Improvements on Higher Order Ambisonics Reproduction in the Spherical Harmonics Domain Under Real-time Constraints

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Motivation
Motivation

\[ X_{nm} \]

\[ x_1 \]

\[ x_2 \]

\[ \vdots \]

\[ x_n \]

\[ H_{nm} \]
Motivation
Measurement Setup
Time Domain

\[ y_{ear}(t) = s(t) \ast hrir_{ear}(\Omega, t). \]  \hspace{1cm} (1)

With: \( \Omega = (\Phi, \theta) \)

Spherical Harmonics Domain

\[ y_{ear}(t) = s(t) \ast \int_{\Omega} SHT\{hrir_{ear}(\Omega, t)\} \cdot Y_n^m(\Omega) d\Omega. \quad (2) \]

\[ y^{l,r}(\omega) = \sum_{n=0}^{\infty} \sum_{m=-n}^{+n} \tilde{S}_{nm}(\omega) \tilde{H}_{nm}^{l,r}(\omega), \quad (3) \]

where \( Y_n^m(\Omega) \) are the spherical harmonics basis functions.
Inverse spherical harmonics transform is given as the Fourier series

\[ f(\Omega) = \sum_{n=0}^{N} \sum_{m=-n}^{+n} f_{nm} Y_{nm}(\Omega). \]  

(4)

Order Truncation
Problem
Order Truncation

Domain CTF difference SH: 3

dB

f (Hz)

left

right

10^2 10^3 10^4

-30 -25 -20 -15 -10 -5 0
Domain CTF difference SH: 15

Order Truncation
Order Truncation - Angle Dependency

Rendered difference SH 3; Source: $\phi = 0.00$, $\theta = 1.57$

Average

```plaintext
Rendered difference SH 3; Source: $\phi = 0.00$, $\theta = 1.57$
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```plaintext
Average
```

```plaintext
Rendered difference SH 3; Source: $\phi = 0.00$, $\theta = 1.57$
```
Order Truncation - Angle Dependency

Rendered difference SH 3; Source: $\phi = 0.79$, $\theta = 1.57$

Average

f (Hz) dB

$10^2$ $10^3$ $10^4$ $10^2$ $10^3$ $10^4$
Order Truncation - Angle Dependency

Rendered difference SH 3; Source: $\phi = 1.57, \theta = 1.57$

Average
Rendered difference SH 3; Source: $\phi = 1.92$, $\theta = 1.57$

Average
Solutions
Order Truncation

Assuming a diffuse incident field

\[ \overline{p}(k r_0)|_N = \frac{1}{4\pi} \sqrt{\sum_{n=0}^{N} (2n + 1)|b_n(k r_0)|^2}. \] (5)

The mode strength on the rigid sphere

\[ b_n(k r_0) = 4\pi i^n \left[ j_n(k r_0) - \frac{j'_n(k r_0)}{h'_n(k r_0)} h_n(k r_0) \right], \] (6)

where \( j_n \) is the spherical Bessel function and \( h_n \) the spherical Hankel function of second kind.

Order Truncation

![Graph showing the relationship between frequency (f in Hz) and power (p in dB) for different mode numbers (0, 3, 7, 15, 30). The graph plots power in dB on the y-axis and frequency in Hz on the x-axis, with lines for each mode number showing their respective behavior.](image-url)
Order Truncation

![Graph showing order truncation effects](image-url)
Order Truncation - Angle Dependency

Inverse spherical harmonics transform is given as the Fourier series

\[ p(k, \Omega) = \sum_{n=0}^{N} \sum_{m=-n}^{+n} p_{nm}(k) Y_n^m(\Omega). \] (7)

On the spherical scatterer assuming a plane wave density \( a(k) \)

\[ p(k, \Omega) = \sum_{n=0}^{N} \sum_{m=-n}^{+n} a_{nm}(k) b_n(kr_0) Y_n^m(\Omega). \] (8)

In case of a unit amplitude plane wave

\[ p(k, \Omega) = \sum_{n=0}^{N} \sum_{m=-n}^{+n} b_n(kr_0) [Y_n^m(\Omega_k)]^* Y_n^m(\Omega), \] (9)

with the spherical harmonics addition theorem

\[ p(k, \Omega)|_N = \sum_{n=0}^{N} b_n(kr_0) \frac{2n + 1}{4\pi} P_n(\cos \Delta). \] (10)
Order Truncation - Angle Dependency

Nsph = 38 (L)
Angle compensation filter between orders 3 and 38
Tapering in SH domain
Tapering Window
Tapering Window
with the half-sided tapering window $w_N(n)$. 

$$\bar{p}(kr_0)|_N = \frac{1}{4\pi} \sqrt{\sum_{n=0}^{N} w_N(n)(2n + 1)|b_n(kr_0)|^2}, \quad (11)$$
But how does it sound?
Order Truncation - No Tapering
Order Truncation - Tapering
Order Truncation - No Tapering
Order Truncation - No Tapering

HRIRs left

HRIRs right

SH5
Order Truncation - Tapering

HRIRs left

HRIRs right

SH5

33
Coloration

Coloration above 2.5kHz

- s_out_t.wav
- s_out_shN5_no.wav
- s_out_shN5_order.wav
- s_out_shN5_taper.wav
Tapering Window
Coloration above 2.5kHz

- s_out_t.wav
- s_out_shN3_no.wav
- s_out_shN3_order.wav
- s_out_shN3_taper.wav
THANK YOU!!