CAPTURING THE RADIATION CHARACTERISTICS OF THE BONANG BARUNG

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Abstract: *Virtual Gamelan Graz (VGG) is an interdisciplinary research project investigating gamelan musical structures, performance practices, and the acoustics of gamelan instruments. VGG tries to combine such different scientific fields as (ethno-)musicology, algorithmic composition, musical acoustics, and sound processing. One research interest within VGG is the real-time synthesis of gamelan sounds including their directional radiation characteristics.*
This paper demonstrates a method of capturing the directivity of sounds emitted by musical instruments, taking as a practical example the bonang barung (a kettle gong instrument in gamelan ensembles). Using a spherical microphone array, and taking simultaneous recordings of the array signals, we obtain a spatiotemporal description of the radiated sound. We propose a suitable array layout and directivity encoding scheme. Further, we develop a model of a total power-spectrogram which contains all spectral information present in the array signals. Based on this spectral descriptor, we are able to find temporal evolutions of the directivity patterns associated with each partial within the instrumental sound. Finally, we illustrate some examples regarding the bonang barung.

Key words: Directivity, spherical harmonics, multipoles, partials

1. INTRODUCTION

In order to simplify the measurement of the directivity of musical instruments, one is tempted to assume that the radiation pattern is static. And it is even more practical to assume that directivity characteristics are independent of the particular excitation (contact point, strength, etc). These assumptions provide a vast reduction to the complexity of the radiation problem. Apparently, they offer the only way of obtaining almost general descriptions of the directivity, though several further compromises have to be accepted in practise, cf. Weinreich [1], Caussée [4], Giron [6], Behler [9].

If we drop all these simplifications, it becomes very difficult to measure general descriptors of the directivity. For instance, the particular measurement (recording) of a musi-

cal sound[1] may be regarded as non-repeatable in a technical sense, and a huge effort has to be taken to obtain representative measurement data from different instruments, sounds, and playing techniques. In this work, we explicitly refuse this kind of generalization claim, but we deal with the description of a particular sound from a particular instrument.

As we consider musical sounds as non-repeatable here, the use of a microphone array for the simultaneous capture of the directional sound is mandatory. In the remainder of this paper, we provide an insight into our approach of multi-channel directivtiy analysis, considering the Javanese *bonang barung* as an example.

Figure 1: Microphone array for directivity capture.

Mic.	φ	ϑ	Mic.	φ	ϑ
mic1	0°	90°	mic14	51°	54°
mic2	30°	90°	mic15	87°	54°
mic3	60°	90°	mic16	123°	54°
mic4	90°	90°	mic17	159°	54°
mic5	120°	90°	mic18	195°	54°
mic6	150°	90°	mic19	231°	54°
mic7	190°	90°	mic20	267°	54°
mic8	210°	90°	mic21	303°	54°
mic9	240°	90°	mic22	339°	54°
mic10	270°	90°	mic23	0°	18°
mic11	300°	90°	mic24	90°	18°
mic12	330°	90°	mic25	180°	18°
mic13	15°	54°	mic26	27°	18°

Table 1: Microphone layout for capturing the directivity with a hemispherical loudspeaker array.

2. SPHERICAL ARRAY LAYOUT

As discussed in Li [10], choosing an appropriate sampling scheme is an essential key to the design of spherical microphone arrays. A description of spatial aliasing on sampled spheres can be found in Rafaely [11]. We assume that the spatial resolution of the directivity patterns to be captured is low (band-limited in terms of spherical harmonics). For our measurements, we chose an empirical hemispherical microphone grid, which approximates uniform sampling. The positions of the 26 microphones are listed in Table 1.

