Spectral Directivity of Singing Bowls

Christina Imbery, Britta Jensen, Reinhard Weber
University of Oldenburg, Acoustics Group, 26129 Oldenburg Germany, Email: christina.imbery@uni-oldenburg.de

Introduction

Singing bowls originate from the Far East (e.g. China or Tibet) and they produce a bell-like sound. As a result of the handcrafted production by hammering and bending, a singing bowl gets its characteristic beating sound due to paired partial tones (Fig 1), so called modal pairs. These modal pairs often have a distinct amplitude and decay pattern [2].

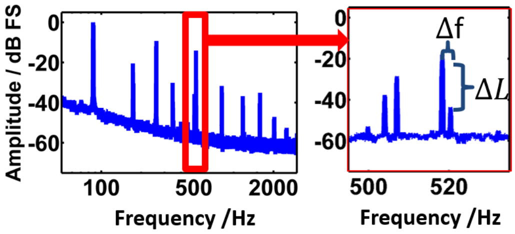

Figure 1: The spectrum of a recording with a duration of $45\,s$. The spectrum consists of a number of partial tones with a distinct amplitude. The partial tones often occure as modal pairs with a slightly different frequency Δf and an amplitude distance ΔL.

In addition to these spectro-temporal characteristics, the frequency dependent directivity also influences the temporal variation of the acoustical impression at a specific listening position. This directivity pattern could be a result of the modeshapes at the bowl rim which consists of radial and tangential components [1]. According to Inácio (2008) [1] the experimentally identified radial modeshape are characterized by an increase of nodal meridians from modal pair to modal pair. Within each modal pair the directivity pattern of the two partials have the same form but differ in the azimuth orientation.
In this respect, the directivity pattern of the sound of a singing bowl for different modal pairs are measured. This includes recordings of the radiated sound for different microphone orientation in the vertical direction ϑ and different positions of the singing bowl in the azimuth orientation φ.

Experimental Setting

To determine the directivity pattern, the sound of a singing bowl is recorded under free-field conditions in an anechoic room. The singing bowl ($2\,kg$, $\varnothing = 28.5\,cm$) is placed on a rotating platform with nine microphones (B&K 1/2" Type 4189) fixed on a semicircle vertically above the singing bowl, Fig 2. The microphones are calibrated with a sound level calibrator (B&K 4230). The angle between neighbouring microphones is max. $\Delta\vartheta = 30°$ and the radius of the microphone array is $115\,cm$.
The singing bowl is excited by an impulse excitation with a rubber stick ($50\,g$, $\varnothing = 5.5\,cm$) at a fixed location on the bowl. The sound is recorded for $45\,s$ through the calibrated microphone array with a sampling frequency of $44100\,Hz$. This measurement is repeated ten times with the same strength while keeping the excitation point fixed. To determine the directivity pattern for different azimuth orientations, the platform rotates by degrees of $\Delta\varphi = 30°$.

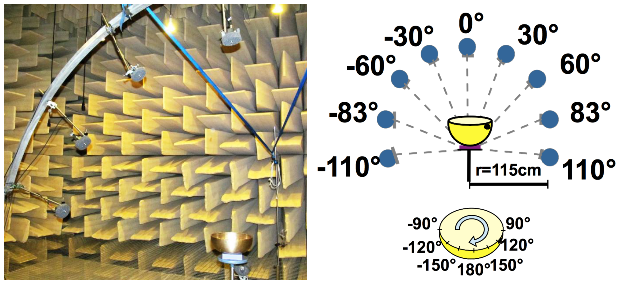

Figure 2: Experimental setup for the recording of the sound of the singing bowl in the anechoic room.

Analysis of the Recordings - Reproducibility

To investigate the reproducibility of the recordings, ten recordings with a duration of $45\,s$ at a specific microphone position and azimuth orientation are evaluated. The magnitude squared coherence $C_{xy}(f)$ between two recordings, an arbitrarily reference recording x and one of the nine remaining recordings y from the other microphone positions is calculated based on the power spectral density of the two recordings $P_{xx}(f)$ and $P_{yy}(f)$ and the cross power spectral density $P_{xy}(f)$ with equation 1.

$$C_{xy}(f) = \frac{|P_{xy}(f)|^2}{P_{xx}(f)P_{yy}(f)} \qquad (1)$$

The estimation of the magnitude squared coherence is frequency dependent with a value between 0 and 1 with 1 as the highest coherence at each frequency.
This procedure is repeated for all of the nine remaining recordings and all nine specific microphone positions. The frequency resolution is $0.17\,Hz$. The median and its quartile ranges over the 81 coherences are shown in Fig 3 as boxplots. There are reproducible frequency components with a median coherence value > 0.9 which includes the partial tones of the singing bowl.

Directivity Pattern

The directivity pattern of each partial tone f_T includes the average of the ten repeated measurements and were calculated for the azimuth φ and elevation ϑ direction with equation 2. The value $\tilde{p}_{max}$ represents the maximum sound pressure level in φ_{max} and ϑ_{max} for the frequency f_T.

$$D(\varphi, \vartheta, f_T) = 20log_{10}\left(\frac{\tilde{p}(\varphi, \vartheta, f_T)}{\tilde{p}_{max}(\varphi_{max}, \vartheta_{max}, f_T)}\right)dB \qquad (2)$$

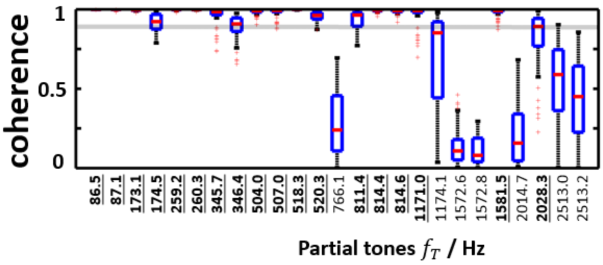

Figure 3: Boxplot with median and quartile range over 81 coherences: There are frequency components (underlined) with a median coherence value > 0.9 (doted line) which are included in the further evaluation as 18 partial tones f_T for the singing bowl. The frequencies f_T range from 80 to 2000 Hz while the most partial tones lie below 1000 Hz.

