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DirPat - Database and Viewer of 2D/3D Directivity Patterns of Sound Sources and Receivers

Manuel Brandner[1], Matthias Frank[1], and Daniel Rudrich[1]

[1] *University of Music and Performing Arts Graz, Institute of Electronic Music and Acoustics*

Correspondence should be addressed to Manuel Brandner (`brandner@iem.at`)

ABSTRACT

A measurement repository (DirPat) has been set up to archive all 3D and 2D directivity patterns measured at the Institute of Electronic Music and Acoustics, University of Music and Performing Arts in Graz. Directivity measurements have been made of various loudspeakers, microphones, and also of human speakers/singers for specific phonemes. The repository holds time domain impulse responses for each direction of the radiating or incident sound path. The data can be visualized with the provided 2D and 3D visualization scripts programmed in MATLAB. The repository is used for ongoing scientific research in the field of directivity evaluation of sources or receivers regarding localization, auditory perception, and room acoustic modeling.

1 Introduction

This contribution is in the spirit of open data and reproducible research. It offers source and receiver directivity data measured at the Institute of Electronic Music and Acoustics (IEM) for download from the persistent data repository[1] of the University of Music and Performing Arts, Graz. For visualization and analysis of the data that is stored in AES69 SOFA format (Spatially Oriented Format for Acoustics [1]), directivity inspection tools developed in the last decade at IEM are also included in the repository.

The database of the IEM is comparable to the database presented in [2], however with a denser measurement grid over a full 3D sphere for the loudspeakers and microphones. For human speakers/singers, 2D directivity data for the horizontal and vertical axis is provided. Acquiring detailed spherical measurement data of human speakers/singers and musical instruments in 3D still remains a time consuming process and is not easy to perform without the commitment of the performers. That data will be added to the DirPat repository in the future. For musical instruments a database is presented in Shabtai et al. [3].

This document is outlined as follows: first, the measurement setups for sources and receivers are described, followed by the necessary signal processing of the recorded audio for each scenario. Subsequently, the directivity viewers are introduced, which can be used to visualize the measured directivity data. Finally, exemplary measurement data is presented:

(1) an AKG C414 large-diaphragm condenser microphone with its selectable directivity patterns,
(2) a combination of two guitar cabinets creating a cardioid radiation pattern,
(3) comparison of two human speakers/singers.

[1] `https://phaidra.kug.ac.at`

2 Measurement of Directivity Patterns

2.1 Measurement Setups

2.1.1 Circular Loudspeaker Array

Impulse response measurements of receivers employ a vertical semicircle of 16 loudspeakers at a radius of 1.5 m with an angular spacing of 11.25°. The used loudspeakers have 3-inch drivers and a wooden rationally symmetric housing [4]. The measurement signal is amplified with a Bittner 8X 100 multichannel amplifier.

2.1.2 Double Circle Microphone Array

For measuring source radiation patterns, a microphone array consisting of two circular rings is employed, cf. Fig. 1. Each of the rings, one placed in the horizontal, the other one in the vertical plane, respectively, can hold up to 32 microphones. The maximum number of microphones is 62 as both rings intersect in the front and back of the array. The angular spacing of the microphones is 11.25° with a radius of 1 m. The apparatus' diameter spans 2.56 m at its widest point. The center-facing side of the rings with a thickness of 21 mm are beveled to reduce reflections. With the setup being held by adjustable loudspeaker stands, the center of the array can be lifted to any height between 1.3 m and 2 m. The microphones mounted to the array are NTI MA 2230 and they are connected to an Andiamo.MC Directout Technologies microphone preamplifier.

2.2 Measurement Procedures

2.2.1 Measurement of Receivers

To measure the directivity pattern of receivers, such as microphones, they are placed on a turntable (Outline ET 250-3D) in the center of the circular loudspeaker array. The impulse response measurement utilizes the multi-sweep method proposed by Majdak et al. [5]. The sweep measurements are repeated for every 10° starting at 0° azimuth until 170° for a full 3D sampling. Prior to the actual measurement, each loudspeaker's transfer function to the center of the array is measured with a reference microphone (NTI MA 2230).