3. TOTAL RADIATED SOUND

It is common practise to use short-time Fourier transforms (STFTs) as an analysis stage for spectral modeling of the partials of a sound. We can apply this approach in the microphone-array multichannel case, too. For partial-tone decompositions, however, it becomes necessary to detect matching partials across the array channels, in order to get a compact description of the sound. Here, we consider the

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concept of a total radiated sound that avoids this tedious task. Summing up the STFT energy of all microphone signals (weighted sum), we obtain a single energy distribution in the time-frequency plane of the totally radiated sound:

$$|\text{STFT}_{\text{total}}[k,t]|^2 = \sum_{p=1}^{M} w_p \, |\text{STFT}_p[k,t]|^2. \qquad (1)$$

Here, t denotes the discrete time instant, k the discrete frequency variable, p the microphone index, and w_p weights the single STFT energy according to the fraction of the sphere surface area the microphone p is representing. Note that the phase of $\text{STFT}_{\text{total}}$ remains unknown. We may choose the weights w_p according to Eq. 8.

Spectral Modeling:
Using the total radiated sound energy $\text{STFT}_{\text{total}}$, we can perform partial-tracking, just like in a single-channel application; the basic approach is given in McAulay [2]. Assuming an appropriate time-frequency resolution, the partial tracks found represent the entire instrumental sound contained in the multichannel recording. For improvements of the frequency resolution, we propose to apply warped Fourier-transforms and parabolic interpolation (Smith [3][8]).

Auditory Masking:
Actually, we only want to analyze the directivity of audible partials of the radiation pattern. For that reason, it is useful to calculate the auditory masking threshold $|AMT_p[k,t]|$ in each channel. We define a simple criterion for the audibility of the spatiotemporal STFT-components $|STFT_p[k,t]|$:

$$\bigcap_{p=1}^{M} |STFT_p[k,t]| < |AMT_p[k,t]|? = \begin{cases} 1: \text{inaudible} \\ 0: \text{audible.} \end{cases}$$
$$(2)$$

In words: we suppose the frequency component k to be inaudible (masked) at the time instant t only if its magnitude stays below the auditory masking threshold in every microphone signal.

4. SPHERICAL HARMONICS DECOMPOSITION

For the encoding of the directivity pattern on the array, we use a Least-Squares spherical harmonics transform. Basically, the array resolution is limited by the number of mi-
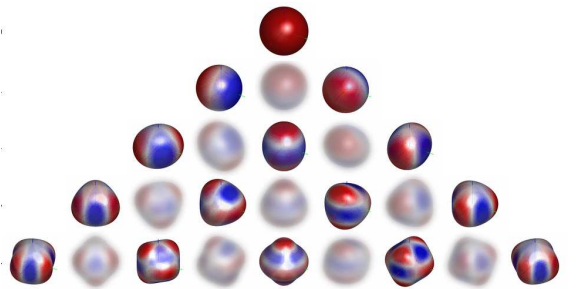

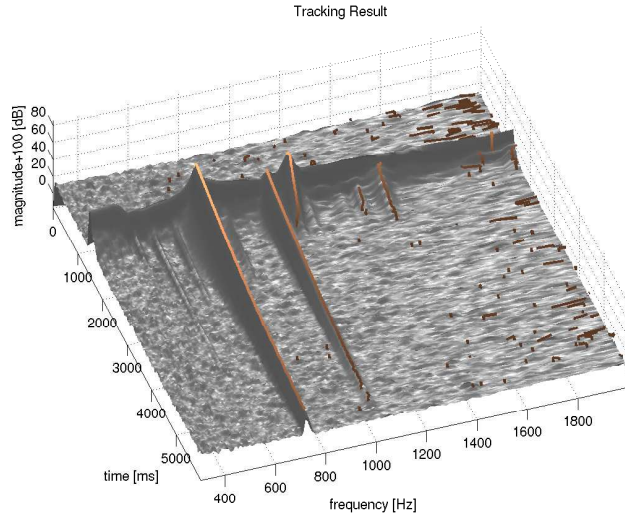Figure 2: Spherical harmonics with even (colored) and odd (gray) symmetry.

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[1] In many cases the excitation of musical instruments with mechanical devices produces unmusical sounds. Therefore we want to forbear from this attempt here.

