Similarity of musical instrument radiation-patterns in pitch and partial

Fabian Hohl, Franz Zotter

Institut für Elektronische Musik und Akustik, KU-Graz, Email: fhohl@cavus.ch, zotter@iem.at

Introduction

Recently, surrounding spherical microphone arrays have been used to synchronously record the sound-radiation of musical instruments in every direction of radiation. This contribution presents measurement results of example instruments out of different families: woodwinds, brass instruments, and strings. The main objective in this paper is to visualize the similarities of the radiation-patterns of all partials originating from different played pitches. Using the spherical correlation coefficient as a similarity measure, similarity of radiation patterns simplifies to a scalar number as demonstrated in [1]. The given examples shall make aware of instruments that exhibit both frequency and pitch dependent radiation-patterns from a perspective of musical acoustics. Additionally the findings illustrate, which instruments allow to neglect the dependency of radiation on the played pitch without severe errors in directivity models.

Microphone Array for Radiation Patterns

This paper presents the analysis of data that has been recorded by a surrounding spherical microphone array dedicated to record the entire radiation patterns of musical instruments [2]. The array consists of 64 microphones mounted on an acoustically transparent frame of 2.7 m diameter.

Figure 1: Musician with trumpet in microphone sphere.

Balloon diagrams using hyperinterpolation. The radiation pattern known at discrete angles is decomposed into a finite series of spherical harmonics (SHs) by hyperinterpolation. This provides an interpolated graphic representation of radiation patterns as balloon diagram on a fine-meshed angular grid. Moreover, if the radiation fulfills a required angular band-limit, hyperinterpolation can also be used as transform for acoustic holography. Tab. 1 gives an example with two interpolated radiation patterns $\boldsymbol{\gamma}_{\mathrm{N}}^{(1)}$ and $\boldsymbol{\gamma}_{\mathrm{N}}^{(2)}$.

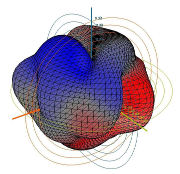
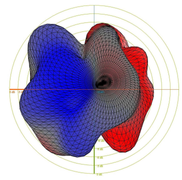
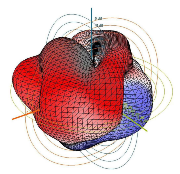
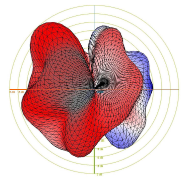
partial	side-view	top-view
$\underset{522}{^{2}\mathrm{c}'}$		
$\underset{529}{^{3}\mathrm{f}}$		

Table 1: Balloon diagram of 3$^{\mathrm{rd}}$ partial of f and 2$^{\mathrm{nd}}$ partial of c', view from side and top, big similarity $c_{(^2\mathrm{c}',^3\mathrm{f}')} = 0.965$.

Similarity measure for radiation patterns. The correlation coefficient $c_{(12)}$ expresses the similarity of the two radiation patterns $\boldsymbol{\gamma}_{\mathrm{N}}^{(1)}$ and $\boldsymbol{\gamma}_{\mathrm{N}}^{(2)}$ (in SH coefficient vectors) as a scalar number between 0 and 1

$$c_{(12)} = \left| \frac{\boldsymbol{\gamma}^{(1)\mathrm{H}}\boldsymbol{\gamma}^{(2)}}{\sqrt{(\boldsymbol{\gamma}^{(1)\mathrm{H}}\boldsymbol{\gamma}^{(1)})(\boldsymbol{\gamma}^{(2)\mathrm{H}}\boldsymbol{\gamma}^{(2)})}} \right| .$$

It is sensible to investigate the similarity of the partials of an instrument. Consequently, recorded sounds are decomposed into partials first. Our first question is:
Do partials at the same frequency, but originating from different played pitch exhibit similar radiation on a given instrument? – Tab. 1 answers this question for the partials $\underset{522}{^{2}\mathrm{c}'}$ and $\underset{529}{^{3}\mathrm{f}'}$ of the cornet: *they nearly match perfectly for the cornet.*

Similarity of radiation patterns. Moreover, the scalar similarity measure facilitates thorough analysis of directivity pattern similarities. In fact, the similarity of all partials can be overseen by neatly arranging the measure in a diagram. Fig. 2 exemplifies an extensive similarity analysis of partial-specific radiation. Compared patterns are sorted in blocks along the x and y axis by increasing partial index, each of which containing the pitch scale. The intensity of the pixels represents their similarity, and the black main diagonal represents the self-similarity (=1). Let us focus on the comparisons that are symmetrical to this diagonal for which associated patterns always correspond to different partials or pitch. Secondary diagonals in the plot indicate partials with matching frequency. The following paragraphs describe some findings.

Cornet: Fig. 3 illustrates that partials of the cornet

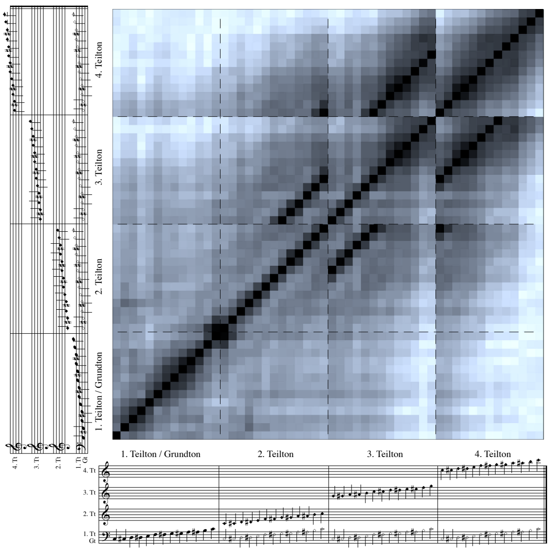


Figure 2: Radiation pattern similarity: chromatic scale of the trombone from c to c$'$, regarding 4 partials.

radiate similarly at similar frequency. In fact, thick connected lines of the secondary diagonals indicate that radiation is dependent on frequency, independently of the played pitch. The cornet represents brass instruments.