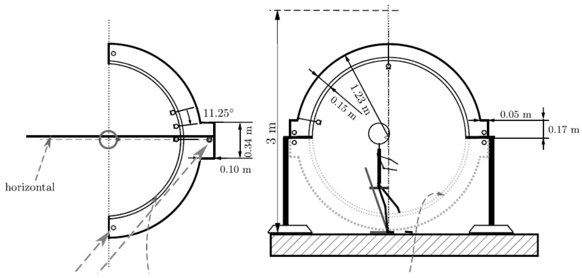


Fig. 1: Double Circle Microphone Array. Schematic of the measurement setup with two wooden circular rings (thickness: 21 mm).

2.2.2 Measurement of Sources

Loudspeakers The measurement of loudspeakers employs the double circular microphone array. As the loudspeakers are placed on a turntable in the center of the array, only the microphones of the vertical ring are used. Typically the acoustical center of a loudspeaker is frequency-dependent, especially in a multi-driver system. Therefore, a frequency-dependent positioning during the measurement or the application of acoustical centering algorithms [3, 6] as a post-processing step might be helpful. For each rotation of the turntable a single logarithmic sweep [7] is played back.

Human Speakers/Singers Impulse responses from directivity measurements for different phonemes used in human speech or singing can be acquired by the glissando method proposed in [8]. The head of the performer is equipped with reflective markers for optical tracking and she/he is asked to sit within the measurement setup close to a centered reference microphone. A visual feedback of his/her position is provided, whereby the mouth is defined as the acoustical center. The performer is asked to sing a glissando starting at a low pitch and ending one octave above the starting pitch. Thus, overlapping of the fundamental frequency and its first harmonic can be avoided. The measurement is made in the horizontal and vertical plane simultaneously to reduce measurement time and positioning drifts.

2.3 Measurement Signal Processing

The impulse responses for the calculation of the directivity patterns are computed by frequency-domain deconvolution of the measured sweep responses with the measurement signal (multi/single sweep, glissando).

A more detailed description of sweep measurement and deconvolution can be found in [7]. In order to exclude room effects such as floor reflections, the impulse responses are truncated to a necessary minimum length using a Hann window. Depending on the application a weighting function should be applied to the impulse response data to compensate for the more dense distribution of the sampling towards zenith and nadir, e.g. for the calculation of the directivity index.

2.4 Visualization using Spherical Harmonics

The visualization uses an interpolation scheme which is applied in the spherical harmonics (SH) domain. Therefore, the sound pressure values are multiplied by an inverse matrix holding SH coefficients $\boldsymbol{Y}_{nm} = [(\boldsymbol{y}_{nm}(\varphi_1,\vartheta_1)\boldsymbol{y}_{nm}(\varphi_2,\vartheta_2)...\boldsymbol{y}_{nm}(\varphi_L\vartheta_L)]^T$ for each distinct measurement point. The inverse transformation of the spherical wave spectra $\boldsymbol{\psi}_{nm}$ in Eq. 1 is done with a denser grid of SH coefficients $\tilde{\boldsymbol{Y}}_{nm}$ to achieve a higher resolution. This process merely corresponds to an interpolation of the pressure values between the spherical measurement points. The vector p describes the frequency-dependent measured sound pressure and the vector p_i the interpolated sound pressure values. The values are evaluated at kr, where k is given by $k = \frac{\omega}{c}$, with k denoting the wave number, c the speed of sound, and r the radius of the measurement aperture, respectively. Further information about the spherical harmonic decomposition can be found in [9].

