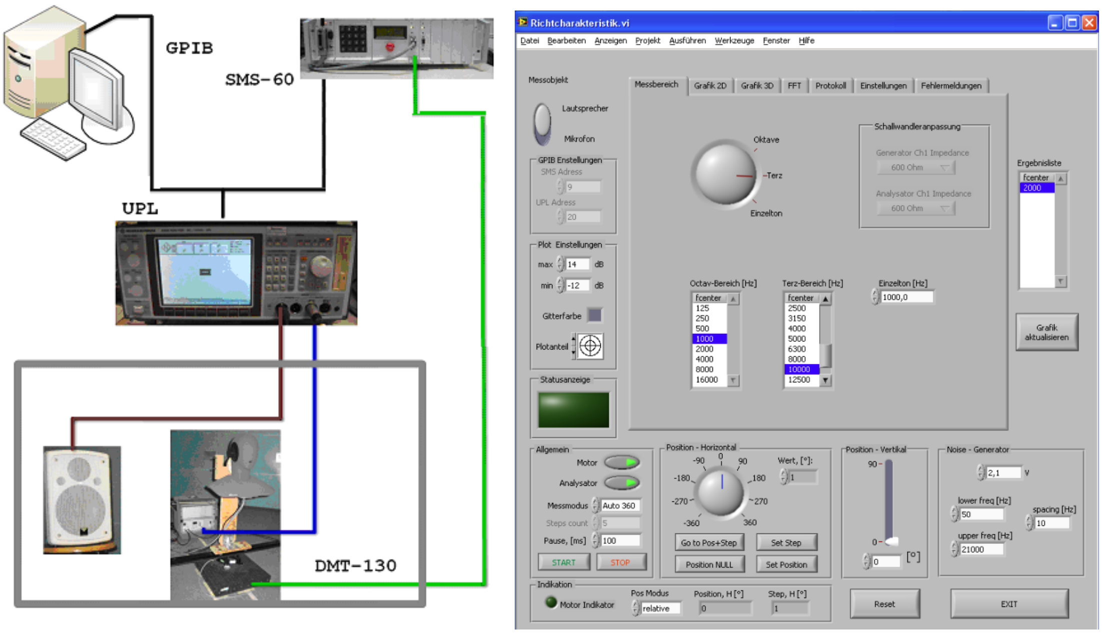

Fig. 4. General block diagram of the setup (left) and screen shot of the GUI that enables controlling the measurement (right).

3 Discussion

3.1 Directional plots in the horizontal plane

Figures 5-6 show directional characteristics for one ear (left ear) in octave bands (center frequency) in the horizontal plane, where the head is positioned in the origin. Between 125 Hz and 500 Hz the transmission is almost omnidirectional, as expected. Above 630 Hz, the dummy-head becomes more directional-dependent. This supports former measurements [1]. Because at some frequencies the dynamic range of the sensitivity is higher than on figures 5-6, figure 7 shows high frequency results on different scales for a better comparison. The goal of this presentation method is to make each result more visible. By comparing figure 2 with figures 6 and 7 it is clearly visible that a rigid sphere model estimation may be mathematically correct, but real measurements show more unsymmetric characteristics due to pinnae effects on both sides.

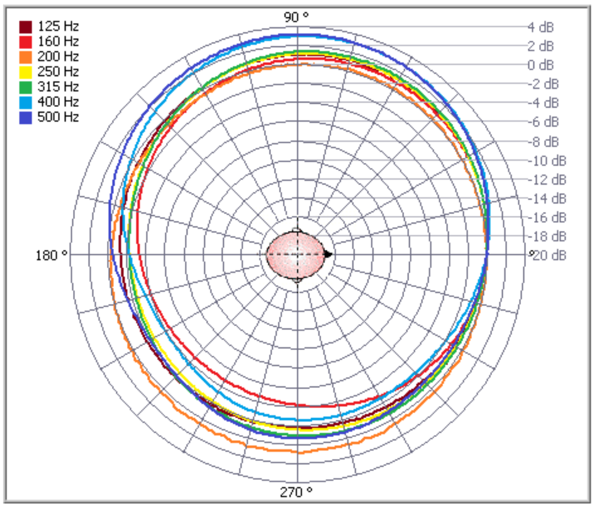

Fig. 5. Directivity plots from 125 Hz to 500 Hz.