Figure 3: Warped spectrogram with tracking results for the *bonang barung* (tone 3, 1st octave).

crophones. For the transform, we can only detect harmonics below a truncation number $n \leq N$ to get a system of linearly independent radiation patterns.

Furthermore, when only regarding the half-space $z \geq 0$, an ambiguity between even and odd symmetric harmonics w.r.t $(z = 0)$ has to be considered. For a hemispherical target array, we are free to either choose even or odd symmetric harmonics as base system for decomposition. In particular, the harmonic $Y_n^m(\varphi, \vartheta)$ has *even symmetry* w.r.t. $z = 0$ for $(n + m)$ *even*, and *odd* symmetry for $(n + m)$ *odd*, i.e.:

$$Y_n^m(\varphi, \vartheta) = (-1)^{(n+m)} \cdot Y_n^m(\varphi, \pi - \vartheta). \quad (3)$$

Even harmonics are a useful choice as they include the harmonic $Y_0^0(\varphi, \vartheta)$, and are therefore capable of describing omnidirectional directivity at the lowest resolution N, unlike otherwise.

Decomposition
For the encoding of the directivity, we use the following matrix equation, yielding the spherical harmonics coefficients $\vec{c}$. The system is solved with a weighted Least-Squares approach, as recommended in Sneeuw [5], or Li [10]:

$$\vec{p} \overset{!}{=} \mathbf{Y}\vec{c} \quad (4)$$

$$\vec{c} = \mathbf{W_2} \left(\mathbf{Y^H W_1 Y^H}\right)^{-1} \mathbf{Y^H W_1} \, \vec{p}, \quad (5)$$

with the sound pressure vector $\vec{p}$ and the spherical harmonics matrix $\mathbf{Y}$:

$$\vec{p} = \left(p_1(\varphi_1, \vartheta_1), \ldots, p_M(\varphi_M, \vartheta_M)\right)^t \quad (6)$$

$$\mathbf{Y} = \begin{pmatrix} Y_0^0(\varphi_1, \vartheta_1), & \ldots & Y_N^N(\varphi_1, \vartheta_1) \\ \vdots & \ddots & \vdots \\ Y_0^0(\varphi_M, \vartheta_M), & \ldots & Y_N^N(\varphi_M, \vartheta_M) \end{pmatrix}. (7)$$

We choose the matrix $\mathbf{Y}$ to contain only *even* harmonics w.r.t. $z = 0$. For a proper solution, the diagonal matrices

$\mathbf{W_1} = \text{diag}(w_p)$ and $\mathbf{W_2} = \text{diag}(w_{nm})$ contain suitable quadrature weights for our quadrature nodes (Table 1):

$$w_p = \begin{cases} 0.2714, & \text{for } \vartheta = 90° \\ 0.4947, & \text{for } \vartheta = 54° \\ 0.4488, & \text{for } \vartheta = 17°, \end{cases} \quad (8)$$

and $w_{nm} = (1.17, 1.17, 1.17, 1.15, 1.09, 1.15, 1.15, 1.25, 1.25, 1.15, 1.14, 1.04, 0.72, 1.04, 1.14, 1.12, 0.82, 0.64, 0.64, 0.82, 1.12).$

5. RESULTS ON THE BONANG BARUNG

The warped spectrogram of the *bonang barung* is shown in Fig 3. The radiation patterns of the three strongest partials are shown in Fig. 4, the contributions of the most relevant partials are plotted together in Fig. 5 which indicates clearly that the timbre of the instrument is changing considerably with respect to the listening position.

6. CONCLUSION

In this paper we have proposed a concept of directional sound analysis applicable to various musical instruments of different kind. As could be illustrated on the example of a central-Javan *bonang barung*, this type of analysis offers particular insights on the radiation of sound. We hope that our technique offers new perspectives in the field of musical acoustics and enables new technical applications in the field of sound field analysis and synthesis.