$$\boldsymbol{\psi}_{nm} = \begin{pmatrix} p(kr,\varphi_1,\vartheta_1) \\ p(kr,\varphi_2,\vartheta_2) \\ \dots \\ p(kr,\varphi_N,\vartheta_N) \end{pmatrix} \boldsymbol{Y}_{nm}^{-1} \tag{1}$$

$$p_i(kr,\varphi,\vartheta) = \boldsymbol{\psi}_{nm}(kr)\tilde{\boldsymbol{Y}}_{nm} \tag{2}$$

3 Evaluation of Directivity Patterns

3.1 Visualization - MATLAB Viewers

The *2D Pattern Viewer* facilitates the comparison of two separate measurements along the horizontal and vertical planes together with features, such as the directivity index (DI) or the correlation coefficient. The directivity index of a sound source is typically defined as the ratio of the on-axis sound power to the overall sound power [2]. Furthermore, the viewer visualizes frequency responses and directivity index over frequency.

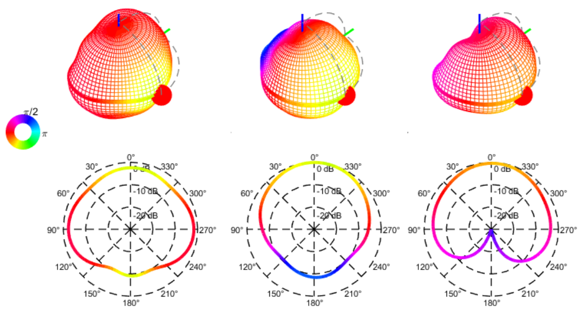
The *3D Pattern Viewer* renders the full 3D patterns in a balloon plot and an adjustable slice plane as 2D polar pattern. The frequency-dependent directivity can be studied by moving the frequency slider.

3.2 Exemplary Measurement Data

The following measurements are all conducted in the anechoic chamber at IEM.

3.2.1 Guitar Cabinets

Fig. 2 shows the measurement results of a self-made guitar cabinet system using a 12-inch speaker driver in a closed-back and open-back configuration. The first one can be presumed to be omnidirectional and the second one to have figure-of-eight characteristic. The measurement results agree with this presumptions for frequencies below 800 Hz. Moreover, the measurement of the stacked cabinets shows that the combination of the two cabinets radiates sound with almost a perfect cardioid pattern. As the two drivers cannot be arranged to be vertically coincident, the cardioid pattern is not achieved rotational symmetric and yields lower sound pressure levels near the zenith and nadir.

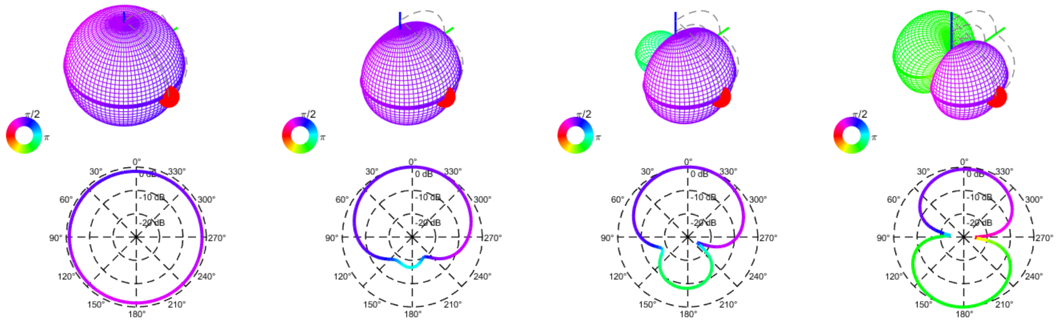


(a) Closed-back only (b) Open-back only (c) Stacked cabinets

Fig. 2: Measured directivity patterns of guitar cabinets for f = 300 Hz.