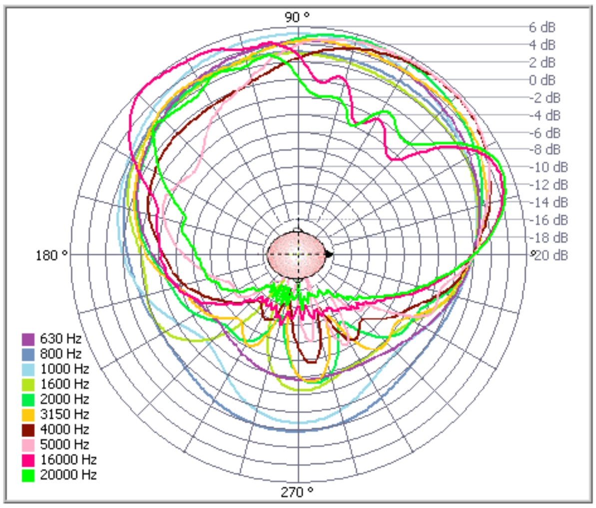

Fig. 6. Directivity plots from 630 Hz - 20 kHz.

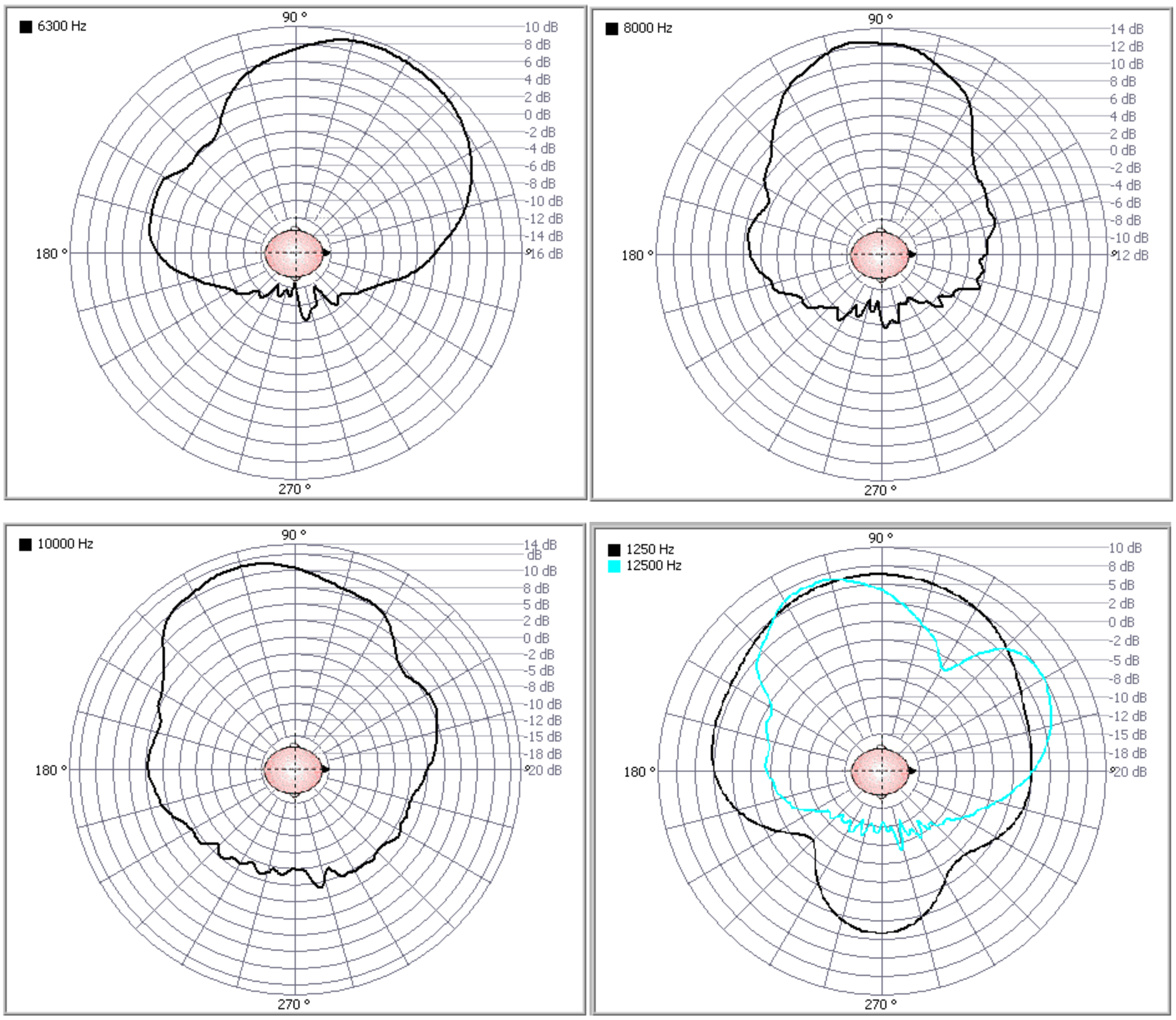

Fig. 7. Directivity plots using different scales at 6300 Hz (top left), 8000 Hz (top right), 10 kHz (bottom left) and 1250 Hz and 12500 Hz respectively (bottom right).

3.2 Directional plots in the median plane

Figures 8 shows results from the median plane. Here, results only at 1250 Hz showed increased dynamic range. Please note, that based on the dummy-head's size and geometry (head and partly torso), measured data from „below" are not valid. The spatial range suitable for evaluation is between about 300 degrees (-60º) in front and 240 degrees in the back.