7. ACKNOWLEDGEMENTS

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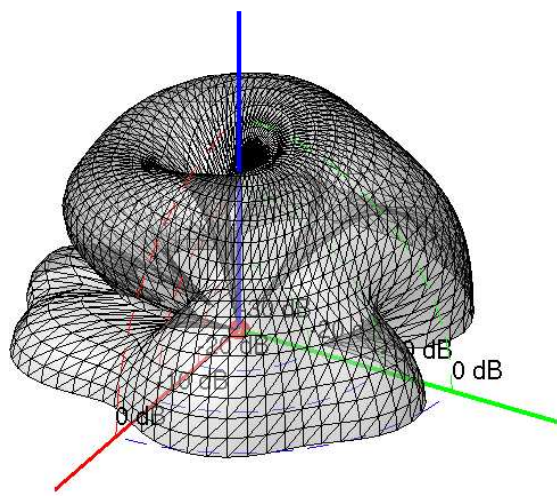
(a) 735Hz at -16dBFS
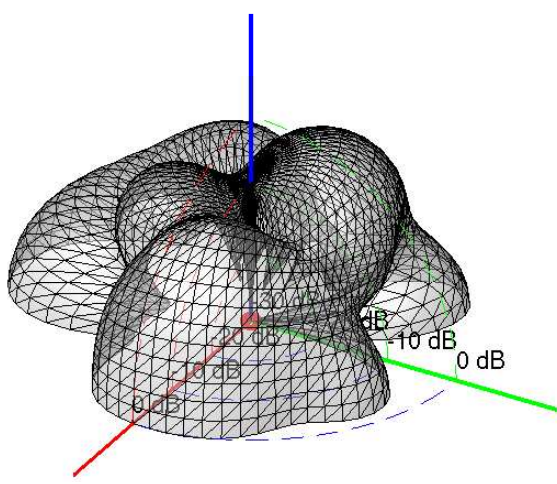
(b) 1095Hz at -37dBFS
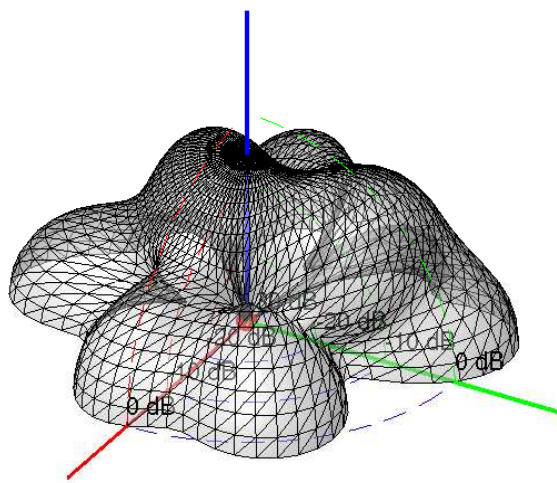
(c) 1006Hz at -42dBFs

Figure 4: Radiation patterns of some relevant partials of the third tone in the first octave of our *bonang barung* at the instant 500 ms after the stroke.
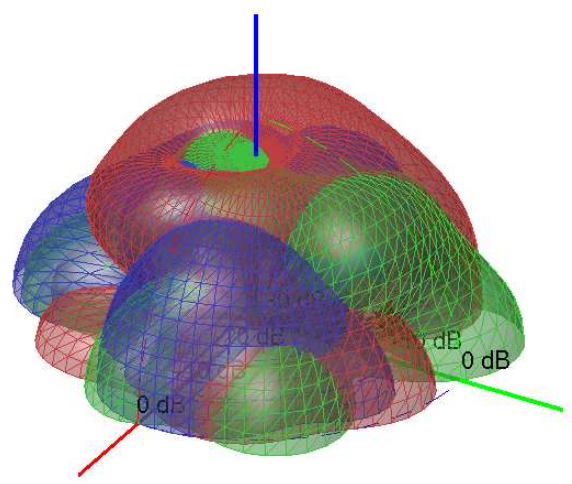

Figure 5: Overlay picture of the directivity of the most relevant partials of our *bonang barung*.

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