The directivity pattern of a partial tone for the angle in azimuth φ and elevation ϑ direction are illustrated as polar diagram with a linear interpolation to 5°.

Characteristic Mode Shapes in the Directivity Pattern

For the further presentation of the directivity patter similar mode shapes in the partial tones are summarized to characteristic mode shapes. These characteristic mode shapes are given by counting equal mode shapes and are expressed as percentage. Besides these characteristic shapes, there are also other mode shapes or variation of these shapes but with no clear match to one of these categories.

In the azimuth direction φ there are three characteristic mode shapes showing up in overall ~60% of the directivity pattern, see Fig 4. One of the most frequent shape

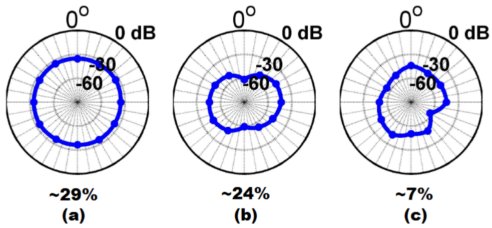

Figure 4: Charakteristic mode shapes (a,b,c) and its percentage distribution in the directivity patter for the azimuth direction

is an omnidirectional shape (a) with ~29% and a dipol shape (b) with ~24% in the partial tones. A cardioid shape (c) occurs for ~7%.

In the elevation direction ϑ there are four characteristic shapes showing up in overall ~77% of the directivity pattern, see Fig 5.

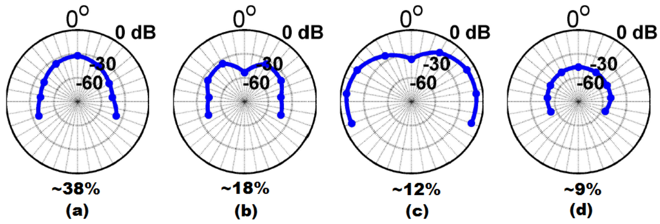

Figure 5: Charakteristic mode shapes (a,b,c,d) and its percentage distribution in the directivity patter for the elevation direction

The most frequent shape with ~38% has a directivity pattern which radiates more upwards to 0° than sidewards at the rim of the bowl at 83°(a). The difference between the two directions is in this example approx. $10\,dB$. In contrast there are also shapes with a notch at 0°, see the next two frequent shapes (b) with ~18% and (c) ~12%. But in contrast to shape (b), shape (c) radiates more sidewards. The fourth characteristic shape with ~9% has a omnidirectional radiation.

Directivity Pattern of Modal Pairs

As an example of the directivity pattern of modal pairs, Fig 6 shows the directivity pattern in the azimuth direction for the first four modal pairs in the plane of the rim of the bowl ($\vartheta = +83°$ and $\vartheta = -83°$). There are modal pairs which produce a direction-independent modulation like the second modal pair at f_3 and f_4. But there are also modal pairs with a direction-dependent modulation like the fourth modal pair at f_7 and f_8. Thus the resulting beats for the modulation also have a directivity pattern.

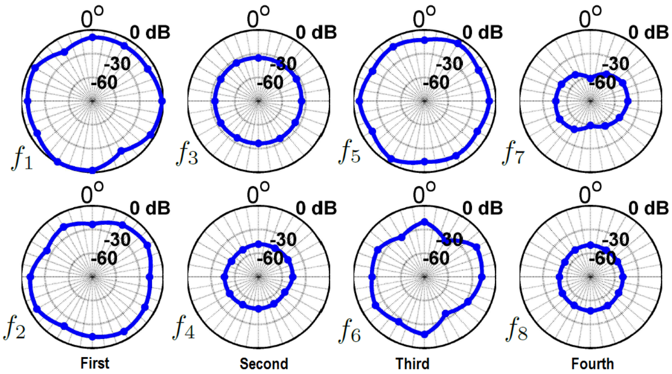

Figure 6: Directivity pattern of the first four modal pairs: The shape of the first modal pair has a dipole character for $f_1 = 85.5\,Hz$. The shape of its modal partner at $87.1\,Hz$ has another shape. The partial tones of the second modal pair at $f_3 = 173.1\,Hz$ and $f_4 = 174.5\,Hz$ have both an omnidirectional pattern with a level difference of approx. $20\,dB$. The shapes of the third and fourth modal pair have a different directivity pattern for each partial.

Conclusion

The sound of a singing bowl consists of modal pairs which are responsible for the characteristic beating. Due to its spectoral-temporal characteristic and the complex directivity pattern of each partial tone, the sound changes on the one hand with passing of time and on the other hand in different spatial directions. Some shapes of the directivity pattern are comparable with the radial modeshapes of the singing bowl from Inácio [1].

References

[1] Inácio O. (2008): A Modal Method for the Simulation of Nonlinear Dynamical Systems with Application to Bowed Musical Instruments. University of Southampton, ISVR, PhD Thesis, p.150-186

[2] Jensen B., Stever J., Imbery C. Weber R. (2014): Systematische Variation komplexer Klangschalenschalle und ihr Einfluss auf die Wahrnehmung. DAGA 2014, Oldenburg, Dega e.V., Berlin