As expected, low frequency plots (below 630 Hz) show almost unidirectional characteristics, whilst with increasing frequency the effect of the head and torso, pinnae becomes more significant in both planes. At higher frequencies the pinnae sound collecting effect creates sidelobes from above at frontal directions. There is reception even from the top and back directions, supporting our former results of a measurement with a different dummy-head and HRTF recording system [10-12].

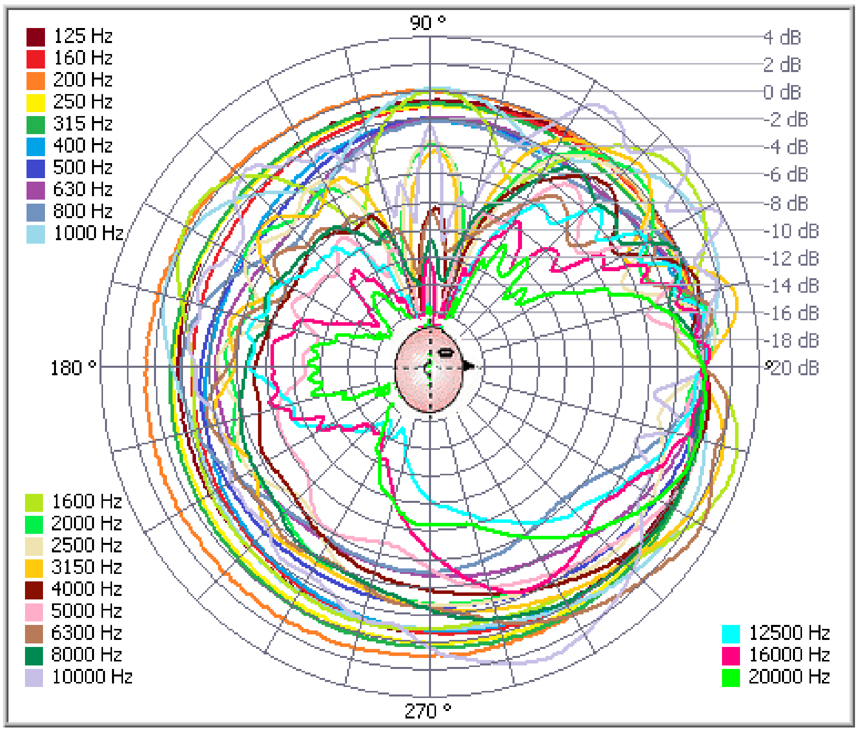

Fig. 8. Directivity plots from 125 Hz to 20000 Hz, without the 1250 Hz plot.