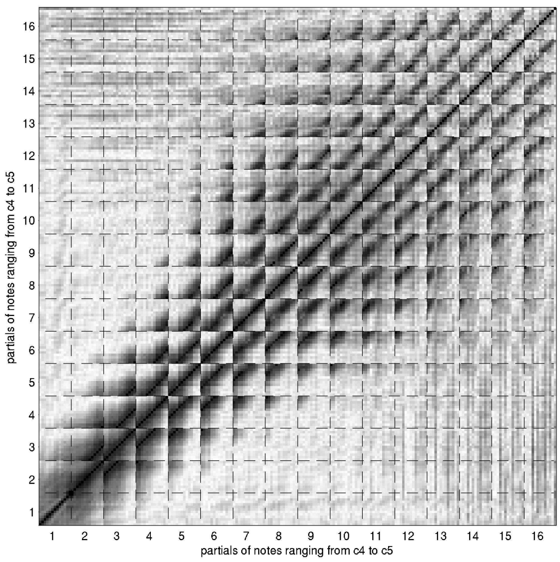


Figure 3: Radiation pattern similarity: one octave of the cornet – scale from c$'$ to c$''$, regarding 16 partials.

Clarinet: Obviously, the clarinet, a woodwind example, exhibits more complex radiation similarity. The square associated to the fundamental harmonics in Fig. 4 apparently splits up into two dissimilar blocks. The split point here is the a$'$, which is the first note that lies in the overblown register. Essentially, radiation produced in this register is based on the register-key hole that produces an additional out of phase radiation. The dipole-like radiation also affects similarities between other partials and yields discuntinued secondary diagonals in the plots.

Cello: Partials of the cello lying at the same frequency radiate equivalently. Thin lines in Fig. 5 indicate strong dissimilarity between radiation at different frequencies.

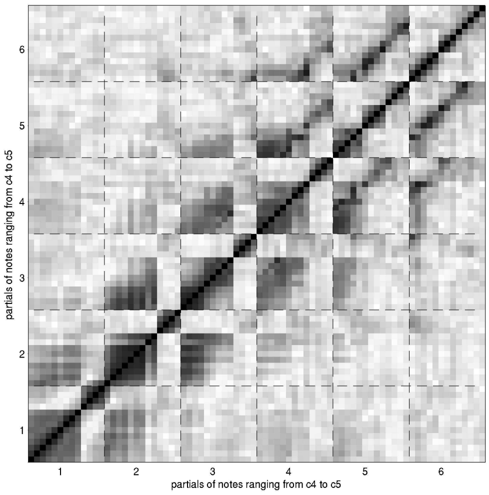


Figure 4: Radiation pattern similarity: chromatic scale of the clarinet in B – scale from c$'$ to c$''$, regarding 6 partials.

Clearly, the large body of the cello bears distinct and complex modes radiating differently.

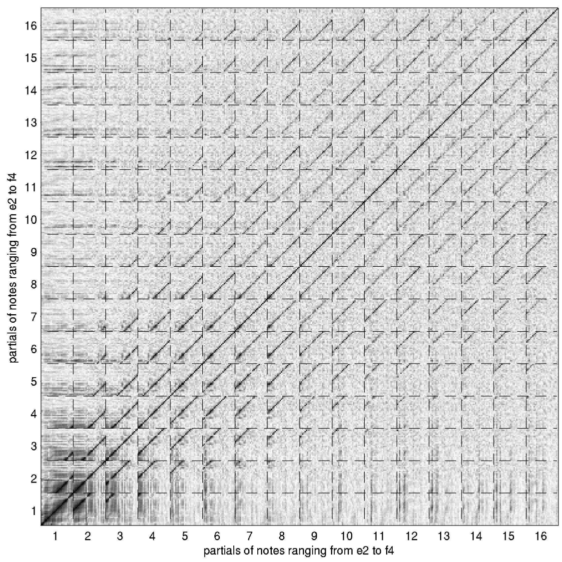


Figure 5: Radiation pattern similarity: chromatic scale of the cello – scale from E to f$'$ for 16 partials

Conclusions. Our paper demonstrates neatly arranged similarity-analyses of radiation-patterns from typical instruments. The proposed visulisation scheme provides a basis for comprehensive analyses. These might be helpful in direct playback of sound-radiation with spherical loudspeaker arrays, spatialisation, or auralisation. The presented similarity-diagrams clearly suggest that accurate modeling of woodwind and string instrument radiation might pose a technical challenge. For more definite statements, psychoacoustic and geometric relations should be investigated.

References

[1] G. K. Behler et al: Messung und Simulation von Raumimpulsantworten für eine realistischere Auralisation. 25. Tonmeistertagung, 2008.

[2] F. Hohl: Kugelmikrofonarray zur Abstrahlungsvermessung von Musikinstrumenten. Diplomarbeit, 2009.