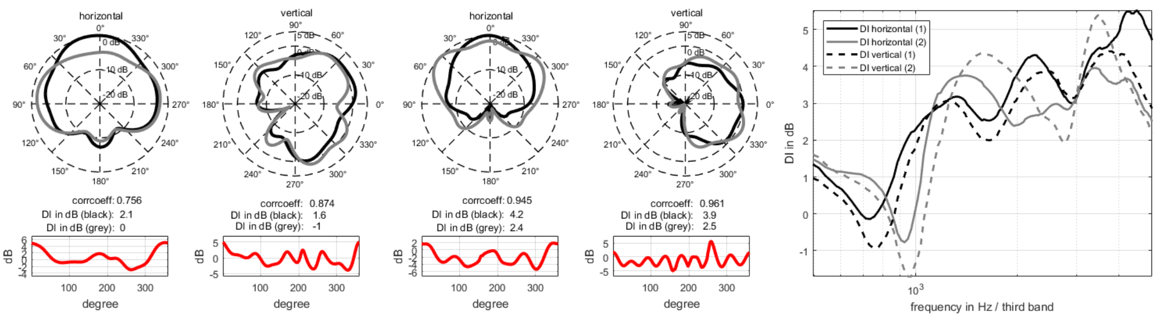
3.2.2 AKG C414 Condenser Microphone

One of the most popular large-diaphragm condenser microphones in recording is the AKG C414 developed in Vienna, Austria. The selectable directivity is one of its key features: the microphone allows switching between omnidirectional, cardioid, supercardioid and figure-of-eight directivity patterns. The measurement results confirm the four directivity pattern settings of the manufacturer, as shown in Fig. 3 for 1 kHz.



(a) Omnidirectional (b) Cardioid (c) Supercardioid (d) Figure-of-eight

Fig. 3: Measured directivity patterns of AKG C414 microphone with selectable directivity at f = 1000 Hz.



(a) Directicity pattern at f = 1000 Hz (b) Directivity pattern at f = 2300 Hz (c) Horizontal and vertical directivity index

Fig. 4: Comparison of two human speakers/singers (back, gray) in the horizontal and vertical plane.

3.2.3 Human Speaker and Singer Directivity

The directivity data for two human speakers/singers is measured with the double circle microphone array using the glissando method, as described above. The polar patterns in Fig. 4 show a difference of at least 4 dB at a frequency of 1 kHz on axis, and at 2.3 kHz in the vicinity of $\pm 50^\circ$. Thus, the differences of the two performers in terms of body shape, posture, and head tilt are noticeable. Alternatively, the radiation characteristics can be compared using the frequency-dependent directivity index. Fig. 4 (c) depicts the horizontal and vertical directivity indeces (HDI, VDI) for the two performers. The repetitive drops along the frequency axis of HDI and VDI are due to destructive interferences by torso reflections. Therefore, the on-axis sound pressure level decreases. For the two performers, these drops of HDI and VDI occur at different frequencies, because of individual physical properties.

Measurements in [10] showed that differences between the directivity patterns of different performers decreased with the measurement distance. Nevertheless, the current results for a measurement distance of 1 m still reveal clear inter-performer differences in the directivity patterns.

4 Conclusion

This report discusses and describes DirPat, a database and viewer of 2D/3D directivity patterns of the IEM. The main idea of this work is to provide data and tools which can be utilized to understand and evaluate directivity characteristics of sound sources and receivers. DirPat is in the spirit of open data and reproducible research: the MATLAB scripts for the 2D/3D viewers, all directivity data discussed here, as well as other measurement data from IEM are freely available here: `https://opendata.iem.at`

The evaluation of exemplary measurement data shows how directivity patterns of sources and receivers can be investigated and how prototypes or products can be analyzed with the currently available tools. Whilst a full 3D measurement of human speakers/singers or instrumentalists is still a time consuming procedure, the measurement of loudspeakers and microphones is less complicated to conduct.

The impulse responses stored in the database enable easy manipulation of multichannel audio and application of specific directivity patterns and can be combined with tools, such as the IEM Plug-in Suite[2], a free VST plug-in package to render 3D audio in a DAW. The plug-ins provide an interactive real-time auralization of directional sources and receivers in simulated rooms. This is interesting for perceptual evaluation in regard to source width, distance, or overall sound quality.

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