In the vertical plane, at 1250 Hz sensitivity (dynamic range) is the highest. Furthermore, the same increased dynamic range can be seen at 5-10 kHz in the horizontal plane. Also the spatial contour (directional dependence) can be observed for all measured frequencies. After measuring the horizontal and vertical plane, planes in between were also measured by tilting the dummy-head in 10-degree steps to the left and the right respectively in order to get a better interpolation for the 3D plots.

3.3 Interactive directional plots using 3D rendering

Today's technique allows representation and plotting of measurement data using image processing techniques and 3D rendering software. In this case, the data points ("the cloud") had to be visualized in a 3D space, where the origin is the head and measured planes are slices of the 3D directional plots. Points have to be displayed properly in the space and furthermore, they can be processed by linking the dots, forming polygons and using shadowing and coloring effects. For an interactive solution, where users can access and manipulate (rotate, zoom etc.) the plots directly on the screen the Qt development environment was used, including C++ and the open-source Point Cloud Libraries [13]. Furthermore, the open-source Visualization Toolkit (VTK) has been applied for the rendering [14]. The software also enables smoothing and interpolation of the data, zooming, re-scaling and displaying anaglyph stereophonic versions of the plots for the red-green or red-cyan glasses. Using the exported data formats, the Objet30 3D printer at the university is able to print these directional plots for demonstration purposes.

Figures 9-12 show rendered 3D data clouds as screenshots at selected frequencies for demonstration. On the right, the point cloud with a schematic blue head can be seen. Nose and the right ear are white, as long the measured ear (left ear) is red. On the left, the 3D directional plots show shadowed polygons based on the raw data, without smoothing.

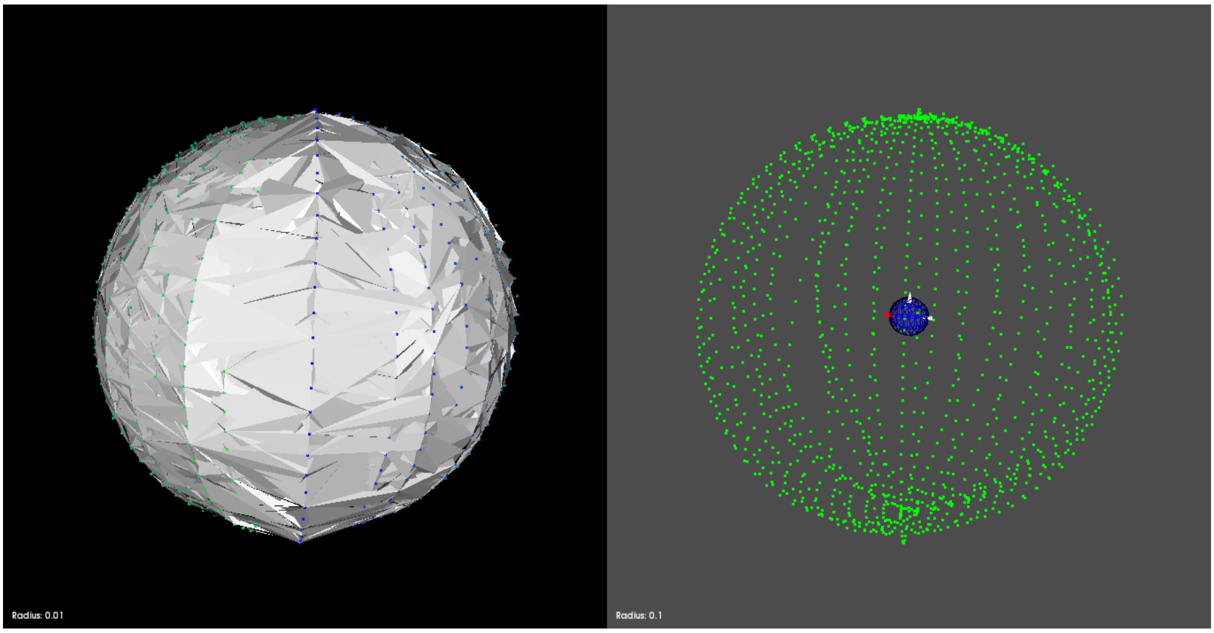

Fig. 9. Directivity plot at 125 Hz.

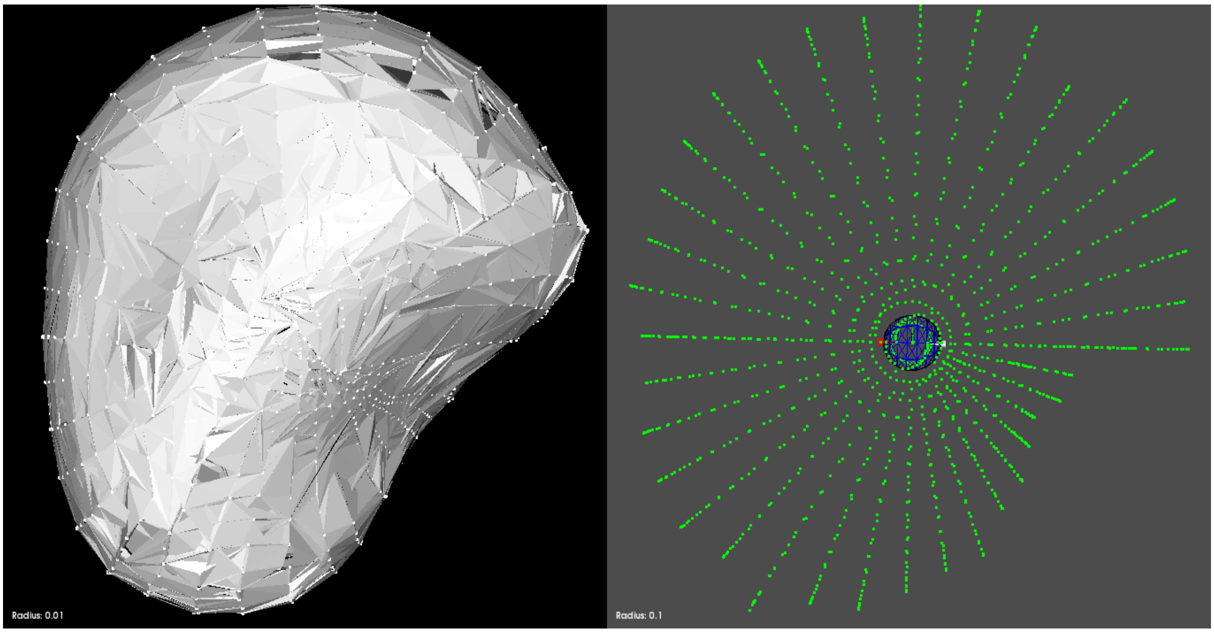

Fig. 10. Directivity plot at 500 Hz.

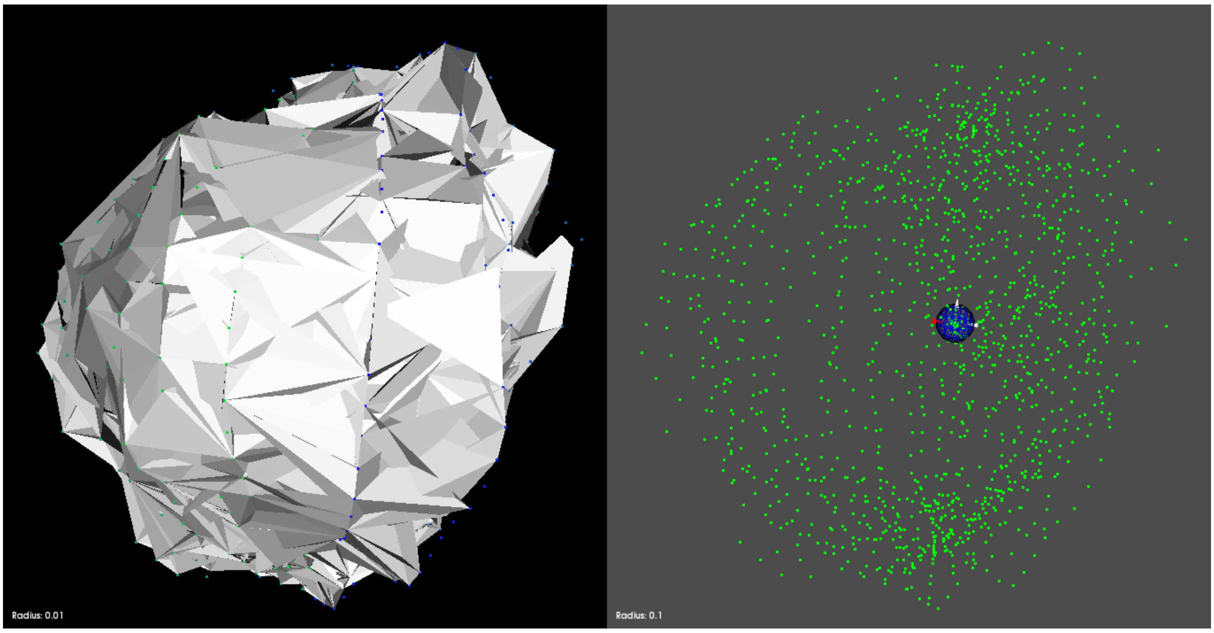

Fig. 11. Directivity plot at 8000 Hz.

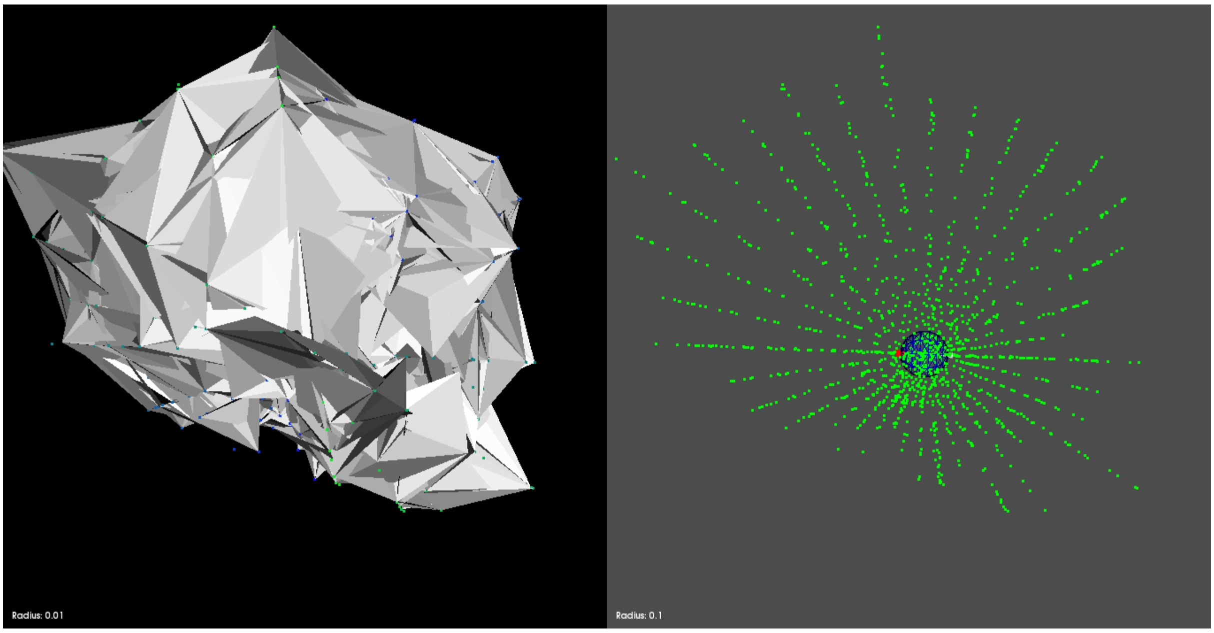

Fig. 12. Directivity plot at 16000 Hz.

4 Conclusion

A measurement system was presented for automated measurements of directional characteristics. It enables direct recording and real-time plotting of HRTF data in the polar coordinate system if dummy-heads are used. The environment is optimized for HRTF data acquisition but it can be used for other equipment as well. Due to the easily adjustable stand and mountings, devices with unusual shapes and forms can be installed and evaluated. 2D color plots show a complete collection of contour plots in octave-band resolution for two planes. Furthermore, a 3D environment was introduced for manipulation and further data analysis or 3D printing. Future works include further measurements and comparison of other dummy-heads as well as comparison with calculated directional plots of human measurements.

5 Acknowledgement

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